

Self-Regulation

BRAIN, COGNITION, AND DEVELOPMENT



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INTRODUCTION

The process of growing up includes gaining control over our own behavior and emotions. This control is essential to human nature; without it, concepts such as *responsibility* and *accountability* wouldn't make any sense (Bronson, 2000; Vohs & Baumeister, 2004). The idea of human willpower has puzzled philosophers and writers since ancient times. It appears as a central theme in many myths (e.g., in Greek mythology, could Pandora have overcome her curiosity and not opened the box?), fables (e.g., in Aesop's fable about the crow and the fox, could the crow have resisted opening its mouth and prevented the cheese from falling?), and philosophical debates (e.g., is it possible for humans to act against their own better judgment?), and it is essential for theological ideas concerning free will and accountability for our actions.

To emphasize the flexibility and adaptability of human self-control, researchers often refer to self-control as *self-regulation*. We self-regulate whenever we adapt our emotions and actions to situational requirements as well as to social standards and norms that we have internalized. Self-regulation encompasses skills such as paying attention, inhibiting reflexive actions, and delaying gratification. We need self-regulation for navigating in the social world (e.g., when we resist revealing a secret even though it is really tempting

to tell it), academic life (e.g., when we study for the test even though we would prefer to watch our favorite TV show), and much more—indeed, in every aspect of life.

Poor self-regulation implies impulsive and unregulated behavior and might have a significant cost for persons and their surroundings. In Vohs and Baumeister's (2004) words, "nearly every major personal and social problem affecting a large number of modern citizens [such as alcoholism, drug addiction, obesity, excessive spending, and violence] involves some kind of failure of self-regulation" (p. 3). Moreover, specific psychological syndromes are associated with more extreme failures of self-regulation, such as depression, autism, obsessive-compulsive disorder, and attention-deficit/hyperactivity disorder (ADHD).

However, in spite of its critical importance for human behavior, there is no universally accepted definition of self-regulation. This concept has many different definitions, depending on the theoretical perspective under which it has been studied. It has been used to refer to the ability to comply with a request; to initiate and/or cease behavior according to situational demands; to modulate the intensity, frequency, and duration of verbal and motor acts in social and educational settings; to postpone acting on a desired object or goal; to generate socially approved behavior in the absence of external monitoring; and to modulate emotional reactivity, among other things (e.g., Fonagy & Target, 2002; Kopp, 1992; R. A. Thompson, 1994; Vaughn, Kopp, & Krakow, 1984).

A broad definition of self-regulation is the ability to monitor and modulate cognition, emotion, and behavior to accomplish one's goal, and/or to adapt to the cognitive and social demands of specific situations. When referring to *emotional regulation*, one is usually referring to the intensity and temporal characteristics of the emotional response (R. A. Thompson, 1994).

Most probably, the definition here does not refer to a single process but to a group of mechanisms underlying the ability to self-regulate. Self-regulation of emotion can be distinguished from self-regulation of cognition, which might or might not include regulation of overt behavior. These processes have mainly been studied separately and seem to be challenged in somewhat different situations. However, some interesting links can be found between these broad categories of regulation (C. M. Carlson & Wang, 2007; Gerardi-Caulton, 2000). These links seem to indicate that there is one common underlying factor behind all forms of self-regulation. This factor seems to be the executive aspect of *attention* (Fonagy & Target, 2002; Kopp, 1982; Posner & Rothbart, 1998; Ruff & Rothbart, 1996). According to this view, attention is the key aspect of the larger construct of self-regulation and is the basis of inhibitory control, strategies of problem solving, and self-monitoring.

This volume synthesizes the latest research in self-regulation—what it is, how it functions, how genetic and environmental factors influence its develop-

ment, how it affects social and academic competence in childhood and adulthood, what pathologies can emerge if it is underdeveloped, and how it might be fostered in children. The chapters integrate research from cognitive and social neuroscience, developmental psychology, and neurobiology, and emphasize the brain basis of basic cognitive functions that enable self-regulation.

The remainder of this introductory chapter provides background information about self-regulation, including how it develops and how other researchers have conceptualized it, and explains the book's organization.

HOW SELF-REGULATION DEVELOPS

The process of developing self-regulation can be conceptualized as a gradual transition from external control to internal and efficient self-control (Bronson, 2000; Schore, 1994; Sroufe, 1995). This development of self-regulatory mechanisms has been considered to be the crucial link between genetic predisposition, early experience, and later adult functioning in society (N. Eisenberg et al., 1995; N. Eisenberg, Pidada, & Liew, 2001; Fonagy & Target, 2002).

Infants are driven mostly by reflexive reactions to inner and outer stimuli and rely heavily on caregivers in almost all aspects of their existence. Still, some initial form of self-regulation can already be observed in the first months of life. At this stage, neurophysiological modulatory mechanisms protect an infant from too much arousal or stimulation (Kopp, 1982). Infants are able to reduce the level of stimulation to some extent by turning away from the source of stimulation (i.e., closing their eyes), engaging in self-soothing activities (e.g., sucking), or both. The next stage begins when an infant starts to demonstrate clearly defined cycles of wakefulness that are relatively congruent with physical and social definitions of day and night. Gradually, during a period that continues until the age of 9 to 12 months, infants become capable of responding to external control. They become aware and capable of intentional means-end actions (e.g., reaching for a pacifier and putting it into their mouth), and they begin to comply with external signals and commands (e.g., with a parental requirement such as "Don't touch this"). The type of self-regulation in this phase is called *sensorimotor modulation*, as infants' increasing mobility and improving motor control become progressively more self-directed. They use their sensorimotor repertoire to modulate their interaction with the environment. As mentioned, one of the important mechanisms that help infants to modulate the level of arousal is the orienting of attention. Indeed, M. H. Johnson, Posner, and Rothbart (1991) found that the probability of disengaging attention from a central attractor to process a peripheral target increased dramatically within the first 4 months of life. Moreover, Harman, Rothbart,

and Posner (1997) showed the interaction between attention and soothing in 3- to 6-month-old infants. They found that infants who were first distressed by visuoauditory stimulation could orient to an alternative interesting stimulus. While the infants reoriented to this new stimulus, their facial and vocal signs of distress disappeared. Harman et al.'s (1997) finding is consistent with caregivers' reports of how attention is used to regulate the state of an infant: Before the age of 3 months, caregivers mainly hold and rock an infant in order to soothe him; when the infant is at about the age of 3 months, caregivers reported trying to distract him by orienting attention toward alternative stimuli.

Toward the end of the first year of life, infants begin to show the first simple forms of compliance with external control. They begin to respond to warning signals and perform one-step simple commands (Kopp, 1982). During toddlerhood (2–3 years of age), children develop a sense of autonomy and awareness of self. Their emotional repertoire becomes more sophisticated and begins to include secondary emotions related to self-consciousness and self-awareness, such as shame and pride (Lewis, 1992; Sroufe, 1995). This emotional development parallels achievements in cognitive abilities as described by Piaget (1926, 1952) and a growing sense of self (Lewis, 1997, 1998). The relevant cognitive achievements include the ability to plan and perform a sequence of actions, the ability to hold in mind a mental representation, the development of language, and so forth. These achievements, together with the growing sense of self, enable toddlers to begin carrying out their own intentions and to comply with external requests to control physical actions, communications, and emotional expressions (Bronson, 2000). At this stage, Kopp (1982) referred to *self-control* instead of *self-regulation*, to emphasize that the child still has limited flexibility in adapting acts to meet new situational demands and a limited capacity for waiting and delaying actions and gratifications (although the reader should notice that others, e.g., Vohs & Baumeister, 2004, use the term *self-control* mainly for the adult mature state of self-regulation). As Kopp (1992) pointed out, children at this stage are not yet fully skilled in managing their emotions. They tend to react with physical aggression and have emotional outbursts, such as crying or temper tantrums, if frustrated. They still depend heavily on their caregivers to help them maintain control in the face of stress, fatigue, or challenge. Adults must set and maintain the standards for behavior, anticipate difficult or frustrating situations, and assist a child who is losing control (Sroufe, 1995). In several studies, experimental tasks that require degrees of inhibition have shown preliminary signs of success already in children at the ages of 2 to 2.5 years (e.g., S. M. Carlson, 2005; Diamond, 2005; Hughes & Ensor, 2005). However, as Kopp (1982, 1989) proposed, it seems that it is not until preschool ages that children actually enter a stage of real self-regulation, becoming increasingly able to use rules, strategies, and plans to guide their behavior.

Examples of situations that mimic daily self-control challenges during toddlerhood that have been studied in the laboratory are delay–response inhibition in the presence of an attractive toy and compliance with maternal directives in a cleanup task (Vaughn et al., 1984). Toddlers begin to succeed in challenges such as not peeking during the gift delay–bow task (S. M. Carlson, 2005). In this situation, experimenters tell the children that they are going to receive a present and show them a large gift bag with a wrapped gift inside. Then the experimenters say they forgot to put a bow on the gift and ask the children to wait until they return with a bow before opening the present. The experimenters leave the room for 3 min, return with a bow, and then invite the children to open the gift (if the children haven’t done so already). Peeking is scored as a *fail*. About 70% of 24-month-old children can cope with this challenge and pass this test successfully (S. M. Carlson, 2005). If the situation is made more challenging, it is not until the age of 5 years that children begin to succeed and reach the 70% probability level of passing the test. The more challenging situation is the gift delay–wrap task (S. M. Carlson, 2005; Kochanska, Murray, Jacques, Koenig, & Vandegest, 1996). Here the children are told they are going to receive a prize. However, the experimenters “forgot” to wrap their present. The experimenters ask the children to turn around in their seat until the present is wrapped so it will be a big surprise. The experimenters then wrap a gift noisily (rifling through a paper bag, cutting wrapping paper with scissors, folding the paper around the box, and tearing off tape) for 60 s. As in the easier version, peeking behavior is recorded.

In addition to age differences and an increase in coherence of compliance measures with age, significant positive correlations have also been reported between self-control and the cognitive developmental status of toddlers. Namely, more developed children were better able than less developed children to inhibit responding and to comply with parental directions (Vaughn et al., 1984).

Between the ages of 3 and 5 years there is a gradual progression in children’s ability to deal with conflict. In addition, this age period seems to bring a significant general jump in their ability to succeed in tasks designed to tap frontal functions, including working memory (WM), inhibition, planning, and set switching (see the review in Garon, Bryson, & Smith, 2008). Most important, these changes occur in parallel to the changes in self- and social understanding (S. M. Carlson & Moses, 2001).

As Bronson (2000) pointed out, at preschool age, children begin to use speech as a technique for controlling actions and thoughts (Berk & Winsler, 1995; Luria, 1961; Vygotsky, 1962). According to Vygotsky (1962), very significant development occurs over the preschool years in the capacity of (private) speech to exert control over behavior: In the beginning, private speech follows action; then it begins to occur simultaneously with the child’s behav-

ior; next, it appears at the beginning of action and becomes a critical self-regulatory mechanism that enables planning and modulation of behavior (Berk, 1999). In other words, private speech is gradually transformed into an externalized instrument of thought, functioning as a plan that has been conceived but not yet realized in behavior (Berk & Potts, 1991). As the child improves in self-regulation, private speech gradually becomes internalized, that is, private speech is the precursor of inner thoughts. This process usually occurs during the first years of elementary school, and in normally developing children private speech utterances become rare by third grade (Berk, 1986).

One of the best-documented transitions is in the improved ability to withhold a response or to make an incompatible response, as demonstrated in experimental tasks designed by Luria (Beiswenger, 1968; Diamond & Taylor, 1996; Luria, 1966; S. A. Miller, Shelton, & Flavell, 1970). Generally, there appears to be a dramatic increase between 3 and 5 years of age in children's ability to switch between two incompatible rules (Kirkham, Cruess, & Diamond, 2003; Zelazo & Jacques, 1996) and to deal with conflict in which they must override a prepotent response, substitute a conflicting response (Gerardi-Caulton, 2000; Posner & Rothbart, 2005; Reed, Pien, & Rothbart, 1984; Rueda, Posner, & Rothbart, 2005), and monitor response error and response-conflict information (Jones, Rothbart, & Posner, 2003). The critical age for these developmental changes seems to be around the 4th year of life, when maturational changes in the frontal lobes result in a qualitative shift in the way children process information, which is a key step in the development of the more agentive (and increasingly self-supervised) learning style that characterizes adulthood (Ramscar & Gitcho, 2007). According to the model proposed by Posner and Rothbart, the time schedule of the ontogenic process described previously is dictated by the unfolding of higher order cognitive capacities, such as executive aspects of attention (Posner & Rothbart, 1998, 2000) and language acquisition, and it is linked to the maturation of the prefrontal cortex and its connectivity. Specifically, Posner and Rothbart suggested that there is a shift in control from the brain's orienting network in infancy to the executive network by ages 3 to 4 years (Rothbart, Sheese, Rueda, & Posner, in press). Others have emphasized the global importance of improving executive functions (EFs) with age, for example, the importance of increasing WM capacities (Davidson, Amso, Anderson, & Diamond, 2006; Espy & Bull, 2005), increasing in the hierarchical complexity of the rules that children can formulate and use when solving problems (Zelazo et al., 2003), increasing the complexity of the conscious representations that allow for conscious top-down control (Marcovitch & Zelazo, 2009), and so forth. EF seems to reflect a unitary single cognitive ability in children (Wiebe, Espy, & Charak, 2008), although in adults three different factors—*inhibition*, *WM*, and *shifting*—have been delineated (Miyake et al., 2000).

Preschool years also bring development in *hot* EFs, that is, in affective decision making, or decision making about events that have emotionally significant consequences (i.e., meaningful rewards and/or losses). For instance, in a child version of the Iowa Gambling Task, Kerr and Zelazo (2004) demonstrated the development between the ages of 3 and 4 years: Four-year-olds made more advantageous choices than would be expected by chance, whereas 3-year-olds made more disadvantageous choices than would be expected by chance.

However, the development of self-regulation is by no means finished at preschool age. In recent years there has been a growing interest in the literature on the changes from childhood to adolescence and the new challenges that puberty imposes on self-regulatory abilities. With optimal development, toddlers who could not regulate their frustration when required to wait and needed the help of their caregivers to calm down slowly become preschoolers who can delay gratification for a short period (e.g., they refrain from eating a small marshmallow for 15 min in order to get two of them; Shoda, Mischel, & Peake, 1990), eventually become schoolchildren who can do their homework before watching TV, and then teenagers who can refrain from drinking in order to drive home safely. In other words, self-regulating abilities continue to develop throughout childhood and adolescence (Barkley, 1997; Bronson, 2000; Davidson et al., 2006; Welsh, 2001).

The self-speech that preschool children use for controlling their actions and thoughts becomes internalized during early elementary school years (Berk & Winsler, 1995; Luria, 1961; Vygotsky, 1962). This internalization is considered to be critical for self-regulation (Barkley, 1997). As largely studied by Flavell and others (Flavell, 1971, 1979, 1986, 1993; Flavell, Green, & Flavell, 1995), children at this age also begin to be more aware of their own thinking processes, developing metacognition. Children become increasingly insightful about different aspects of their own thinking. Within this process they become increasingly aware of the existence of inner speech as a cognitive activity. They realize that it occurs frequently, when planning, solving problems, daydreaming, and so forth. With this realization they also learn a lot about the inner life of others, and therefore their theory of mind also becomes more sophisticated and complex (Flavell, Green, Flavell, & Grossman, 1997).

Compared with preschool children, elementary school children are more responsible and more conscious about their behavior. As summarized by Bronson (2000),

Early elementary school children are able to control emotional expression and behavior more effectively than younger children. They have better control of attention and can use internalized language for self-regulation. They become more self-aware and begin to be able to reflect consciously and make deliberate decisions about the course of action in different situations. They are also beginning to understand the feelings

and perspectives of others more clearly and are able to work and play with them more cooperatively. (p. 78)

Through these changes, during the early elementary school years, one can observe the improvements in the various EFs (Levin et al., 1991; Welsh, 2001; B. R. Williams, Ponesse, Schachar, Logan, & Tannock, 1999) such as improvements in executive control of attention (e.g., selection, conflict resolution), flexibility, error monitoring, inhibition, WM update, and so forth. The progress in EF is described in more detail in Chapter 3 of this volume. These advances in the control of attention, WM, inhibition, and switching seem to enable or lead to the more flexible thinking and reasoning of children at what Piaget (1983) originally described as the operational stage.

As described in detail in Chapter 5 of this volume, at early elementary school age, self-regulation, especially the regulation of negative emotionality, affects children's functioning within their peer groups. Children who are better able to inhibit inappropriate behaviors and control their emotion and behavior tend to be socially competent overall, liked by their peers, and well-adjusted (Calkins & Dedmon, 2000; N. Eisenberg et al., 1996, 1997, 2001; Gilliom, Shaw, Beck, Schonberg, & Lukon, 2002; Lemery, Essex, & Smider, 2002; Lengua, 2002).

The huge changes that puberty brings and the challenges for self-regulation were pointed out already by Rousseau in the 18th century and have been emphasized by all the 20th century psychological icons, such as Freud, Piaget, and Erikson. Adolescent tendencies toward irrational emotionally influenced behavior have been recognized throughout human history, leaving us with immortal phrases like Aristotle's "Youth are heated by nature as drunken men by wine" (Dahl, 2004). This is a critical period of transition between immaturity–dependence to maturity–independence that can be identified across mammalian species (Spear, 2007).

There are interesting across-species commonalities, such as increased focus on interaction with peers, increased pressure for independence from parents, increased novelty seeking and risk-taking, and so forth, which suggests they have an adaptive significance (Spear, 2007). Still, in other species the period of puberty does not fully show the complexity in brain, behavior, and psychopathology evident during human adolescence.

In humans, one of the most critical challenges of this period seems to be the development of a conscious and autonomous identity (Erikson, 1968). This process might be linked to the development of cognitive skills, such as abstract thinking (Tucker & Moller, 2007), during this period.

The stormy nature of the adolescence period has been traditionally linked to the hormonal reawakening that characterized puberty. These hormonal changes lead to sexual maturation and physical body growth, to which adolescents are required to adjust. However, in recent years brain imaging

techniques have provided a new perspective on the changes in the brain that occur in this life period (Nelson, 2004; Sowell et al., 2004; Spear, 2000). Moreover, there is increasing evidence that the stress that characterizes adolescence has a strong impact on these brain processes, which might explain on the one hand the improvement in most EFs and self-regulation, and on the other hand the high vulnerability to the onset of psychopathology that characterizes this age period (Bales & Carter, 2007; Dahl, 2004; Grace, 2007; Gunnar, 2007; Hemby & O'Connor, 2007; Pine, 2004; Walker, McMillan, & Mittal, 2007). Brain changes related to puberty include brain maturation, that is, neural changes that precede and lead to the hormonal cascade at the beginning of puberty. They also include changes that are the consequence of certain higher levels of pubertal hormones, that is, beta-estrogen receptors that have been found in the brain and may affect serotonergic regulation and may be related to emotional changes in puberty (Dahl, 2004). I describe the changes in the brain that characterize adolescence in Chapter 3.

ALTERNATIVE APPROACHES TO CONCEPTUALIZING SELF-REGULATION

The perspective adopted in this book about the nature of self-regulation is that of an ability or skill that emerges and develops during infancy and childhood. This ability is based on cognitive processes that belong to the broad concept of EF, that is, the ability to control and manipulate attention, the ability to inhibit automatic responses, the ability to maintain current goals and requirements in WM, and so forth, as well as motivational ones. Moreover, these basic processes that enable self-regulation are mediated by specific brain networks and mechanisms. In other words, the present book presents a developmental neurocognitive perspective of self-regulation.

Still, there are additional approaches to conceptualizing self-regulation in the literature that are outside the scope of this book and should be, at least briefly, mentioned here.

Self-Regulation as a Strength

The self-regulatory strength model, suggested by Baumeister and colleagues (Baumeister, Muraven, & Tice, 2000; Schmeichel & Baumeister, 2004; Vohs & Heatherton, 2000), proposes that the ability to actively move the self closer to a desired state relies on a limited “willpower” resource. When this limited regulatory resource is depleted, a state of ego depletion results, and self-regulation failures are more likely to occur. Self-regulation is conceived in this model as *strength*, in analogy to a muscle: After it is used, some

“resting” period is needed for recovery. Moreover, it can be strengthened by gradually increasing exercise (Schmeichel & Baumeister, 2004).

According to this model, regulatory resources are required only in actions that demand active self-control, so automatic behavior does not rely on regulatory resources. Baumeister and colleagues’ model highlights, therefore, conscious self-regulation. It should be noted that Bargh (Fitzsimons & Bargh, 2004) proposed an alternative view, according to which the full sequence of goal pursuit—from goal setting to the completion of the attempt to attain the goal—can proceed outside of conscious awareness and guidance.

The strength-limited resource idea differs from cognitive models of limited resource (i.e., attention) in that it predicts subsequent, not concurrent, decrement in self-regulation ability (Schmeichel & Baumeister, 2004). The idea in a typical ego-depletion research paradigm is that participants perform two tasks, one after the other, and show poorer performance in the second task because of the resources expended in the first one. For example, Vohs and Heatherton (2000) applied the ego-depletion idea to the field of dieting. In one of their experiments, they sat their participants in a waiting room with a tempting bowl of snacks near them (Task 1), then moved the participants to a different room for ice cream tasting and rating (Task 2). The dependent measure was the amount of ice cream consumed by the participant in grams. The researchers manipulated two variables: (a) the instruction to participants in the first task—whether they were told to touch the snacks—and (b) the degree of temptation—whether the snacks were placed within arm’s reach of participants or on the other side of the room. They found that the manipulations affected “chronic dieters” and nondieters differently. As indicated by the higher consumption of ice cream in the second task, the self-regulation resources of the dieting participants were more strongly “depleted” if they experienced the high-tempting conditions in the first task (i.e., the snacks were placed near them and the experimenter had told them to “help themselves”). Nondieters were not affected by the experimental manipulations. In addition to illustrating the logic of ego-depletion experiments, this study emphasizes the existence of individual differences in self-regulation strength and the vulnerability to resource depletion (Schmeichel & Baumeister, 2004). Alternatively, results of this type could raise questions in regard to the degree of generalizability of the ego-depletion phenomena.

In general, research on ego depletion tends to adopt a contextual approach, focusing on situational determinants of behavioral self-regulation more than on specific processes that underlie such regulation or the specific brain infrastructure involved. In an attempt to delineate the involved process with more precision, Schmeichel (2007) manipulated attention control, response inhibition, memory updating, or response exaggeration in Task 1 and had different target measures of executive control in Task 2. He found

that (a) controlling attention in Task 1 impaired subsequent efforts to update the contents of WM in Task 2; (b) inhibition in Task 1 impaired memory performance that required both maintaining and updating the contents of memory, whereas maintenance alone was spared; and (c) memory updating in Task 1 impaired the inhibition of emotional expression in Task 2. Exaggerating the expression of negative emotional responses in Task 1 reduced subsequent WM span in Task 2. These results seem to indicate that different forms of executive control can have similar aftereffects. Still, one common criticism of resource models concerns their lack of specificity. What activities consume the resource, and precisely how does the resource operate? Moreover, to what extent can explanations of changes in fatigue, alertness, and motivation provide alternatives to the ego-depletion model?

Overall, the strength model of self-regulation contributes the axis of time to our discussion about self-regulation, suggesting that there might be immediate consequences or a “price” to pay for the attempt to self-regulate.

Self-Regulation as a Choice Between Goals

An additional approach to self-regulation emanates from social psychology research about the relation between values and actual behavior, and it contributes the conceptualization of regulation in terms of choices between goals. In this context it has been suggested, for example, that time perspective affects this relation, as temporal distance increases the influence of superordinate, desirability aspects (i.e., the value of an action’s end state) and decreases the influence of subordinate, feasibility aspects (i.e., the means for reaching the end state) in choice of future activities (Liberman, Sagristano, & Trope, 2002). In the words of Fujita, Trope, Liberman, and Levin-Sagi (2006), “Self-control can be broadly conceptualized as making decisions and acting in accordance with global, high-level construal of the situation rather than local, low-level construal. Self-control is enhanced when individuals are able to see the proverbial forest beyond the trees” (p. 352). Moreover, according to Eyal, Sagristano, Trope, Liberman, and Chaiken (2009), since perceptions of distant future situations highlight more abstract, high-level features than near future situations, they are more influenced by high-level constructs such as values. Consequently, people are more likely to use their values in construing and forming behavior intentions with respect to distant-future situations than near-future situations. Eyal et al. showed that people expect others to express their personal dispositions (general attitudes, traits) and act consistently across different situations in the distant future more than in the near future. On the basis of these results, Eyal et al. suggested that people may view themselves in terms of “what is really important to me in life” only when they think of themselves in a distant, abstract way; when they think of their actions from

a proximal perspective, their “true” self may lose its clarity to pragmatic, situational constraints (e.g., money, time). Moreover, different emotions seem to be related to different goals, depending on their abstraction level, that is, abstract emotions (e.g., pride, guilt) monitor pursuit of high-order goals (e.g., study), whereas concrete emotions (e.g., happiness, sadness) monitor pursuit of low-order goals (e.g., leisure; T. Eyal, personal communication, January 15, 2010).

How do people proceed to fulfill their goals? What are the dynamics of self-regulation according to this framework? Fishbach (2009) proposed that a person feels motivated to choose actions that reduce the discrepancy between an existing undesirable state and a desirable end state. Moreover, he proposed that a person perceives the pursuit of congruent actions as a signal of high commitment to that goal. According to this proposal, the representation of goals in terms of making progress versus expressing commitment then determines the patterns of self-regulation that a person adopts when trying to balance between simultaneous multiple goals.

Self-Regulation as a Necessary Condition for Learning

A more specific, applied use of the term *self-regulation* than the one presented in this book can be found in the education literature, focusing on the schooling context. The idea is that learners’ skills and abilities do not fully explain their achievement, suggesting that other factors, such as motivation and self-regulation, make an important contribution to successful learning (Schunk, 2005).

In an interesting and fruitful line of research in educational psychology, the effects of interventions designed to improve the learning environment and encourage *self-regulated learning* (SRL) are being studied (e.g., Perels, Gurtler, & Schmitz, 2005; Rozendaal, Minnaert, & Boekaerts, 2005). The implementation of self-regulation in the learning context gives rise to the definition of a *learner* as being one who is proactive in the effort to learn by being aware of his or her own strengths and limitations and being guided by personally set goals and task-related strategies, such as using an arithmetic addition strategy to check the accuracy of solutions to subtraction problems (Zimmerman, 2002). This type of learner monitors his or her behavior in terms of goals and self-reflects on his or her increasing effectiveness. This enhances self-satisfaction and motivation to continue to improve the learning methods (Zimmerman, 2002). The types of changes in the learning setting that foster SRL include encouragement of students to set goals, use of effective task strategies, monitoring of progress, note taking, organization of studying, establishment of a productive work environment, and so forth.

Different models of SRL can be found in the literature, including the ones proposed by Boekaerts and Niemivirta (2000), Borkowski (1996), Pintrich

(2000), Winne (1996), and Zimmerman (2000; for a review of these models, see Puustinen & Pulkkinen, 2001), with somewhat different definitions of SRL emerging from the different models. On one hand, Boekaerts, Pintrich, and Zimmerman all defined SRL as a goal-oriented process and emphasized its constructive or self-generated nature. In these models, monitoring, regulating, and controlling one's own learning include cognitive, motivational, emotional, and social factors. Borkowski and Winne, on the other hand, defined SRL as a metacognitive process aimed at adapting the use of cognitive tactics and strategies to tasks (Puustinen & Pulkkinen, 2001). Beyond the differences between the models, there seems to be a consensus that there are different phases or stages in the SRL process. For instance, according to Pintrich (2000), SRL is composed of four phases: forethought, monitoring, control, and reflection. Zimmerman (2000) emphasized that the entire SRL process is cyclical in nature, as thoughts, feelings, and actions are cyclically adapted through feedback to the attainment of personal goals.

Almost 3 decades of research have presented an optimistic conclusion about the effectiveness and feasibility of self-regulation-focused interventions in school contexts, indicating that those students who display more adaptive self-regulatory strategies demonstrate better learning and higher motivation for learning (Pintrich, 2000). For example, Perels, Gurtler, and Schmitz (2005) showed that combining training in self-regulation with instruction in problem solving was especially effective in enhancing self-regulation and achievement, and Rozendaal, Minnaert, and Boekaerts (2005) found that teachers who practiced collaborative interactive teaching strategies promoted deep-level cognitive processing in their students. These two studies demonstrated that students' self-regulatory capabilities can be affected by a relatively brief intervention. However, as the field of SRL research grows, some conceptual and methodological problems are beginning to emerge (Schunk, 2008), and there is an urgent need for clearer conceptual definitions (Dinsmore, Alexander, & Loughlin, 2008).

The Need to Integrate Different Conceptualizations

What seems to be needed is cross-talk between the research fields, where there is mutual enrichment between basic research dealing with underlying mechanisms and the applied implementation in the educational context. My hope is that this book contributes to this integration process. For example, although many times the self-regulation "ego" strength view is presented as opposite to the skill view that I adopt (Schmeichel & Baumeister, 2004), I do not think that these views are necessarily contradicting. Saying that self-regulation develops and matures does not contradict the idea that the exertion of this regulatory ability requires effort and can lead to a transient fatigue,

that is, ego depletion. Moreover, the evidence that I present in Chapter 4, showing that effective parenting practices that foster self-regulation are those that provide opportunities and encouragement for a child to self-regulate, could be fully compatible with Baumeister's idea of a self-regulation "muscle," which, when trained, gets stronger and stronger over time (Schmeichel & Baumeister, 2004).

ORGANIZATION OF THIS BOOK

Because of this book's focus on the brain basis of self-regulation, Chapter 2 provides an overview of basic mechanisms involved in self-regulation and their brain infrastructure.

Next, Chapter 3 focuses on the maturation of these basic mechanisms and brain networks. Increasing connectivity is viewed as the fundamental process that dictates the unfolding of self-regulation during childhood.

Children differ widely in their self-regulation, and the origins of these individual differences have captured researchers' attention for many years. Chapter 4 focuses on the nature and nurture elements that affect an individual's ability to self-regulate. In the section on the early biological bases of self-regulation, the chapter discusses the contributions of genetics and temperament. As readers will see in Chapter 4, a child's biological endowment interacts with environmental variables already present at early infancy. The combined effect of nature and nurture is reflected in the individual differences among children in their ability to self-regulate.

Individual differences in the ability to self-regulate have crucial implications for a child's adjustment to the school environment, both in relations with peers and other social figures and in academic achievements. Therefore, Chapter 5 is dedicated to the consequences of individual differences in self-regulation for the functioning of a child.

Chapter 6 illustrates the consequences of failure in self-regulation by focusing on ADHD, one of the most common developmental pathologies involving self-regulation deficits. This chapter follows each of the causes and consequences of self-regulation described in Chapters 3, 4, and 5 and illustrates their relevance to ADHD.

Diamond and Amso (2008) recently suggested that the greatest contribution of neuroscience research to the study of cognitive development is in illuminating mechanisms that underlie behavioral observations made earlier by psychologists. Moreover, neuroscience has made important contributions to our understanding by demonstrating that the brain is far more plastic at all ages than previously thought—and, thus, that the speed and extent to which experience and behavior can shape the brain are greater than imagined (Diamond

& Amso, 2008). In this context, an intriguing applied question that would be of special interest for the educator audience is how attentional–executive control training and curriculum-based interventions can improve self-regulation. There is some initial evidence that training can be beneficial in normally developing preschoolers and school-aged children. The extant data are reviewed in the last chapter of this book, Chapter 7. Although it is still too early to conclude whether it is feasible to foster self-regulation through short interventions and training, and how long the resultant effects would last, this is certainly an interesting and provocative possibility that deserves further exploration.

This book focuses on development from infancy to adulthood. It is my hope that this book will be useful for researchers in developmental psychology, developmental neuroscience, and in particular, those interested in attention, self-regulation, and their deficits. Moreover, I hope that the volume will be useful and enlightening for educators and teachers coming from research circles who are interested in the growing bridge between the brain sciences and education.

2

NEUROCOGNITIVE AND NEUROMOTIVATIONAL MECHANISMS OF SELF-REGULATION

This chapter is dedicated to the mechanisms involved in self-regulation. These include not only cognitive but also motivational processes. For the sake of simplicity of presentation, the different mechanisms are reviewed here separately, although self-regulation in ongoing daily life behavior surely involves them all within complex interactive combinations. For each mechanism or function, I begin with a short description and definition, and then I describe the ways this function is studied, including common laboratory tasks that are extensively used. Moreover, I describe the brain infrastructure that stands behind all these processes. By *brain infrastructure*, I mean neuro-anatomical and functional circuitry, that is, networks of brain areas that together support specific cognitive or emotional functions, as well as the involved physiological mechanisms.

This chapter integrates the interdisciplinary knowledge emerging from behavioral, lesion-based, electrophysiological, and pharmacological studies in animals (mainly primates) and humans as well as the increasing literature in human brain imaging.

NEUROCOGNITIVE MECHANISMS

Several different neurocognitive mechanisms come into play in self-regulation. The one most basic and essential involves selective deployment and control of attention.

Attention

A common underlying factor behind all forms of self-regulation and a key factor of this construct is attention, especially the anterior mechanisms of executive control of attention (Fonagy & Target, 2002; Kopp, 1982; Posner & Rothbart, 1998; Ruff & Rothbart, 1996). By the term *attention*, I refer to the mechanisms that enable adaptive behavior by selecting, integrating, and prioritizing among competing demands on our cognitive and emotional systems by the outside world as well as from internally generated goals. According to Posner's model, attention involves different mechanisms subserved by separate brain networks (Posner & Petersen, 1990). In this model, attention encompasses three subsystems: orienting, alertness, and executive control (Figure 2.1 shows the main brain areas involved in each attention network). Although these are separable networks, they are also functionally integrated and definitely interact with one another (Fan et al., 2009). As mentioned, the key aspect of attention involved in self-regulation is the third one. Therefore, I briefly define the first two attention networks and then focus mainly on the anterior, executive one.

Orienting

Orienting of visual attention to a point of interest is commonly accompanied by overt movements of the head, eyes, and/or body. Attending may originate at will, as when one decides to look at a particular location where something of interest is expected, or it may originate reflexively without intention when something captures one's attention, as when one orients to a flash of light in the dark or to a movement in the periphery of the vision.

Basic research in this area has been based on the paradigm developed by Michael I. Posner (1980) to study visual spatial attention. With this paradigm it has been found that orienting to a location in space, either overtly or covertly (with or without eye movements), facilitates responding to targets appearing at that location.

Orienting of attention involves engagement, moving, and disengagement processes or stages. The initial view claimed that the superior parietal lobe is involved in the operation of disengaging attention, the colliculus in moving it, and the pulvinar in engaging the target (Posner & Petersen, 1990). More

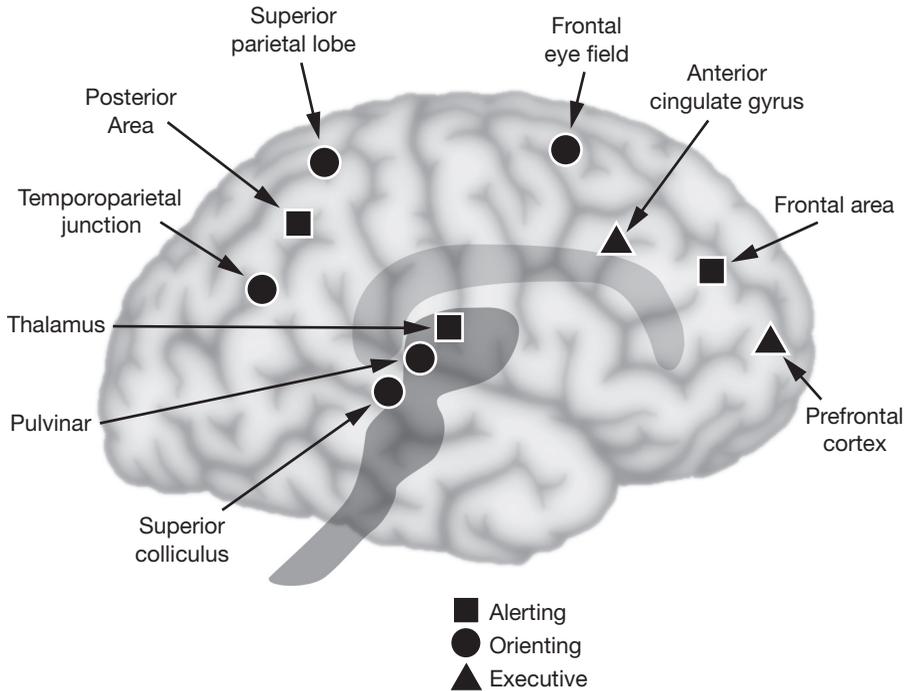


Figure 2.1. Brain areas involved in the different attentional networks: alerting, orienting, and executive attention. Reprinted from *Educating the Human Brain* by M. I. Posner and M. K. Rothbart, 2007, p. 51, Washington, DC: American Psychological Association. Copyright 2007 by the American Psychological Association.

recent frameworks indicate that the superior parietal areas seem related to voluntary movements of attention, whereas disengaging to handle novel inputs appears to involve the temporal parietal junction (e.g., Corbetta & Shulman, 2002).

Research has suggested that brain injuries, especially in posterior areas of the brain, damage the orienting system. In particular, damage to the temporal parietal junction and the parietal lobe produces a syndrome called *neglect* or *extinction* (Friedrich, Egly, Rafal, & Beck, 1998; Karnath, Ferber, & Himmelbach, 2001). Damage to the midbrain superior colliculus (Sapir, Soroker, Berger, & Henik, 1999) and to the frontal eye fields (Henik, Rafal, & Rhodes, 1994) also incurs deficiency in performance of the orienting system. These different brain areas within the orienting network seem to be involved to different extents in engagement, moving, and disengagement. Neuroimaging studies are in line with patient studies and confirm that the superior parietal lobe is involved in voluntary shifts of attention and is active following a cue that informs a person to shift attention covertly (without

eye movement) to a target (Corbetta, Kincade, Ollinger, McAvoy, & Shulman, 2000). Moreover, it has been demonstrated that attending to an object in a spatial location increases blood flow and electrical activity in extrastriate visual regions, particularly the fusiform gyrus (Mangun, Buonocore, Girelli, & Jha, 1998). Pharmacological studies in primates relate the orienting system to the neurotransmitter acetylcholine (Davidson & Marrocco, 2000).

As explained in more detail in Chapter 3, the ability to orient attention is important for self-regulation early in infancy.

Alertness and/or Sustained Attention

This network is involved in establishing a vigilant state and maintaining readiness to react. One way to study this system is by manipulating parameters of warning signals (e.g., a fixation point) that precede targets (Posner & Boies, 1971) and measuring the transient alerting effects of these signals. However, in many situations the readiness to react needs to be kept constantly at a tonic level. Maintaining the state of alertness over time is a function often referred to as *sustained attention*. To study this ability, a long and boring task is presented and fluctuations in performance over time are measured. An example of a task of this sort is the continuous performance task. In this type of task, the participant must pay close attention and respond correctly to an infrequent target. For example, the letters X and O are presented one by one at the middle of a screen. The Xs are infrequent and defined as targets. The Os are frequent and should be ignored by the participant.

The alerting network seems to involve areas in the right frontal lobe (especially the superior region of Brodmann's area 6), the right parietal lobe, and the locus coeruleus (Posner & Petersen, 1990). Studies in alert monkeys have shown clearly that the readiness induced by warning signals can be blocked by drugs that reduce norepinephrine (Davidson & Marrocco, 2000).

Executive Attention

This network has been related to the control of goal-directed behavior, including selection, target detection, conflict resolution, inhibition of proponent responses, monitoring and error detection (Berger & Posner, 2000). Executive attention embodies the *supervisory attentional system* in the Norman-Shallice model (Norman & Shallice, 1986). Norman and Shallice (1986) proposed that this supervisory system is necessary when routine functions are insufficient for a required situation, when adjustment is required due to environmental or goal changes, or both. As is seen in further detail in this chapter, the executive control network seems to comprise the midline frontal areas, including the anterior cingulate cortex (ACC), supplementary motor area (SMA), and portions of the basal ganglia (Posner & Petersen, 1990).

According to Posner and DiGirolamo (1998), “the ACC and other midline frontal areas are involved in producing the local amplification in neural activity that accompanies top-down selection of items . . . providing a boost in activation to items associated with expectation” (p. 411).

Selection and Conflict. *Selection* refers to the ability to focus on a certain stimulus or feature of a stimulus and ignore irrelevant ones. The most common way to experimentally study selective attention is by creating conflict situations in which participants are asked to respond to one stimulus or to one aspect of a stimulus and ignore another stimulus or another aspect of the stimulus. The well-known Stroop task (Stroop, 1935) is an example. Participants are presented with written color words (e.g., blue, red) printed in colored ink and are asked to name the color of the ink (or font) as fast as possible while ignoring the meaning of the written word. In the computerized version of the task, there are three different experimental conditions: (a) congruent, in which the written word is congruent with the color of the font (e.g., “red” written in red); (b) neutral, in which a neutral string of letters is written in color (e.g., XXX written in red); and (c) incongruent, in which the written word is the name of a different color than the color it is written in (e.g., “blue” written in red). In all of these presented examples, the participant needs to respond “red” to correctly name the color of the ink. However, participants usually show a robust interference component, namely, they are slower to respond to an incongruent condition than to the neutral condition. In addition, there is a small facilitation component, indicated by faster responding to congruent than to neutral trials. This pattern of effects indicates that participants fail to fully apply selective attention to the relevant dimension—the color of the font—while filtering out the irrelevant dimension—the semantic meaning of the word (Henik & Salo, 2004; MacLeod, 1991; MacLeod & MacDonald, 2000). Many Stroop-like tasks have been developed and used in the literature, all sharing the pairing of two dimensions that can be congruent or incongruent with each other and the instructions to respond to one dimension while ignoring the other.

Additional types of paradigms used as marker tasks for executive attention are the flanker (Eriksen & Eriksen, 1974) and Simon tasks (Simon & Small, 1969). In the flanker task, participants are presented with a stimulus at the center of a screen, flanked on either side by two irrelevant stimuli that are supposed to be ignored. An incongruent condition is created when response to the target should be with one hand while the flanker triggers a contradicting response. A congruent condition is created when the flanker and the target induce the same response (Magen & Cohen, 2007; J. Miller, 1991). The price of longer reaction times (RTs) in the incongruent condition than in the congruent one is indicative of a failure in selective attention, that is, the inability of the participants to completely ignore the irrelevant flankers.

In the original Simon task (Simon & Small, 1969), participants were asked to respond with their right or left index finger to a high- or low-pitch tone (i.e., respond with a right keypress to a high-pitch tone and with a left keypress to a low-pitched tone). The tones were presented to the right or left ear. The effect that was found was that reaction time was faster when the stimulus location was spatially congruent with the assigned response (e.g., right-hand response to a stimulus presented to the right ear) than when it was incongruent (e.g., right-hand response to a stimulus presented to the left ear). The same effect is found when stimuli are presented in other dimensions (e.g., visually) and is very robust.

The mentioned paradigms involve conflict and therefore tap executive attention. An interesting approach has been developed by Fan and colleagues (Fan, Fossella, Sommer, Wu, & Posner, 2003; Fan, McCandliss, Flombaum, Thomas, & Posner, 2001; Fan, Wu, Fossella, & Posner, 2001). They developed the attention network test (ANT) with the idea of having a single task that involves all three attentional networks and can be used to obtain a measure of the efficiency of each of the networks (see the children's version of this task in Chapter 3, Figure 3.1). The ANT is a combination of the mentioned spatial-orienting paradigm (Posner, 1980) and flanker task (Eriksen & Eriksen, 1974). Participants are required to determine whether a central arrow points left or right. The arrow appears above or below fixation and may or may not be accompanied by flankers. The efficiency of the three attentional networks is assessed by measuring how response times are influenced by alerting cues, spatial cues, and flankers (Fan, Wu, et al., 2001).

The ANT has been used as a phenotype, that is, the overt behavior showing individual differences, in genetic studies designed to determine the sources of individual variations in network efficiency (Fan, Wu, et al., 2001; Fossella et al., 2002). In a study with 26 pairs of monozygotic and 26 pairs of dizygotic same-sex twins, Fan, Wu, et al. (2001) found strong correlations between the monozygotic twins for both the executive and alerting networks. For the alerting network they found a similar although somewhat smaller correlation among the dizygotic twins, but for the executive network the dizygotic twins were only slightly correlated. This led to an estimate of .89 for the heritability of the executive network. Because of the small sample, the estimate of a 95% confidence interval for heritability is between 0.3 and 0.9. Nonetheless, these data support a role for genes in the executive and possibly in the alerting network (Posner & Fan, 2004). Consistently, indices of heritability have also been found in twin studies for the Stroop task (Stins, van Baal, Polderman, Verhulst, & Boomsma, 2004; J. Taylor, 2007).

Brain Circuitry Involved in Conflict Resolution. As mentioned previously, performance of conflict tasks produces activation in the ACC and areas of the lateral prefrontal cortex, especially the dorsolateral prefrontal cortex (DLPFC),

which seems to operate together in tasks that require this type of mental effort (Bush, Luu, & Posner, 2000; Fan, McCandliss, et al., 2001; Peterson et al., 2002).

The activated areas sometimes also included additional frontal areas, such as the dorsolateral prefrontal, the inferior frontal, and the supplementary motor (SMA and pre-SMA); parietal areas; basal ganglia areas, mainly the caudate nuclei; and several other areas, such as visual association areas; with slight differences in the strength of activation in each task (X. Liu, Banich, Jacobson, & Tanabe, 2004). For example, although the Simon task activates more than the Stroop task in the ACC, SMA/pre-SMA, and superior parietal brain areas, the opposite has been found for the inferior parietal cortex. Moreover, activation of the insula has been found to be important for interference suppression in the flanker task (Bunge, Dudukovic, Thomason, Vaidya, & Gabrieli, 2002).

The widest consensus is that tasks involving conflict (whether visual, manual, or oculomotor, and whether involving the spatial or verbal domains; Barch et al., 2001) activate both the ACC and the DLPFC. However, there are inconsistencies in the literature in regard to the lateralization of the DLPFC activity. Although some studies have found right-side activity (e.g., J. G. Kerns et al., 2004), others have found left-side homologous activity (e.g., MacDonald, Cohen, Stenger, & Carter, 2000), and still others have found bilateral activity (e.g., van Veen, Cohen, Botvinick, Stenger, & Carter, 2001).¹ Moreover, as readers will see, there are different views in regard to the exact function of each of these structures and the functional relation between them. For example, MacDonald et al. (2000) used a version of the Stroop task in which they gave participants a clue before each trial, instructing them whether the task was to name the color of the font or to read the word. Their event-related functional magnetic resonance imaging (fMRI) data indicated that during the preparation of the task, that is, after the participant received the cue and was preparing for the coming task, the left DLPFC was more active for the task that required a higher level of control (i.e., color naming). The ACC, on the other hand, was more active at the response stage and more for incongruent than congruent stimuli. On the basis of this finding, MacDonald et al. suggested that the ACC monitors the appearance of a conflict, whereas the DLPFC implements control when an attention-demanding task is at hand. Although, in contrast to the authors' interpretation, it can be argued that the DLPFC activity found in this study was mainly related to the need to hold in working memory (WM) the instructions for which task was required in the specific trial.

An additional fMRI study that arrived at a similar conclusion was conducted by Carter et al. (2000). Their study manipulated the proportions of

¹These last two studies revealed the bilateral dorsolateral prefrontal cortex activation with a flanker task, whereas the unilateral examples were revealed with Stroop tasks.

congruent and incongruent Stroop trials in different experimental blocks, under the assumption that the participants' degree of strategic control would differ under those different conditions. Indeed, they found a smaller behavioral congruency effect in the block with a high rate of incongruent trials compared with the effect in the block with a high rate of congruent trials. ACC activation was larger in the incongruent than in the congruent condition in the block with the high rate of congruent trials, but no difference was found in the mostly incongruent blocks. In addition, the activation in the incongruent condition in the block with the high rate of congruent trials was larger than the activation in the incongruent condition in the block with the high rate of incongruent trials. Moreover, the correlation between the congruency effect and ACC activation in the block with the high rate of congruent trials was relatively high and positive ($r = .58$). This pattern of results was taken as an indication that ACC activity reflects the degree of conflict rather than the implementation of control, although Carter et al. rolled out a simpler view that the ACC activation reflected the surprise of the participant on encountering the infrequent incongruent trial.

The view of this research group has been supported by their computational models (Botvinick, Braver, Barch, Carter, & Cohen, 2001) and summarized in the work of Botvinick, Cohen, and Carter (2004). It includes the idea that the ACC response to conflict triggers strategic adjustments in cognitive control and therefore reduces conflict in subsequent performance. One of the most interesting studies by this research group on this topic was published in *Science* by J. G. Kerns et al. (2004). Their idea was that more behavioral adjustment would be elicited by an incongruent Stroop trial than by a congruent one. In other words, greater cognitive control would be elicited by the higher degree of conflict in incongruent trials, and this would affect the following trial. Therefore, they compared incongruent trials and congruent trials preceded by incongruent or congruent trials. They found that responses to incongruent trials preceded by incongruent trials (iI) were faster than to incongruent trials preceded by congruent ones (cI). The imaging data consistently showed less ACC activity on iI trials than on cI trials, supporting the idea that the additional recruitment of control on a preceding incongruent trial reduced the degree of conflict on the following trial. Moreover, they median-split the iI trials and compared trials that were defined as high-adjustment trials (iI trials with shorter RTs than the median) with trials that were defined as low-adjustment trials (iI trials with longer RTs than the median). They found that greater ACC activity was associated with high adjustment of behavior on the subsequent trial. Moreover, this adjustment was associated with increased activity in the DLPFC. Similar results were found in regard to posterror adjustment. This pattern supported their hypothesized model that the ACC implements a conflict-monitoring function that leads to the recruitment

of cognitive control, whereas the DLPFC is more directly involved in the implementation of this control.

The biggest advantage of the event-related-potentials (ERP) methodology is its accurate temporal resolution. For this reason, ERP studies could potentially reveal critical information on ACC–DLPFC functioning during conflict. Hanslmayr et al. (2008) carried out a study that has contributed supporting evidence for the view that was presented earlier. Their data showed that an interference Stroop effect elicited increased negativity at frontocentral electrodes around 400 ms after stimulus onset. An effort to localize the brain generator of the ERP by using a computational method designed to relate the distribution on the scalp to the underlying brain source (brain electrical source analysis or BESA) indicated that this effect was likely to be generated in the ACC, which was more active for incongruent and negative priming trials than for congruent and neutral trials. At about 600 ms after stimulus onset, the ACC showed an increase in theta oscillations (4–8 Hz) that was correlated with interference and sustained phase coupling with the left PFC. Hanslmayr et al. concluded that the early ACC activation played a crucial role in conflict monitoring and interference detection, and it engaged the control mechanisms of the PFC.

On the other hand, there are ERP studies that contradict this view of the ACC–DLPFC relationship. Markela-Lerenc et al. (2004) also used the Stroop task and BESA algorithm for source localization. They found an early negativity between 350 ms and 450 ms after stimulus onset, which was localized to the left PFC. A later positive effect was found between 450 ms and 550 ms over frontocentral scalp electrodes and was localized to the right cingulate cortex. In other words, the results of this study indicated that the ACC activation followed the left PFC activation, supporting the view that the PFC evaluates the need for executive control, whereas the ACC implements it.

An interesting additional piece of information about the ACC–DLPFC relationship comes from single-cell recording studies in monkeys, and it can be considered to be consistent with findings of Markela-Lerenc et al. (2004). Matsumoto et al. (2003) showed that when monkeys select one of two actions on the basis of anticipation of a reward and their recent experience of the contingency between action and goal, the neuronal activity representing the anticipated goal occurs first in the PFC. After a short delay, there is neuronal activity representing a combination of the anticipated goal and intended action in the ACC. On the basis of these findings, Matsumoto and Tanaka (2004) suggested that the initial PFC activity triggers the ACC one and this sequence of activities might underlie goal-based action selection. Specifically, they suggested that

the ACC may be *consequential*, that is, based on conflicts between evoked plans of concrete action. In contrast, in the LPFC, control may

be *preemptive*, that is, capable of preventing future conflicts, and may occur at a more strategic level, for example, by increasing attention to the task-related aspects of sensory stimuli. (Matsumoto & Tanaka, 2004, p. 970)

Additional information about the relationship between the ACC and the DLPFC comes from studies on monitoring and error detection and is presented in the next section.

It is interesting to note that the ACC is clearly involved not only in cognitive but also in emotional regulation, for example, in the evaluation of the salience and emotional significance of events (Luu, Tucker, Derryberry, Reed, & Poulsen, 2003), including pain (Luu, Collins, & Tucker, 2000). The ACC plays a role in cognitive and emotional circuitry and could be considered to be at the crossroad of these systems (Pessoa, 2008).² It has even been proposed that there are two separate subdivisions in the ACC, a dorsal ACC cognitive division and a rostral–ventral affective one (Bush et al., 2000).

There is clear evidence that the ACC, as well as the PFC, is involved in the cognitive modulation of emotion, for example, in reappraisal, which involves rethinking the meaning of affectively charged stimuli or events in terms that alter their emotional impact (Ochsner & Gross, 2008). In a study by Ochsner, Bunge, Gross, and Gabrieli (2002), participants viewed aversive photographs and were instructed to increase, maintain, or decrease (reappraise) their emotional reactions. Ochsner et al. (2002) found a positive correlation between ACC activation and effective reappraisal; in other words, the stronger the ACC activation, the more the participant succeeded in cognitively modulating the negative effect of the specific photograph. Moreover, Ochsner et al. demonstrated that cognitive increase of negative emotions (what they called “up-regulation”) involves increased activity in the left rostromedial PFC and ACC as well as in the left amygdala, whereas cognitive lowering of negative emotion (down-regulation) involves activation in the right lateral and orbital PFC, implicated in behavioral inhibition, and activation in the ACC with bilateral decrease in activation of the amygdala (Ochsner et al., 2004).

Monitoring. The ability to detect and evaluate errors and monitor performance and outcomes is essential for adjusting and interacting with one’s surroundings (i.e., is a critical aspect of self-regulation). Behaviorally, error detection leads to a slowing of responses in the trial following the one in which the error was detected (Jentsch & Dudschig, 2009; Laming, 1979;

²An additional brain structure considered to be at such a crossroad is the epithalamus, especially the lateral habenula (Hikosaka, Sesack, Lecourtier, & Shepard, 2008). This is an additional middle-line structure in the brain that has extensive connections to both the basal ganglia and the limbic system. Hikosaka et al. (2008) proposed that it is uniquely positioned both anatomically and functionally to participate in the circuit mediating the effect of emotion on decision making, through its influence on the activity of dopamine and serotonin neurons.

Rabbitt, 1966). At the brain level, recognition of errors activates the ACC (Dehaene, Posner, & Tucker, 1994). Activity in the ACC is found to be related to performance monitoring, regardless of the source of this feedback information. It has been proposed that the ACC has a fundamental role in relating actions to their consequences, both positive reinforcement outcomes and errors, and in guiding decisions about which actions are worth making (Rushworth, Walton, Kennerley, & Bannerman, 2004). Holroyd et al. (2004) presented participants with one of two types of stimuli—stimuli that had a fixed stimulus–response mapping that could be learned and stimuli that were associated with a random stimulus–response mapping that could not be learned. Accordingly, the evaluation of performance could rely on internal error monitoring in the case of the fixed mapping stimuli but was totally dependent on external feedback for the random mapping condition. Feedback stimuli indicated whether the participant received a financial reward (+10 cents) or a financial penalty (–10 cents). Their fMRI data showed that areas of the ACC were more active for error trials than for correct trials, regardless of the source of error information—self-detected following a response or provided by external feedback. This localization of error processing in the ACC and generally the “mesial PFC” was also found by Rubia, Smith, Brammer, and Taylor (2003).

Electrophysiological studies of self-performance monitoring have focused on two main ERP components: the error-related negativity (ERN) and the feedback-related negativity (FRN). The ERN is a negative component found in response-locked analyses over the medial frontal cortex, between 50 ms and 150 ms after the execution of an incorrect response in a RT task, even in the absence of explicit performance feedback (Coles, Scheffers, & Holroyd, 2001; Luu et al., 2003; Luu & Tucker, 2001; Luu, Tucker, & Makeig, 2004; Scheffers & Coles, 2000). The FRN relates to a negative electrical deflection similar to ERN, following a feedback associated with unfavorable outcomes (M. X. Cohen, Elger, & Ranganath, 2007; Yeung, Botvinick, & Cohen, 2004; Yeung, Holroyd, & Cohen, 2005; see Color Plate 1).

An important characteristic of the brain’s electrical activity related to the ERN and FRN components is that both are expressed in synchronized (phase-lock) theta activity (M. X. Cohen et al., 2007; Luu & Tucker, 2001; Luu et al., 2003, 2004). Moreover, the theta activity related to the ERN and FRN components has been localized specifically to the ACC (Luu et al., 2003, 2004; Yeung et al., 2004, 2005).

Using a BESA, van Veen et al. (2001) showed the same source dipole model at the ACC for conflict processing (activity before the response was made, i.e., the N2 component) and for error processing (activity after an erroneous response was made, i.e., ERN). These results support the idea that ACC activity reflects a monitoring mechanism dealing with conflicts and

that errors are processed under this category. It is interesting to note that a relationship has been found between individuals' emotional regulation and the ERN. Luu et al. (2000) found that negative affect and negative emotionality were both positively correlated to ERN amplitudes. Chiu and Deldin (2007) found enhanced ERN in major depressive disorder.³

In a series of studies conducted in my lab, we found data that support and expand this view (Berger, Tzur, & Posner, 2006; Tzur & Berger, 2007, 2009; Tzur, Berger, Luria, & Posner, 2010). We showed that the ACC monitoring activity in the theta frequency band could be seen as a violation of expectation process, that is, a monitoring process that compares and analyzes the similarities and differences between an expected stimulus and/or action and a presented and/or performed stimulus and/or action. In other words, we suggested that conflict and error detection are subcategories of the detection of a violation of expectation. This includes the detection of erroneous information. Our data indicate that, for example, when a participant is presented with an incorrect solution to a simple arithmetic equation (e.g., after being presented with the equation $1 + 2 = _$, the participant is presented with the solution 4), there is a middle-central negative wave on the scalp, which reflects an increase in the power of theta brain activity. This model predicts that the larger the conflict or mismatch between the expected and the presented stimulus, the greater the activity that will be elicited in the ACC. Indeed, we found that the theta effects, localized to the ACC, depended on the salience of the error. That is, incorrect solutions with bigger deviations from the correct solutions (e.g., $1 + 2 = 8$, "big" error) were related to greater increases in phase-lock theta activity than were smaller deviations (e.g., $1 + 2 = 4$, "small" error).

Additional interesting information for the understanding of the different brain areas that implement control emanates from fMRI studies of functional connectivity during task performance compared with during a resting and/or default state, including studies that use the innovative application of graph theory. Different networks have been found to be active during task performance, while the *default network* reflects the spontaneous activity during a resting state (Fair et al., 2009). A frontoparietal network that includes the DLPFC and intraparietal sulcus seems to be related to adaptive control on a trial-by-trial basis. A second network, including the dorsal ACC, anterior insula–frontal operculum, and anterior PFC, seems to be involved in controlling goal-directed behavior through the stable maintenance of task sets (Dosenbach et al., 2007). Specifically regarding the ACC, Margulies et al. (2007) mapped its functional connectivity during rest. They examined the patterns of functional connectivity for 16 regions of interest (where they planted

³Patients with depression have been found to have an impaired Stroop effect relative to healthy controls (Moritz et al., 2002).

“seeds,” looking for the network of brain areas that act in synchrony with each of them). First, activity in the caudal division of the ACC was correlated with activity in sensorimotor circuits, whereas more rostral portions were correlated with prefrontal regions. Between these rostral and caudal zones they found transition regions, associated with a combination of ventral and dorsal brain systems. Margulies et al. suggested that this probably allows for the integration of affective and sensorimotor processes required for conflict detection and error monitoring. Moreover, this study found meaningful negative relationships between some of these different networks. For example, they found that the dorsal aspect of the caudal ACC, which was positively correlated with regions typically implicated in attentional processes (e.g., dorsolateral and posterior inferior prefrontal cortices), was negatively correlated with the rostral ACC and other regions of the default mode network, including ventromedial prefrontal and posterior cingulate cortices. Moreover, they found that rostral ACC regions that positively correlated with limbic and paralimbic areas implicated in affective processing were negatively correlated with superior parietal regions involved in higher order cognitive processes such as attentional control. Margulies et al. proposed that these relationships may delineate some of the circuits through which emotional and cognitive processes interact.

Inhibition

Inhibition is the executive function that reflects the ability to deliberately inhibit dominant, automatic, or prepotent responses (Miyake et al., 2000). Properly selecting actions that are behaviorally advantageous and withholding actions that are either inappropriate in a given behavioral context or unwanted because they interfere with completion of motor goals, cognitive goals, or both, are critical aspects for self-regulation and control (Simmonds, Pekar, & Mostofsky, 2008). Simmonds et al. (2008) pointed out that

much emphasis has been placed on the ability to suppress inappropriate and unwanted actions, often referred to as response inhibition, not only because of its importance for control of human behavior, but also because deficient response inhibition has been hypothesized to contribute to several neuropsychiatric disorders. (p. 224)

Although the requirement to suppress a prepotent response may be present in multiple task contexts, such as task switching, Stroop interference, and so forth, it is most clearly measured by go/no-go and stop-signal paradigms (Aron & Poldrack, 2005). The go/no-go task involves two types of stimuli: a go stimulus and a no-go stimulus. Participants are instructed to respond rapidly, generally with a keypress, to the appearance of the go stimulus only and refrain from responding to the no-go stimulus. Efficient withholding of responses to the no-go stimulus reflects response inhibition. Typically, the

task is weighted toward go stimuli to build up a prepotent tendency to respond, thereby increasing the inhibitory effort necessary to successfully withhold responding to no-go stimuli (Simmonds et al., 2008).

The stop-signal task is designed to measure a particularly challenging form of response inhibition because it requires inhibiting a response that has already begun to be prepared for execution (Logan, 1994; Logan, Cowan, & Davis, 1984; Schachar, Mota, Logan, Tannock, & Klim, 2000; and many others). This task is built on a go/no-go task. In addition to the regular go and no-go conditions, in a small proportion of the go trials (usually 25%–30%), a stop signal appears at an unpredictable delay after the go stimulus. The stop signal tells the participant to withhold the response to the go stimulus. When the stop signal appears shortly after the go stimulus, the task is relatively easy. In contrast, when the stop signal appears at a long delay after the go stimulus (close to the time of response), participants often fail to inhibit their response, which has probably already been “launched” (Schachar & Logan, 1990). It is possible to calculate stop-signal reaction times (SSRTs) and inhibition functions (percentages of failed inhibitions as a function of the go–stop delay intervals) using this task (Schachar & Logan, 1990).

The theoretical model that has commonly been suggested to explain the cognitive processes that underlie performance in the stop-signal task is the horse race (Logan, 1994). This model rests on the following assumptions: (a) there are two independent processes—the go process and the stop process; (b) if the stop process is faster than the go process, the response is inhibited; and (c) if the go process is faster than the stop process, the response is executed. The main advantage of the stop-signal paradigm is that based on this simple set of assumptions, it provides a way to measure the latency of a challenging act of control even though there is no overt behavior.

To study the stopping behavior, the delays between the go and the stop signals should vary, covering the range between the shortest point in which there is a close-to-zero stopping probability and the longest point in which there is a close-to-one stopping probability (Logan, 1994). In the early versions of the stop-signal task, the delays were fixed and predetermined for all participants (Logan, 1981; Logan & Burkell, 1986; Logan & Cowan, 1984; Logan et al., 1984). A more advanced strategy for choosing the delays is dynamic, based on a staircase tracking of the participants’ performance (Osman, Kornblum, & Meyer, 1986, 1990; Schachar et al., 2000, 2004; Schachar & Logan, 1990). The advantage of the tracking option is that it locks on the delay range in which the individual participant succeeds in stopping about 50% of the time and therefore requires fewer trials than the nondynamic paradigm. Successful implementations of the tracking paradigm include an initial block of go trials only, within which it is possible to calculate a mean go reaction time (MGRT) for the specific participant. Afterward, the finishing

time of the stopping process (SSRT) can be estimated, using the formula $SSRT = MGRT - \text{median delay}$.

Research in monkeys has shown that the brain area critical for inhibition is the DLPFC (Diamond, 1991; Diamond, Werker, & Lalonde, 1994). Adult rhesus monkeys with lesions in this region perform tasks that require inhibition (and WM, see the next section) at the level of human infants. These tasks include, for example, the A-not-B task, in which a reward is hidden in location A for several trials and successfully found by the monkey (or infant). Then the reward is hidden in location B. The subject needs to inhibit mistakenly reaching for location A, in which the reward was found in the previous trials. Adult monkeys with lesions of the DLPFC mistakenly reach for location A, especially if a delay of at least 2 s is imposed before the subject is allowed to reach for the reward. This is called an *A-not-B error* and is made by human infants at about 8 to 9 months of age (Diamond, 1991). Lesions in no other area of the monkey brain produce this pattern of performance (Diamond & Goldman-Rakic, 1989; Diamond, Zola-Morgan, & Squire, 1989; see reviews in Diamond, 1991; and in Diamond et al., 1994).

Imaging studies in humans support this localization. A meta-analysis of block-designed and event-related neuroimaging studies in healthy adults with go/no-go and stop-signal tasks supports a role for the prefrontal cortex (PFC), especially the right inferior frontal cortex, in response inhibition (Aron & Poldrack, 2005). Although this meta-analysis emphasizes activation on the right side, some studies have found bilateral activation of this brain region (Durstun et al., 2002; Rubia et al., 2000). Bunge, Hazeltine, et al. (2002) also found bilateral activation; however, when they identified the brain regions that were activated for response inhibition (i.e., during the go/no-go task) as well as for interference suppression (i.e., during the flanker task), they found that the activation on the right was more critical. At this point it should not be too surprising to realize that in addition to the DLPFC, the ACC and the caudate are also important for inhibition. For example, Durston et al. (2002) found that the activation in the ACC and caudate head was correlated with successful inhibition of responses in no-go trials.

It is interesting to note that the DLPFC and ACC are involved not only in the inhibition of overt responses but also in the inhibition (suppression) of thoughts. Mitchell et al. (2007) scanned their participants while they were alternately trying to suppress thoughts about a specific target (a white bear) or thinking freely about any topic. The different block types were cued by the color of a traffic light presented on a screen. During suppress blocks (cued by a red traffic light), participants attempted to avoid thinking about a white bear for 120 s. During free-thought blocks (cued by a green traffic light), participants were free to think about anything at all (including a white bear) for 120 s. In both conditions, participants made a button response whenever

they thought about a white bear, thereby enabling the researchers to distinguish neural activity associated with thoughts that differed only in respect to whether they were forbidden (occurring during the suppress task) or permissible (occurring during the free-thought task). They found that the DLPFC demonstrated sustained increases in activation during attempts at thought suppression, whereas the bilateral ACC demonstrated transient increases associated with occurrences of unwanted thoughts.

Functional connectivity studies, that is, studies that look at the correlation and coherence between activity in different brain areas and define functional networks by this, also contribute information regarding the circuitry involved in inhibition. Margulies et al.'s (2007) study, which was presented in the previous section, found that areas of the ACC that primarily correlated positively with the motor cortex negatively correlated with subcortical circuits, including the basal ganglia, the thalamus, and the cerebellum. It was suggested that this connection may have a role in the inhibition of prepotent stereotyped responses.

Working Memory

WM is one of the main mechanisms that enable people to deal with ever-changing environmental demands and goals. Using a latent variable analysis with behavioral data, Miyake and colleagues (Friedman et al., 2008; Miyake et al., 2000) identified WM as a core executive function, together with *inhibition* and *shifting*. Its function allows us to hold and manipulate the content of our thoughts and update them to accommodate new input (Kessler & Meiran, 2008). WM function requires monitoring and coding incoming information for relevance to the task at hand and then appropriately revising the items held in memory by replacing old, no longer relevant information with newer, more relevant information. Moreover, the essence of WM lies in the requirement to actively manipulate relevant information, rather than passively storing it (Miyake et al., 2000), and is related to attentional control (Kane, Bleckley, Conway, & Engle, 2001). Studies comparing monozygotic and dizygotic twins indicated that individual differences in WM are significantly influenced by genes (Ando, Ono, & Wright, 2001; Friedman et al., 2008).

One of the most influential theoretical models for WM was developed many years ago by Baddeley (1992; Baddeley & Hitch, 1974). According to this model, WM consists of an attentional control system (the *central executive*) that operates in conjunction with two subsystems that serve to maintain representations of information of different modalities: the *visuospatial sketchpad* and the *phonological loop*. The visuospatial sketchpad is for processing and storing visual and spatial information, and the phonological loop is for verbal information. The phonological loop is thought to consist, on the one hand, of a phonological store that holds auditory information for a few seconds and

on the other hand, of a phonological rehearsal mechanism that is analogous to subvocal speech (Baddeley, 2003).

Research on the brain substrates of the visuospatial sketchpad has been markedly influenced by research in monkeys (Smith & Jonides, 1999). Single-cell recordings made in alert monkeys while they engaged in a spatial-storage task revealed *spatial memory* cells in the DLPFC. These cells fired during a delay period while the monkey needed to hold in mind a specific position in space toward which a saccadic eye movement was required (Wilson, Scalaidhe, & Goldman-Rakic, 1993). Additional relevant work in monkeys has been already mentioned in the previous section. Success in the mentioned A-not-B task seems to reflect not only the inhibition of a previously reinforced response but also the ability of holding the location in WM during the delay, after which the infant or monkey is allowed to reach for the object. As mentioned, at 8 months of age, human infants make the A-not-B error even when a 2- to 3-s delay is used. In contrast, at 12 months they can withstand delays of 10 s and still succeed in the task (Diamond et al., 1994). As mentioned, lesion studies in monkeys also support the idea that the critical involved brain area for WM is the DLPFC (Diamond, 1991; Diamond et al., 1994).

Another type of cell identified in single-cell recordings in monkeys is *object-memory* cells, usually found in more ventral PFC regions (Wilson et al., 1993), although there is some controversy about the degree of separation between object and spatial regions in the PFC (see the summary in Smith & Jonides, 1999). Neuroimaging evidence tends to support a distinction between human spatial and object WM as well; however, it is still not fully clear whether the DLPFCs in monkeys and humans are indeed fully homologous structures (Smith & Jonides, 1999).

An additional brain area that has been consistently found to be related to memory retention during visuospatial WM tasks is the posterior parietal cortex, specifically, the intraparietal sulcus (e.g., Gnadt & Andersen, 1988). In a recent study published in the *Proceedings of the National Academy of Sciences, USA*, Edin et al. (2009) suggested that although this parietal region might store the memories themselves, a major role of the DLPFC in WM is to exert top-down control by boosting parietal memory capacity. Their model proposes that although lateral inhibition in the parietal cortex usually limits mnemonic capacity to a maximum of two to seven items, at high loads inhibition can be counteracted by excitatory prefrontal input, thus boosting parietal capacity. Edin et al. tested their model's predictions with fMRI and found supporting evidence for the idea that memories were stored in the parietal cortex, whereas interindividual differences in memory capacity were partly determined by the strength of prefrontal top-down control. These conclusions are consistent with Smith and Jonides's (1999) claim that there is dissociation between the areas involved in relatively passive short-term storage of information versus

areas involved in active updating, or more executive aspects of WM. In other words, whereas the simple storage and maintenance of information is associated with premotor areas of the frontal cortex and the parietal lobes, the updating function is directly linked to the DLPFC (Jonides & Smith, 1997).

With regard to the substrates of the phonological loop, neuropsychological and neuroimaging studies have indicated that left prefrontal areas such as Broca's area and premotor areas play a crucial role during the phonological rehearsal process (Koelsch et al., 2009). In a recent fMRI study by Koelsch et al. (2009), participants were presented with strings of four sung syllables and given the task to remember either the pitches (tonal information) or the syllables (verbal information). Rehearsal of verbal as well as of tonal information activated a network comprising the ventrolateral premotor cortex (including Broca's area), dorsal premotor cortex, planum temporale, intraparietal sulcus, and anterior insula, as well as some subcortical structures, such as the basal ganglia and thalamus, and also the cerebellum. The topography of activations was identical for the rehearsal of syllables and pitches, showing a remarkable overlap of the WM components for the rehearsal of verbal and tonal information (see Color Plate 2). When the WM task was performed under articulatory suppression, the activation in those areas decreased and additional activations arose in anterior prefrontal areas.

Many different experimental paradigms have been developed for the study of nonspatial WM. For example, an extensively used task that illustrates the holding of information, while constantly updating it and manipulating it, is the N-back task. In this task, in each trial, participants view a single letter presented at fixation. They are asked to decide whether each letter is identical to the letter that appeared N-items previously (e.g., two items back in the sequence; Awh et al., 1996). Studies using fMRI have demonstrated increased activation of the inferior and middle frontal gyri in this sort of task. This localization has been found in adults (J. D. Cohen, Forman, Servan-Schreiber, & Noll, 1994) as well as in school-age children (Casey et al., 1995).

At the electrophysiological level, WM updating has been related to the P3 component (Donchin & Coles, 1988), a positive voltage wave usually measured over middle-line frontoparietal scalp areas approximately 300 ms after stimulus onset. The P3 is produced by the distributed network of brain processes associated with attention (P3a) and memory operations (P3b; for a comprehensive review of these subcomponents, see Polich, 2007). It has been suggested that attention-demanding stimuli elicit a P3a when the contents of WM change, and this initiates neural activity toward the areas associated with P3b production and subsequent memory storage (Polich, 2007). Accordingly, the sources of the "memory" aspect of this component, although not yet fully identified, plausibly involve temporoparietal, hippocampal, parahippocampal, and thalamic regions (Key, Dove, & Maguire, 2005). The P3a seems to be mostly

associated with a frontal–dopaminergic pathway, whereas the P3b is mostly associated with a parietal–norepinephrine pathway (Polich, 2007). P3 peak amplitude and latency are sensitive to task-processing demands (Polich, 2007) and vary with age and cognitive capability (e.g., WM span; Polich, Ladish, & Burns, 1990). Moreover, individual differences in P3 amplitude and its decrease with age seem to be highly heritable (S. R. Carlson & Iacono, 2006).

Task Switching

The third executive function according to Miyake et al.'s (2000) nomenclature is *shifting*. By shifting, he meant the ability to switch from an ongoing task or state of mind to another. It concerns shifting back and forth among multiple tasks, operations, or mental sets (Monsell, 1996), providing the adaptive cognitive flexibility that enables goal-oriented self-control. This ability is strongly related to attention control (Arrington & Yates, 2009) and is sometimes referred to as *attention switching* and considered part of the mentioned *executive attention* mechanism (Posner & Petersen, 1990) or *supervisory attentional system* (Norman & Shallice, 1986). However, extensive current literature devoted to the study of shifting focuses on *task switching* (for a recent review of this literature, see Meiran, 2010). It has been shown that individual differences in shifting are not just a simple reflection of the ability to engage and disengage appropriate task sets per se but may also (or even instead) involve the ability to perform a new operation in the face of proactive interference or negative priming of the previous task (Miyake et al., 2000).

In the current literature, researchers often refer to the *task-switching paradigm*, whereas there are many different paradigms, and it remains to be seen whether these paradigms tap the exact same abilities (Meiran, 2010). Task-switching paradigms involve two or more tasks, but they can differ in the type of task, the modality of response, the methods to instruct participants about the task change, and so forth. Beyond these differences, a common finding is that task switching is associated with performance cost in the first trial following the switch (switch trial) compared with when the task is repeated from the previous trial (no-switch trial). It has also been found that providing advanced information about the next trial's task identity markedly reduces this switching cost; although it rarely completely eliminates it, and the remaining cost is called the *residual switching cost* (Meiran, 1996; Meiran, Chorev, & Sapir, 2000; Rogers & Monsell, 1995). There are a number of hypotheses regarding the nature of this residual switch cost. Most of these hypotheses share the idea that some, but not all, of the task set is prepared in advance. This preparation, although useful, is rarely complete, and in most circumstances the inner obstacles influence (but do not dictate) behavior at least until the first execution of the next task or activity (Meiran, 2010).

In addition to the actual switching, several control processes are involved when a participant performs a task-switching paradigm. First, there is a need to decide which task to execute and to maintain a goal representation in WM; second, there is a need for inhibition of the alternative tasks and to filter out task-irrelevant information and so forth (Meiran, 2010). Therefore, it is clear that in practice, it is almost impossible to design a task that specifically taps shifting without involving additional EFs at all. Still, shifting, WM, and inhibition EFs have been found to be moderately correlated with one another but clearly separable (Miyake et al., 2000). Consistently, in a twin study, Friedman et al. (2008) showed that although EFs as a whole are highly heritable, each one of them separately has specific additional heritability.

Flexible task switching generally relies on the lateral PFC (see reviews in Bunge, 2004; and Bunge et al., 2005). In addition, neuroimaging studies have shown that the parietal cortex and presupplementary motor cortex (pre-SMA) are also involved (Dreher & Berman, 2002; Rushworth, Passingham, & Nobre, 2005; Sohn, Goode, Stenger, Carter, & Anderson, 2003). There is ERP evidence that indicates that activity in the lateral PFC precedes activity in the parietal cortex during the updating of task rules (Brass, Ullsperger, Knoesche, von Cramon, & Phillips, 2005), supporting the hypothesis that the lateral PFC provides an abstract task representation that is then transmitted to and/or further specified in posterior cortices (Bunge et al., 2005).

Crone, Wendelken, et al. (2006) provided neuroimaging evidence for the dissociability of two components of task switching. In their study, the correct response to a target stimulus in each trial was based on an instructional cue. For *bivalent* targets, the appropriate response depended on the currently relevant rule. In contrast, *univalent* targets were always associated with the same response. Crone et al.'s analysis of brain regions of interest was based on their participants' responsiveness to bivalent versus univalent targets, within rule-switch and rule-repetition trials. They found that although the ventrolateral prefrontal cortex (VLPFC) was primarily associated with retrieval of the currently relevant task rule, the pre-SMA/SMA and the basal ganglia (caudate nucleus) were more closely linked to suppression of the previously relevant responses or response contingencies. Moreover, parietal activation reflected both rule retrieval and task-set suppression demands (see Color Plate 3).

NEUROMOTIVATIONAL MECHANISMS

Basic motivational systems are based on the limbic circuitry in the brain and have evolved to serve appetitive, defensive, and nurturant needs. They receive both simple perceptual inputs from the thalamus and complex perceptual and conceptual inputs from the cortex, and they can promote

adaptive responses through endocrine, autonomic, motor, and attentional mechanisms (Derryberry & Rothbart, 1997).

The appetitive (approach) system encourages approach behavior toward stimuli associated with the prediction of rewarding (positive) events (outcomes). Gray (1978, 1982) named it the *behavioral activation system* (BAS). A related system was defined by Panksepp (1992) and termed the *expectancy–foraging system*. In any case, from an evolutionary point of view, this capacity to seek rewards as goals is essential for the survival and reproduction of mobile organisms (Walter, Abler, Ciaramidaro, & Erk, 2005). The basic idea of this approach model is that the circuits in the orbitofrontal cortex (OFC), basolateral amygdala, and lateral hypothalamus respond to reward-related inputs by activating dopaminergic neurons in the brainstem’s ventral tegmental area. These dopaminergic neurons project to the nucleus accumbens, where they facilitate approach responses directed toward the rewarding input (Derryberry & Rothbart, 1997; Rothbart & Bates, 1998).

The details of the brain-reward circuitry have been studied extensively in animals, such as rodents and monkeys. Single-cell recordings in monkeys indicate the involvement of several brain structures in reward processing. Apart from the mesolimbic–mesocortical system, the DLPFC, the ACC, the posterior cingulate cortex, the frontal eye fields, the parietal cortex, and the thalamus have been implicated in reward processing (Walter et al., 2005). Structural and functional imaging techniques have shown that this circuitry in humans is markedly close to primate anatomy (Haber & Knutson, 2010). As reviewed and summarized by Haber and Knutson (2010), the key structures in the reward network are the ACC, the orbital prefrontal cortex, the ventral striatum, the ventral pallidum, and the midbrain dopamine neurons. Additional structures include the dorsal prefrontal cortex, amygdala, hippocampus, thalamus, lateral habenular nucleus, and specific brainstem structures such as the pedunculopontine nucleus and the raphe nucleus.

It has been shown that dopamine neurons detect the receipt of reward by an increase in activity after the reward has been obtained. Moreover, after the monkey learns that a cue predicts a reward, there are neurons that after conditioning, respond to these reward-predicting stimuli. Moreover, if the predicted reward is omitted, dopaminergic neurons decrease their firing rate at the time of reward. The basic reward information is then fed to higher brain structures involved in decision making and organization of behavior, such as the DLPFC. Neurons in the DLPFC and the striatum show activations during the mnemonic and movement preparatory periods of delayed response tasks, which differentially reflect the predicted rewards (Schultz, 2004).

This system has been extensively studied in the context of drug abuse and addiction (Volkow, Fowler, Wang, & Swanson, 2004; Volkow & Wise, 2005), which has been shown to involve the dopamine mesolimbic circuitry.

The dopamine projections proceed from the ventral tegmental area, and its different branches innervate the nucleus accumbens, the ACC, and so forth (see Figure 2.2).

There is an interesting and relevant debate in the literature in regard to the precise causal contribution made by the mesolimbic dopamine systems to reward approaching. There are three competing explanatory categories: liking, learning, and wanting. Berridge's (2007) review of the available scientific evidence concludes that dopamine is neither necessary nor sufficient to mediate changes in hedonic liking for sensory pleasures. Moreover, dopamine is not needed for new learning, and it is not sufficient to directly mediate learning by causing teaching or prediction signals. By contrast, dopamine contributes causally to incentive salience. Dopamine appears necessary for wanting a specific reward, and it enhances cue-triggered incentive salience. In other words, dopamine's contribution appears to be mainly to cause wanting for hedonic rewards.

Studies in humans support this brain localization of the reward system and show involvement of the VLPFC, including the OFC, the DLPFC, the ACC,

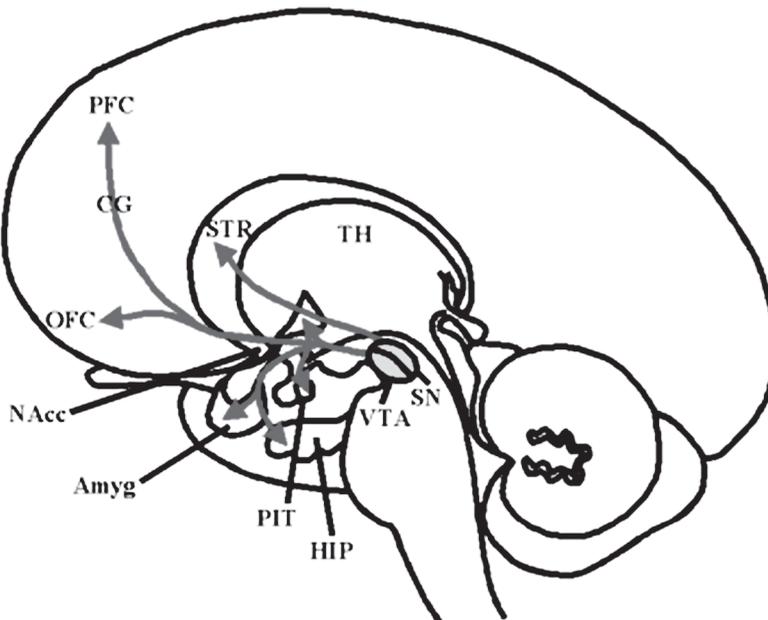


Figure 2.2. Dopaminergic pathways in the brain. Notice the left-most arrow depicting major projections of the dopaminergic system toward the cingulate gyrus (CG), prefrontal cortex (PFC), and orbitofrontal cortex (OFC). Reprinted from "How Can Drug Addiction Help Us Understand Obesity?" by N. D. Volkow and R. A. Wise, 2005, *Nature Neuroscience*, 8, p. 556. Copyright 2005 by Nature Publishing Group. Reprinted with permission.

the hippocampus, and the amygdala in decision making based on reward expectation (Bechara, Damasio, & Damasio, 2000; Bechara, Damasio, Tranel, & Damasio, 1997) and also in regret (Coricelli et al., 2005). Damage to the orbital prefrontal cortex impairs the ability to maximize benefits due to deficits in reversal learning or the ability to reverse previous stimulus–reward associations (see the review in Bunge et al., 2005).

Gehring and Willoughby (2002) presented participants with a gambling game in which their choices were followed by the presentation of an outcome gain or loss of various values. They measured ERP and found that starting 200 ms after the outcome stimulus, a negative polarity wave appeared. Dipole modeling suggested that the source of this wave was located in the medial frontal cortex, in or near the ACC. This effect was determined by the direction of the outcome; it was larger for loss trials than for gain trials and was not modulated by correctness of responding. In another study, Williams and colleagues (Gehring & Taylor, 2004; Z. M. Williams, Bush, Rauch, Cosgrove, & Eskandar, 2004) recorded activity of single human neurons in the dorsal ACC (dACC) during a reward-processing task. Five patients with severe depression or obsessive-compulsive disorder underwent cingulotomy (ablation of the dACC). Single-unit recording was conducted prior to surgery. Participants were asked to move a joystick to the left or right, according to the presented instruction, and they received feedback after responding. In 80% of the trials, the instruction consisted of five dollar signs (\$\$\$\$\$), meaning that participants received a reward of 15 cents for their performance and that they should respond in the same direction as in the previous trial. In the rest of the trials, they were instructed to change direction. In 10% of the trials, the instruction consisted of three dollar signs (\$\$\$), indicating a lower monetary reward of 9 cents, and in 10% of the trials the instruction was a double arrow, indicating no change in monetary reward (in spite of the need to change direction of movement). Activity of 39% of the recorded neurons was modulated by the instruction to change direction, and most of those showed increased activity in response to a reduced-reward cue. This change in neural activity in response to the reduced-reward cue predicted whether the participant would respond correctly after the appearance of the cue. There was no such connection between neural activity and responding for the two other cue conditions. This finding suggests that the activation was related to the reduced-cue situation. Moreover, when participants repeated the task right after surgery, they showed an impaired ability to change direction in response to instructions, especially under the reduced-reward condition. These results fit the notion that the ACC plays an important role in evaluation of outcomes of action and in signaling the need to make necessary changes that will produce better outcomes.

Delay discounting is the tendency to prefer smaller, sooner rewards over larger, later ones, which is an important indicator of self-control. Activity in

the anterior PFC has been directly related to delay discounting (Shamosh et al., 2008). In addition, extensive imaging research with the Iowa and similar gambling tasks (in which the participant can choose the win–lose ratio within which he would “play”—between high-winning probability of small rewards and low-winning probability of big rewards) strengthens the relevance of ventromedial PFC activity, including the OFC, to reward evaluation and decision making (Bechara, Damasio, Damasio, & Anderson, 1994; Bechara et al., 2000, 1997).

A complementary motivational system is a defensive system that mediates avoidance of negative outcomes. In Gray’s (1978, 1982) model it is called the *behavioral inhibition system* (BIS). This system is activated not only in situations that involve punishment but also in novelty and high-intensity stimulation. These situations elevate the arousal level (in the ascending reticular activating system in the brain), and this activates the medial septal area (which is monitored by the OFC). The activation in the medial septal area then leads to an increase in the theta rhythm, resulting in inhibition of behavior (Rothbart, 1989a; Rothbart & Bates, 1998). As described in the first part of this chapter, error detection (and violation of expectation in general) produces an increase in the power of the theta rhythm, and this effect has been related to the ACC.

Although Gray’s model focuses on the hippocampus and on passive avoidance, other researchers have suggested that the hippocampus is involved primarily in processing contextual information relevant to fear, whereas it is the circuitry within the amygdala that processes fear-related object information (Derryberry & Rothbart, 1997). For instance, according to LeDoux (1996), the amygdala’s lateral nucleus receives conditioned fear signals from the hippocampus, thalamus, and cortex, and it projects to multiple areas of the brainstem, where it regulates specific components of fearful behavior, including freezing, facial and vocal expressions, heart rate changes, and so forth. Moreover, it can enhance attention to threatening inputs through connections to reticular and cortical circuits, including to the ACC (Rothbart & Bates, 1998).

Punishments have motivationally opposite effects from rewards and constitute negative outcomes. They foment withdrawal behavior and serve as negative reinforcers in aversive conditioning by reducing the behavior that leads to punishment and increasing the behavior that leads to its avoidance and thereby produce aversive predictions for decision making in choice behavior (Schultz, 2007). Research in animals indicates that dopaminergic neurons respond mostly with activity depression to such aversive stimuli. It has been found that the time course of this neural response differs from the response to positive rewards and is slower and extends for longer periods (Schultz, 2007).

Approach and avoidance are considered to be mutually inhibitory motivational forces that affect behavior.⁴ Gray has proposed that imbalance between the strength of the BIS and the BAS is related to anxiety disorder at one end of the spectrum and extroversion and/or impulsivity at the other (Gray, 1982; Gray & McNaughton, 1982). However, these basic motivational systems (which humans share with other creatures) can be modulated by higher systems, enabling self-regulation and voluntary control, for example, the approach of situations in the face of immediate cues for punishment, or avoidance of situations in spite of cues for immediate reward (Posner & Rothbart, 2000), such as resisting the temptation to eat a bowl of delicious ice cream while one is on a diet (e.g., Vohs & Heatherton, 2000). The relevant concept is *effortful control* (Posner & Rothbart, 1998, 2000; more details about this concept can be found in Chapter 4, in this volume, in the section about temperament) or *willpower* (Mischel & Ayduk, 2004), which enables one to keep important long-term goals even when facing available short-term gratifications. The effective pursuit of delayed rewards and difficult-to-attain long-term goals depends on the availability of cognitive-attention strategies essential for overcoming stimulus control (Mischel & Ayduk, 2004). For example, preschoolers' ability to effectively direct their attention away from tempting aspects of the rewards in a delay-of-gratification task has been found to be a developmental precursor for the ability to perform inhibitory tasks, such as the go/no-go task, 10 years later (Eigsti et al., 2006).

BRAIN BASES OF COLD AND HOT EXECUTIVE CONTROL

Functionality in the brain is obtained within networks of structures and the white matter circuitry that connects these structures. Today, these white matter connections are understood in impressive detail from works on monkey brains (Schmahmann & Pandya, 2006). These white matter pathways connect the different brain areas that embody a functional network. In other words, they are the highways through which the functional connectivity between the different brain areas is driven. The mechanisms of self-regulation that have been reviewed in this chapter involve a specific orchestra of structures. The cognitive mechanisms of control reviewed in the first

⁴It is interesting to note that both systems can be involved in anger and aggression. On the one hand, instrumental anger is related to the BAS and would be elicited when the appetitive system is challenged, that is, when there is an obstacle preventing the obtainment of a desired stimulus (Panksepp, 1982). On the other hand, anger as disappointment would be elicited through the BIS when there is a signal predicting nonreward (Gray & McNaughton, 1982).

sections of this chapter have been often characterized as *cold* EFs (Metcalf & Mischel, 1999). We have seen that these processes involve dorsal thalamo–fronto–striate circuitry and, at the cortical level, focus on the DLPFC and ACC. This circuitry also seems to involve the cerebellum and basal ganglia (Nigg & Casey, 2005). Motivational control, reviewed in the second part of the chapter, has been often referred to as a *hot* aspect of EFs (Metcalf & Mischel, 1999). We have seen that it involves more ventral frontoamygdala connections and focuses on the VLPFC, including the OFC (Banfield, Wyland, Macrae, Munte, & Heatherton, 2004). Hot functions clearly also involve the ACC.

Moreover, although gamma-aminobutyric acid and glutamate are the excitatory and inhibitory neurotransmitters in these systems, dopamine is the key neuromodulator in both (Nigg & Casey, 2005; Sonuga-Barke, 2005). Reciprocal effects of serotonin (5-HT) and dopamine on innervation of the cortex have been found, suggesting that 5-HT and dopamine neurons interact competitively (Benes, Taylor, & Cunningham, 2000). As described in more detail in Chapter 6, both circuitries seem to be impaired in syndromes characterized with low self-regulation abilities, such as ADHD (Nigg, 2005; Nigg & Casey, 2005).

However, ongoing human behavior must combine hot and cold functioning. Different theoretical and computational models have been proposed in the literature for such integration. An example of such a conceptual metaphor combining hot and cold processing in self-regulation is the cognitive-affective personality system proposed by Mischel and colleagues (Mischel & Ayduk, 2004; Mischel & Shoda, 1995). Furthermore, speaking separately of cognitive regulation versus emotion regulation simplifies the discussion but may even be misleading. Lewis and Todd (2007) claimed instead that some forms of regulation are carried out by executive processes subject to voluntary control, whereas others are carried out by automatic processes that are far more primitive. Both sets of processes are in constant interaction, and that interaction gives rise to a stream of activity that is both cognitive and emotional. In the brain, this reciprocal regulation is implemented within a vertical stream between the phylogenetically newer cortical structures that regulate older subcortical ones through executive modulation of prepotent appraisals and emotional responses. In turn, subcortical systems regulate the cortex by tuning its activities to the demands or opportunities provided by the environment. In Lewis and Todd's words, "Cortical controls buy us time, as needed for planning and intelligent action. Subcortical controls provide energy, focus, and direction, as needed for relevant emotion-guided behavior" (Lewis & Todd, 2007, p. 406). According to this view, the ACC is the hub that mediates downward and upward control.

3

DEVELOPMENTAL NEUROPROCESSES SUPPORTING THE EMERGENCE OF SELF-REGULATION

Behind the emergence of self-regulation throughout childhood and adolescence stands a chain of developmental processes. Brain maturation, especially in the frontal cortex, and myelination of the functional connections of this brain area support the development of all the cognitive and motivational mechanisms that were presented in Chapter 2. The integration of these complex mechanisms provides the necessary infrastructure that makes self-regulation possible.

This chapter focuses on the progressive development of the brain infrastructure. As was evident in Chapter 2, dealing with conflict, inhibition, switching, or working memory (WM) results in the activation of related but not identical brain circuitry and electrophysiological components. However, in this chapter, I cover the developmental imaging and event-related-potential (ERP) evidence for the maturation of the functional network relevant for cold self-regulation within one section because similar principles of brain functional specialization seem to apply to the underlying mechanisms. I present a separate parallel review for the maturation of hot self-regulation. I maintain here the cold-hot classification for the sake of simplicity of presentation, in spite of the discussion presented at the end of Chapter 2. For the same reason, I cover functional magnetic resonance imaging (fMRI) and ERP research

separately in the cold section, given the vast amount of extant literature on these topics.

The refinement of brain functional circuitry is not really linear with age. It should be noted that several works indicate specific characteristics of the adolescent period compared with children and adults, and these characteristics show a specific relation with puberty.

The first part of this chapter focuses on the maturational processes in the brain, especially those related to enhanced connectivity with age. Then, in the second part, I review the evidence that supports the idea of specialization of self-regulative functional networks during development.

BRAIN MATURATION PROCESSES

Two major brain developmental processes related to connectivity begin in humans while in the womb toward the end of the 2nd and beginning of the 3rd trimester of pregnancy and continue throughout infancy to adolescence: (a) synaptogenesis (which includes both proliferation and pruning) and (b) myelination (for a more detailed description, see Berger, Kofman, Livneh, & Henik, 2007). A massive increase in total brain size is observed until the age of 5 to 6 years. Afterward, there is no significant increase in total brain size (Durstun et al., 2001), but the gray- and white-matter subcomponents of the brain continue to undergo dynamic changes throughout adolescence (Casey, Galvan, & Hare, 2005). Because these processes occur mostly after birth, they are markedly influenced by experience.

White-matter volume increases in a roughly linear pattern, increasing throughout development until young adulthood (Gogtay et al., 2004), and it results in increased axonal conduction speed and transmission of information between the brain hemispheres (Toga, Thompson, & Sowell, 2006). This developmental change can be observed with brain-imaging techniques and seems to be reflected in changes in the thickness of gray matter at different cortical regions throughout development. As shown by Sowell, Toga, and their colleagues (Sowell et al., 2004; Toga et al., 2006), increased myelination can be observed in structural neuroimaging as a progressive, relative “thinning” of cortical gray matter, which occurs at different rates in the different parts of the cortex. Specifically, higher order association cortices seem to mature only after lower order somatosensory and visual cortices are developed, the functions of which they integrate. In other words, motor and sensory brain areas mature first, followed by areas involved in spatial orientation, speech and language development, and attention (upper and lower parietal lobes). Later to mature are areas involved in executive function (EF) and motor coordination (frontal lobes; Gogtay et al., 2004). As reviewed by Paus (2005), postmortem

studies have consistently documented late myelination in various cortical regions, including the frontal and parietal cortices. The relative gray matter thickness in the different brain regions is highly heritable (Toga et al., 2006); their trajectory, primarily in the frontal regions, is relevant to intelligence (Shaw et al., 2006); and they are compromised in developmental pathologies such as early onset schizophrenia, William's syndrome, fetal alcohol syndrome, and attention-deficit/hyperactivity disorder (Toga et al., 2006).

Keep in mind that the gray matter thinning is probably not only the result of myelination but is also at least partly related to pruning. Gray matter volume shows an inverse U shape throughout development (Giedd et al., 1999), with pruning of redundant connections that regulates the initial overproduction of synapses occurring much later in the frontal cortex than in other cortical areas (Huttenlocher & Dabholkar, 1997). Moreover, pruning is more dramatic in the prefrontal cortex (PFC) than in other cortical areas, and it seems to be a targeted mechanism to sculpt the adolescent brain into its mature form (Spear, 2007). Some decrease in gray matter volumes with age has been documented, for instance in the basal ganglia, especially in the head of the caudate (P. M. Thompson et al., 2000).

Returning now to the process of myelination, it should be mentioned that the developmental trajectory of this myelination in the corpus callosum has been delineated using tensor maps (P. M. Thompson et al., 2000). In a series of repeated scans across time spans of up to 4 years, P. M. Thompson et al. (2000) found that children ages 3 to 15 years actually displayed a front-to-back wave of growth. This is surprising because in general, and as indicated earlier, the frontal parts of the brain are considered to be the latest to mature (Giedd et al., 2004; Sowell, Thompson, Holmes, Jernigan, & Toga, 1999). In regard to the corpus callosum, P. M. Thompson et al. found that between ages 3 and 6 years, peak growth rates are found in frontal circuits, whereas in older children the fastest growth was at the callosal isthmus (which is the part of the corpus callosum between its middle *body* and its posterior portion, called the *splenium*), which innervates temporoparietal systems. Between the ages of 11 and 15 years, they found that growth rates still peaked at the isthmus but were more attenuated (P. M. Thompson et al., 2000).

The diffusion tensor imaging technique has also been used to study the myelination of fibers that connect cortical and subcortical brain structures (Casey et al., 2005; Durston & Casey, 2006). Diffusion tensor imaging is based on the magnetic resonance (MR) signal being made highly sensitive to the movement of water molecules. Within white-matter tracts, the movement of water molecules is restricted by cell membranes and is faster in the direction of the tracks (perpendicular to their membranes). The water movement speed (termed *anisotropic diffusion*) is influenced mostly by the thickness of the myelin sheet and of the axons (Klingberg, Vaidya, Gabrieli, Moseley, & Hedehus, 1999).

Using this technique, it has been shown, for example, that the anisotropy in frontal white matter is lower in 8- to 12-year-old children than in adults, supporting the idea that there is frontal maturation of white matter in late childhood that increases axonal and myelin thickness (Klingberg et al., 1999).

Additional supporting evidence for the improvement in functional connectivity throughout childhood comes from resting fMRI studies focusing on brain intrinsic spontaneous activity, that is, the default network (Tau & Peterson, 2010), which was mentioned in Chapter 2. Spontaneous activity seems to reflect functionally relevant communications among neurons and serves to maintain network integrity by reinforcing the synaptic connections that subserve the network's typical functioning (Kelly et al., 2009). The basic default network connectivity appears to be present already at early infancy (Fransson et al., 2007), although according to Gao et al. (2009), it is still very incomplete in the first weeks of life. There is some inconsistency in the literature concerning the maturation timeline, probably because of differences in analysis methods: Gao et al. (2009) claimed that by the age of 2 years the default network already becomes similar to that observed in adults, including the medial PFC, posterior cingulate cortex–retrosplenial, inferior parietal lobule, lateral temporal cortex, and hippocampus regions, whereas Fair et al. (2009) showed a very significant maturation in functional brain connectivity between childhood and early adulthood. They showed that with development there is a trend toward a general decrease in correlation strength between brain regions close to each other in anatomical space and an increase in correlation strength between selected regions distant in space. In other words, brain regions in children communicate with other regions more locally, and gradually this communication becomes more distributed; that is, connectivity becomes organized according to functionality instead of anatomical closeness.

Moreover, the development in functional networks that connect with the anterior cingulate cortex (ACC), from childhood through adolescence until young adulthood, has been demonstrated within resting-state fMRI. Kelly et al. (2009) focused on five of the networks described in the study by Margulies et al. (2007), mentioned in Chapter 2, which were associated with self-regulatory control. They looked for correlations with caudal, dorsal, rostral, perigenual, and subgenual regions of the ACC, respectively considered being associated with motor control, attentional–cognitive control, conflict monitoring, social-cognitive functions (e.g., mentalizing, self-reflection), and emotional regulation (see Color Plate 4). Consistent with Fair et al.'s (2009) study, they found that children have a more diffuse pattern of correlation with voxels proximal to the region of interest, whereas adults show a greater number of long-distance correlations, and adolescents show an intermediate pattern (Kelly et al., 2009). It is interesting to note that they also found that the

greatest developmental effects were in the connections associated with social and emotional functions.

Color Plate 4 shows five connectivity networks, elicited by five seeds placed in different areas of the ACC. The following are of special interest: Seed S1, in the caudal ACC, is related to a network involved in movement execution and the control of motor behavior; Seed S3, in the dorsal ACC (dACC), is related to a network involved in the top-down control of attention and is commonly activated during WM, response selection, and inhibition, and in response to task cues; Seed S5, located in the rostral section of supragenual ACC, is related to a network typically associated with more evaluative functions than the dACC, including monitoring and signaling of conflict or interference, response to errors, reasoning, and decision making; Seed S7, located in the perigenual ACC, is implicated in social-cognitive functions such as mentalizing and self-reflection; and Seed I9, located in the subgenual ACC, which is central to a limbic and paralimbic system, subserves emotional responsiveness and regulation and the monitoring of rewarding or punishing outcomes. The B panels illustrate significant positive (green—red) and negative (blue—pink) connectivity for each ACC seed, for each group (child, adolescent, adult). The right side of the brain is depicted on the right side of the image, in Talairach space. Notice that frontal activations in the different types of control tend to be negatively correlated with activity in posterior brain areas. Moreover, notice that with development, the networks, especially the ones of cognitive control and conflict monitoring, become better delineated.

As can be seen further in this chapter, improvements in connectivity and speed of neural communication have marked functional implications for executive functioning (Olesen, Nagy, Westerberg, & Klingberg, 2003). Moreover, developmental neuroimaging studies of cognitive control suggest that cognitive development is supported by changes in patterns of brain activation, including enhancement of activation in critical areas, attenuation in others, and changes in the extent of activation as well as shifts in lateralization (Durstun & Casey, 2006). The maturation of the functional use of the PFC is suggested to be the critical limiting factor in the growth of cognitive control (Bunge, Dudukovic, et al., 2002). This process continues from childhood to adolescence and even to young adulthood. It is interesting to note that researchers are considering the brain transformations related to puberty with increasing interest, instead of treating adolescence as just a transitional phase between childhood and adulthood (Paus, 2005; Spear, 2000). In addition to the changes in white matter and gray matter described at the beginning of this chapter, Spear (2000, 2007) has claimed that the pubertal increases in gonadal hormones are connected with developmental transformations in the PFC and limbic brain regions of adolescents. This has been found across a wide range of animal species and seems to cause a shift in the balance between

mesocortical and mesolimbic dopamine systems, playing an important role in gating motivational information associated with stimuli. According to Spear, these brain changes impose challenges to self-regulation (Tucker & Moller, 2007), leading to the characteristics of adolescence regarding risk taking, drug abuse, and so forth.

DEVELOPMENTAL INCREASE IN FUNCTIONAL SPECIALIZATION

Increased Functional Specialization of Cold Regulation

Maturation of the circuitry involved in cognitive control has been demonstrated with brain imaging as well as electrophysiological techniques. Overall, clear differences have been found among children, adolescents, and adults in regard to the brain areas recruited when control is required and the strength of these activations, although there are also inconsistencies in the literature as to the direction of the results.

fMRI Studies

Bunge, Dudukovic, et al. (2002) used event-related fMRI to demonstrate the differences in brain activation in 8- to 12-year-old children versus adults in interference suppression and response inhibition. Their task combined the flanker and go/no-go paradigms. Participants viewed an array of stimuli on the screen and were requested to decide whether the central arrow pointed to the left or right and press a key accordingly. Flanker stimuli on both sides were congruent, neutral, or incongruent with the direction of the central target arrow or indicated to the participant to inhibit their response (in no-go trials). Bunge, Dudukovic, et al. found that children were more susceptible to interference and less able to inhibit inappropriate responses than were adults. At the brain activation level, effective interference suppression in adults was associated with right PFC activation. In contrast, effective interference suppression in children was associated with prefrontal activation in the opposite hemisphere. Specifically, it was associated with activation in the left insula and inferior frontal gyrus—brain regions related to language. A plausible explanation for this activation was that although adults could recruit the specialized required circuitry, children may have used verbal aid for succeeding in the task. Bunge, Dudukovic, et al.'s finding, replicated in several additional studies, was that children failed to activate a region in right prefrontal regions that were recruited by adults. One such consistent finding was reported by Marsh et al. (2006) with a much larger sample and across a wider range of ages. They used the Stroop task and fMRI scanning with 70 healthy individuals ranging in age from 7 to 57 years. The associations of sig-

nal activation across the entire cerebrum with age and with behavioral performance were assessed. Results of the study indicated that the magnitude of the MR signal changed in the incongruent condition and increased with age in the right inferior-lateral PFC and right lenticular nucleus. Overall, greater activation of this area was associated with better performance of the task. In a prior developmental fMRI study with the same task, but with a smaller sample and a more restricted range of ages, Adleman et al. (2002) found that young adults displayed bilateral activation in the inferior and middle frontal gyri, inferior and superior parietal cortices, and unilateral left activation in the ACC. Their between-groups comparisons revealed that young adults had greater activation than adolescent participants in the left- middle frontal gyrus and that young adults showed greater activation than children in the anterior cingulate and left parietal and parieto-occipital regions, as well as in the left-middle frontal gyrus. Moreover, compared with children, adults and adolescents had greater activation in the parietal cortex. Adleman et al. concluded that the Stroop task-related functional development of the parietal cortex occurs by adolescence, whereas the Stroop task-related functional development of the PFC continues until adulthood. It should be noted that the left-side effects found in this study were not replicated in Marsh et al.'s (2006) study with this same task. Less activity in children, at the critical cortical regions required for a mature performance of a given task that required self-regulation, indicates that with development there is an increase in the ability to recruit the critical circuitry for successful performance. This has also been found in WM tasks (Crone, Wendelken, Donohue, van Leijenhorst, & Bunge, 2006; Klingberg, Forssberg, & Westerberg, 2002a), flexible change in rules (Bunge & Zelazo, 2006), and oculomotor response suppression (Luna et al., 2001).

In addition, a substantial number of fMRI studies using the same sort of tasks mentioned above have shown that when children activate the same brain areas that adults do, they show *greater* activation. Casey, Trainor, Orendi, et al. (1997) found that the no-go and go conditions differed in the bilateral activation of the ACC and the inferior-, middle-, and orbitofrontal cortex (OFC). These locations were similar in children and adults, but activation was greater in children. Moreover, they found that the activity in the ACC correlated with the number of false alarms in both age groups. The greater activity in the PFC in children could be due to maturational factors such as cerebral vessel size, synaptic density, blood flow, and oxygen use. However, Casey et al. proposed that because the differences were found to be isolated to specific brain regions and the activation did not differ during the control condition, the findings may be attributed to developmental differences in the involved cognitive processes. Similar results were reported by Casey et al. (1998) in a WM task (see the review in Casey, Giedd, & Thomas, 2000).

Similar results were also found by Durston et al. (2002) in a go/no-go task in which the no-go trials were preceded either by one, three, or five go trials. They found that the bilateral ventral PFC, right dorsolateral prefrontal cortex (DLPFC), and right parietal cortex showed increased activation in no-go compared with go trials, both in children and adults. This increased activity was larger for the children than for the adults. Adults showed increased MR signals in no-go trials as a function of increasing number of preceding go trials. Children did not show this context effect, and their MR signal was at its highest in no-go trials regardless of the amount of preceding go trials. In addition, they found that the MR signal in several brain regions, that is, the ACC, the left caudate nucleus, and the bilateral inferior frontal gyrus, was correlated with performance (accuracy).

One of the plausible interpretations of such patterns of greater activity in the younger ages is that the activity in the children is more diffuse, or in other words, less tightly focused on critical and specific locations. However, this may also be related to longer connectivity, that is, functional connections between brain areas that are farther apart, in adults. Findings consistent with this view can be found in the work of Durston et al. (2006). Alternatively, it could be that this pattern reflects the differences in the performance level between the different age groups. This is important to consider because developmental differences in patterns of brain activity during cognitive control tasks might reflect maturation, but they might also reflect differences in task performance (Casey et al., 2005), although correlations between performance levels and MR activity levels were found in most but not all of the above-mentioned studies. Rubia et al. (2000) found an equal level of performance for adolescents and adults in a stop-signal task, and they found that the two age groups recruited different neuronal routes for achieving these comparable performance levels: left hemispheric prefrontal regions in adults and right-inferior frontal cortex and caudate in adolescents. It should also be mentioned that in a delayed task, which was a second task used in this study, there were performance differences: The adults performed better than the adolescents. In this task, there was an increase in power of activation in the adults in a fronto-striato-parietal network, including the right-inferior frontal gyrus that extends medially to the insula and the anterior and right posterior cingulated gyri.

Collectively, the developmental imaging studies seem to support the idea that children recruit larger, more diffuse prefrontal regions when performing cognitive control tasks than do adults (Casey et al., 2005; Durston & Casey, 2006). Consistent with this idea, Tamm, Menon, and Reiss (2002) used a go/no-go task and found more extensive and diffuse activation in their younger participants in the PFC, whereas their adult participants showed increasingly focal activation in the specific brain regions critical for response inhibition.

Event-Related-Potential Studies

ERP studies also tend to demonstrate age differences in the maturation of wave components related to conflict resolution, inhibition, and WM, although here too there are inconsistencies. Rueda and colleagues created a version of the Attention Network Task (ANT) that was mentioned in Chapter 2, adapted for children (Rueda, Fan, et al., 2004; Rueda, Rothbart, Saccomanno, & Posner, 2007; see Figure 3.1), in which they showed behavioral improvement in conflict resolution from the age of 4 years up to 7 years. Using a dense array electroencephalogram–ERP recording, Rueda, Posner, Rothbart, and Davis-Stober (2004) demonstrated marked differences in the 4-year-old versus adult-brain electrical components related to conflict within this task. They found that the conflict effect in adults was seen mainly in the N2 and P3 components. In the children’s ERP, the effects were delayed and sustained for longer periods of time. Moreover, in the children, a frontal conflict effect was observed (late positive component) prior to the parietal one. This frontal effect could be considered consistent with the fMRI evidence presented in the previous section, indicating greater frontal activation observed in

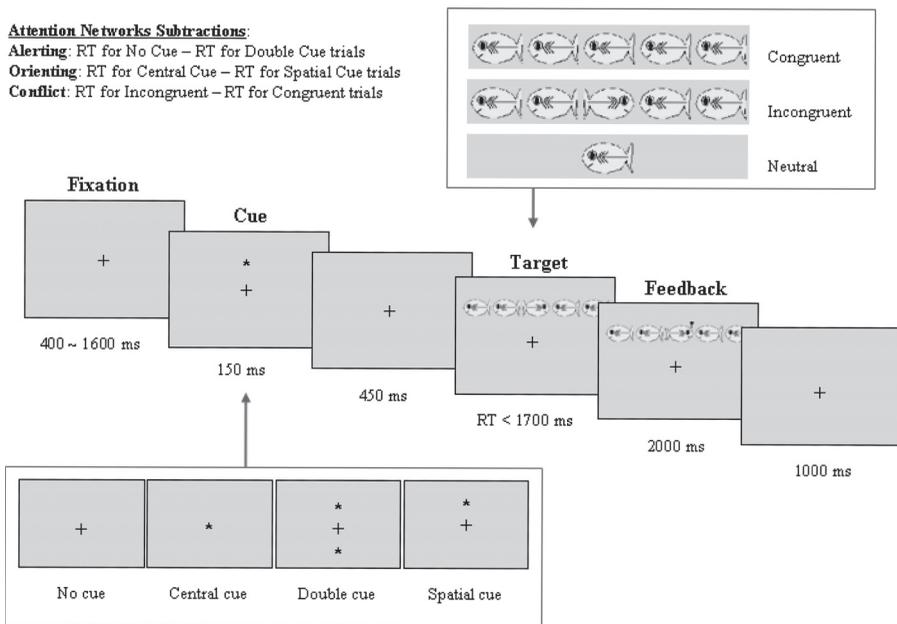


Figure 3.1. Schematic of the children’s version of the Attention Network Test (ANT). Reprinted from “Development of Attentional Networks in Childhood,” by M. R. Rueda, J. Fan, B. D. McCandliss, J. D., Halparin, D. B. Gruber, L. P. Lercari, and M. I. Posner, 2004, *Neuropsychologia*, 42, p. 1031. Copyright 2004 by Elsevier. Reprinted with permission.

children when a response has to be inhibited (Casey, Trainor, Giedd, et al., 1997; Durston et al., 2002).

In addition, as is usually the case in young children, Rueda, Posner, et al. (2004) found that the scalp distributions were broader and the amplitudes bigger in the 4-year-old group. Longer latencies of components that reflect conflict have also been demonstrated by Ridderinkhof and van der Molen (1995) using a flanker task. In this study, incongruent arrays delayed the onset of the P3 and lateralized readiness potential (LRP). This effect did not change with age for the P3, but it did for LRP onset. The authors interpreted this pattern of findings as suggesting that the locus of developmental change in the sensitivity to flankers is at the level of response activation rather than at the level of perceptual analysis.

A very interesting study attempting to disentangle the contribution of age versus EF ability on the amplitude and latency of the N2 within a go/no-go task was conducted by Lamm, Zelazo, and Lewis (2006). They studied children and adolescents ranging from between 7 and 16 years of age. Lamm et al. (2006) assessed EF independently from the ERP measurement during the go/no-go task, using a battery of tasks. They found that better performance on the Stroop and the Iowa Gambling Task was associated with smaller N2 amplitudes in the go/no-go task, over and above effects of age. Regarding the N2 latency, they found a decrease with age but no correlation with performance in the EF tasks. Moreover, their source-modeling analysis of the N2 indicated neural generators in the cingulate and orbitofrontal cortex. Lamm et al. found that the locations of these generators were dependent on EF: The cingulate generator was more anterior for participants at all ages having good EF, whereas the orbitofrontal generator was on the right OFC for older participants with good EF and relatively more left lateralized for younger participants and those with poorer EF. They concluded from these findings that age-related decrease in N2 amplitude but not in N2 latency reflects the development of cognitive control and cannot be attributed solely to incidental changes with age, such as increases in skull thickness. Moreover, they suggested that the functionally relevant decreases in N2 amplitude may reflect changes in the regions of the cortex that give rise to the N2. Johnstone, Pleffer, Barry, Clarke, and Smith (2005) also found a reduction in the amplitude and latency of the N2 when comparing children with adults in a go/no-go auditory task.

However, not all studies are consistent with an age progressive decrease in amplitude and latency of components related to control. For example, Ladouceur, Dahl, and Carter (2007) actually found greater amplitudes of the N2 conflict-related component for adults and late adolescents compared with early adolescents, and they localized this component to the ACC by using an arrow flanker task. Increase in the N2 amplitude with age was found also by Jonkman, Lansbergen, and Stauder (2003) in a visual go/no-go task.

Enlargement of amplitude of specific ERP components with age has been also demonstrated in some of the studies related to error detection, as is described in the next section. Moreover, such inconsistencies exist also in the literature related to the P3 ERP component. Although some studies have found latency decrease and amplitude increase with age (e.g., Polich et al., 1990), others have demonstrated amplitude decrease with age (e.g., S. R. Carlson & Iacono, 2006).¹

Increased Functional Specialization for Dealing With Errors

The basic brain infrastructure that reacts to errors seems to be operational already in infancy. My colleagues and I (Berger et al., 2006) showed that the brain response of 6- to 9-month-old infants to an erroneous solution of a simple arithmetic equation was comparable to the brain response of adults in a similar situation (although at this age the infants are not yet able to regulate their own behavior when detecting their own errors, and several years are required until they can show a mature pattern of reaction-time adjustments after the detection of a self-made error; Jones et al., 2003). This seems to be one of the earliest indices of the mechanism that unfolds with development into later capacities that enable the self-regulation of behavior and emotion. At the electrophysiological level, the error brain response in the infants was later in time (longer latency) and included a broader frequency band compared with the adults' response. As mentioned in Chapter 2, in adults this brain response was narrowly focused on the theta frequency band (J. D. Cohen et al., 2007; Luu et al., 2003, 2004; Luu & Tucker, 2001). Amplitudes were also much larger in the infants group, but this extreme difference is commonly found in the ERP literature with such young participants and is due to major changes in the skull and conductivity that occur after this age.

Current research in my lab is dedicated to the delineation of the maturational process with age, until the adult pattern of brain response to errors is achieved. Preliminary results seem to suggest a gradual decrease in amplitude and frequency range, with girls showing a more mature pattern earlier than boys. If confirmed, this pattern of development would be in line with what is known in the literature on the maturation of the more classic error-related negativity (ERN) component related to "self-made" errors (Davies, Segalowitz, & Gavin, 2004; Ladouceur et al., 2007; Segalowitz & Davies, 2004). The advantage of our line of study is that since no response is required from

¹One plausible explanation for the discrepancy in the direction of the P3 amplitude change with age is that this could be a matter of sensory modalities. In other words, for example, although studies that measure an auditory P300 amplitude would find an increase over childhood and adolescence, studies that measure a visual P300 amplitude would find the opposite trend. However, this is unlikely given the general consensus in the field that stimulus modality has no significant effect on the P3 amplitude and latency (Key et al., 2005).

the participants, it allows us to compare a much broader range of ages and does not require the adjustment of performance levels. Davies and colleagues (Davies et al., 2004; Segalowitz & Davies, 2004) measured ERPs while 7- to 18-year-old participants performed a visual flanker task and analyzed the ERN and positivity (Pe) components elicited by incorrect responses. They found that the ERN amplitude increased with age, with this component becoming better delineated. However, this change with age was not linear but quadratic, with an initial drop in amplitude until the beginning of puberty (the lowest was at a different age in boys and girls, according to the different timing of puberty between the sexes) and then a progressive increase through adolescence (see Figure 3.2).

Increase in the ERN amplitude between early and late adolescence has been also reported in the study by Ladouceur et al. (2007) mentioned previously. For the Pe component, they found that the amplitude increased between early adolescence to late adolescence, but then it was somewhat reduced at adulthood. No latency age effects were found in the ERN and Pe in either of the mentioned studies (Davies et al., 2004; Ladouceur et al., 2007; Segalowitz & Davies, 2004).

Increased Functional Specialization of Hot Regulation

fMRI Studies

Until very recently, only a few imaging developmental studies have focused on hot EF. However, these studies have provided consistent important evidence for the general thesis presented so far in this chapter of increased brain functional specialization with age. This is reflected in more specific recruitment of brain areas that are functionally relevant for regulation and less recruitment of less efficient brain areas, with critical changes happening in the adolescent period and much of the mature tuning being achieved only at adulthood.

In a very interesting study that used an adapted-for-children gambling task (including high- and low-risk two-choice decisions), van Leijenhorst, Crone, and Bunge (2006) scanned 9- to 12-year-old and 18- to 26-year-old participants, looking for developmental differences in risk estimation and feedback processing. Their whole-brain data analysis showed overlapping patterns of brain activation associated with risk estimation and feedback processing for children and adults, suggesting that both age groups performed the task in a similar way. In addition, van Leijenhorst et al. performed a region of interest analysis based on the relevant adult literature. They focused this analysis on the OFC, ACC, DLPFC, and midbrain in regard to risk estimation and on the ventrolateral prefrontal cortex (VLPFC) and medial PFC in regard to the negative feedback processing. Results of these region-specific analyses

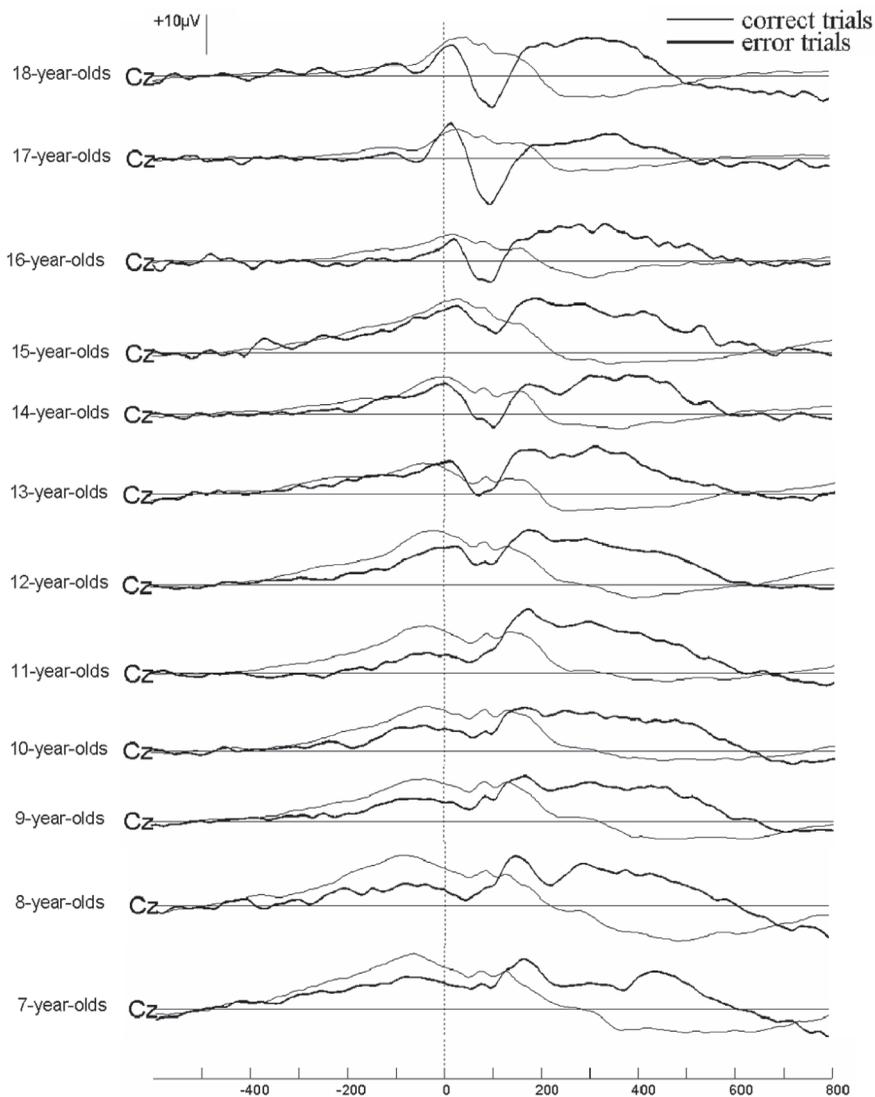


Figure 3.2. Grand average response-locked event-related potentials (ERPs) for the different age groups at electrode Cz for correct (thin line) and error trials (thick line). The vertical hashed line represents the time of the response (0 on the time axis). Notice gradual maturation of the error-related negativity with increasing age. Reprinted from "Development of Error-Monitoring Event-Related Potentials in Adolescents," by P. L. Davies, S. J. Segalowitz, and W. J. Gavin, 2004, *Annals of the New York Academy of Sciences*, 1021, p. 325. Copyright 2004 by Wiley-Blackwell. Reprinted with permission.

indicated that children and adults exhibited similar patterns of activation in the OFC and DLPFC related to risk estimation, but children recruited the ACC more strongly for high-risk choices relative to low-risk choices than did adults. The authors suggested that the higher ACC activation for high-risk trials in children could indicate that performance monitoring for high-risk decisions is more effortful for children compared with adults. In other words, this enhanced ACC activity reflects children's greater difficulty in making the right decision under uncertainty. In addition, they found that both adults and children recruited the bilateral VLPFC for negative versus positive feedback processing, and in addition, children recruited a region in the right lateral OFC. There was no difference between age groups for positive feedback in this region. Van Leijenhorst et al. concluded that the right lateral OFC is more strongly attuned to negative feedback in children than in adults.

Reward-related brain responses in children, adolescents, and adults were also studied by Galvan et al. (2006). Participants were scanned using fMRI while performing an adapted version of a delayed response two-choice (location discrimination) task in which the reward values were manipulated. Across ages, the nucleus accumbens and the OFC showed an effect of reward value: More activation was found for larger rewards. In both brain areas, there were developmental differences in the percentage of change in the MR signal. However, in the nucleus accumbens, the adolescents showed the greatest signal change, significantly higher than children and adults. In contrast, in the OFC, children showed the greatest signal change, significantly higher than adolescents and adults. The pattern of results was different for the extent of activity, that is, the number of activated voxels; the volume of activity in the nucleus accumbens was largest for children relative to both adolescents and adults. For the OFC, children and adolescents showed larger (i.e., more diffused) activity than adults. In other words, the results showed enhanced nucleus accumbens activity during adolescence and delayed tuning until adulthood of the extent of activity in the OFC. The authors suggested that these immature brain activations related to reward evaluation may contribute to suboptimal choices in adolescents being driven more by appetitive systems than control systems (Spear, 2000). Consistent with this claim about adolescence, Monk et al. (2003) compared adolescents' and adults' brain responses to emotional face expressions, and they showed that adults had greater modulation of activity in relevant brain structures (ACC and OFC) based on attentional demands, whereas adolescents had greater modulation based on emotional content.

Event-Related-Potential Studies

Increased maturation with age of brain mechanisms involved in self-regulation when hot aspects of regulation are involved has also been docu-

mented with ERP methodology. Lewis, Lamm, Segalowitz, Stieben, and Zelazo (2006) manipulated frustration in a sample of 7- to 16-year-old participants carrying out a go/no-go task in which points for successful performance earned a valued prize. They recorded brain electrophysiological activity using a tracking paradigm and provided the same level of challenge for all participants, ensuring that there was a sufficient number of correct no-go trials for ERP averaging. Participants were told and constantly reminded that a high number of points was needed to win the big prize. Moreover, their accumulated points were displayed in red in a window on the screen. In the first part of the task, participants saw their points steadily increase, usually to over 1,000. Then, in the second part, changes in the point-adjustment algorithm caused them to lose all of their points by the end of this block of trials. This loss of points was intended to induce anxiety, anger, distress, or a combination thereof, at the possible loss of the prize. In the last part of the task, the algorithm caused the participants to regain their points and win the desirable prize. For the first part of the task (before emotion was induced), they found a linear decrease in amplitudes and latencies for the N2 with age. Age differences were less distinct for the P3 component. In the block after the emotion induction, they found an increase in amplitudes for the adolescent participants (> 13 years). N2 latencies decreased with age, independently of the emotional condition. For the middle-frontal P3 in the no-go trials, they found that both amplitude and latency decreased with age. It is interesting to note that this decrease with age was found only in the no-go condition, whereas the amplitudes of P3 were stable across ages in the go condition. In contrast to the N2 results, participants of all ages showed an enhanced P3 component in the emotion-induction block. The authors suggested that the higher amplitudes following the emotion induction suggest more extensive or more effortful activation of response inhibition mechanisms when anxiety or frustration threatened performance; however, they could not explain why a different pattern of amplitude enhancement with the emotion induction was obtained for the P3 and N2. Moreover, Lewis et al.'s (2006) source-modeling analysis for the N2 suggested a steady developmental decline in the activation of a mid- or posterior-cingulate source and a developmental increase in the activation of an ACC source. This frontalization process in activity related to inhibition is consistent with the findings from the aforementioned fMRI studies (e.g., Bunge, Dudukovic, et al., 2002; Rubia et al., 2000).

Additional ERP studies of emotion regulation in children used a different manipulation of emotion: They presented stimuli with emotional valence (i.e., emotional faces) in a task that requires control and self-regulation. For example, Lewis, Todd, and Honsberger (2007) presented 4- to 6-year-old children with pictures of angry, neutral, and happy faces within a go/no-go task. The emotion displayed was irrelevant to the task, as go versus no-go trials were

cued by the gender of the presented face (counterbalanced across participants). This study did not reveal age differences in the ERP components' amplitudes and latencies. However, the authors found that, similar to adults, angry faces generated the greatest N2 amplitudes and fastest N2 latencies in the children, and happy faces produced the smallest amplitudes and slowest latencies (consistent results were also reported by this research group in an additional study; Todd, Lewis, Meusel, & Zelazo, 2008). Moreover, they found a correlation with maternal reports of child temperament (for more details about the concept of temperament, see Chapter 4 of this volume); specifically, they found that more fearful children showed a faster N2 latency to angry faces. A relation between middle frontal negativity (Nc) around 200 ms after stimulus onset and maternal temperament reports of emotional regulation was reported also by Dennis, Malone, and Chen (2009), using the ANT with emotional faces as distracters.

4

INDIVIDUAL DIFFERENCES IN SELF-REGULATION

Just as not all children achieve the same ability level in any of the other aspects of development, there are many individual differences in their development of self-regulation. Clear individual differences in the ability to self-regulate are evident already at early infancy. One of the most useful terms for conceptualizing these innate individual differences is *temperament*. Temperamental differences are probably related, at least partially, to genetic allelic variations (Auerbach, Faroy, Ebstein, Kahana, & Levine, 2001). However, children do not develop in isolation, and a lot of evidence indicates that the early environment has a great impact on the development of self-regulation. Regarding the regulation of emotions, for example, Sroufe (1983, 1995) suggested that the roots of self-regulation are the dyadic regulation within the relationship with the attachment figure. Moreover, the social and physical environment provides the goals and constraints for the adaptive modulation of behavior and emotion (Bronson, 2000; Denham et al., 2003; Sroufe, 1995; R. A. Thompson, 1994). There is increasing empirical support for the idea that these two sources of variability—genetics and environment—assert their influence on the development of self-regulation in an interactive way. For example, the epigenetic model stresses the view of DNA as an active target for remodeling by cellular signals that

are activated by environmental events, affecting genes' transcription and expression (Meaney, 2010). In other words, environmental conditions in early life might structurally alter DNA, providing a physical basis for the influence of the environmental signals on phenotype over the life of an individual.

This chapter is dedicated to the sources of individual differences in self-regulation. I focus first on how early environmental factors affect the development of self-regulative skills in the child. I then discuss individual temperamental differences, followed by a discussion of how genetic variations relate to self-regulation. In concluding the chapter, I provide evidence for the interaction between genetic and environmental factors.

CAREGIVING ENVIRONMENT

The early caregiving environment is found to be critical for later development. The parent–child rhythmic interaction that begins already at pregnancy (Feldman, 2007b) provides the timing for synchrony and a coordinated relationship, which lays the foundation for a child's later self-regulation and even capacity for intimacy throughout life (Feldman, 2007a).

In the first part of this section, I focus on the very early interaction between the infant and the parent and the importance of the harmony within this interaction. Following that, I describe the different dimensions of parental behaviors and strategies when coping with the challenges of parenthood as the child grows and their influence on the development of self-regulation. Parents are critical for the child's development of self-regulation at several parallel levels, as they are the main providers of (a) most of the regulation that the child initially requires before becoming able to self-regulate, (b) the models and strategies of self-regulation that the child eventually internalizes, (c) the primary environmental contingencies for the child's behavior, and (d) the opportunities and encouragement for the child to exert self-regulation. It is worth noticing that although this chapter reviews general rules of parenting, these rules are likely to interact with the individual temperamental and biological endowment of the child.

Early Interactions

Early, sensitive caregiving and the quality of the attachment that the child develops toward his caregiver are known to have long-lasting effects on the mental representational model of adult attachment relationships (Bowlby, 1973, 1980), as well as on the self-regulatory mechanisms for coping with stress (Goldberg, 2000; Schore, 1994) that the child develops. Evidence in support of the critical impact that early maternal care has on the development of self-

regulation in offspring has been found across a broad range of species. For instance, on the basis of rodent studies, Hofer (1996) asserted that the mother–infant relationship regulates the infant’s neuronal system, and the relationship’s loss or dysfunction implies poor modulation and coordination of physiological function, affect, and behavior.

Plenty of animal studies show that staying close to and interacting with the mother not only seems to be important for the infant’s survival but also offers many opportunities to regulate the infant’s physiological and behavioral systems (Caldji, Diorio, & Meaney, 2000; Hofer, 1995; D. Liu, Diorio, Day, Francis, & Meaney, 2000; Polan & Hofer, 1999; Suomi, 2000). Animal studies show, for example, that maternal separation during the first 3 weeks of life (before weaning), when synaptogenesis is taking place, increases anxiety behaviors (Parfitt et al., 2004; Romeo et al., 2003) and leads to either a blunted (Mirescu, Peters, & Gould, 2004) or exaggerated (Parfitt et al., 2004) release of corticosterone by the adrenal glands in response to stress. In addition, maternal separation reduces stress-induced neurogenesis, a critical process in neural plasticity (Mirescu et al., 2004). There is an increasing awareness in the literature that in humans, as in rat pups and baby monkeys, the mother–infant unit ensures the ontogenetic development of biological regulators (Fonagy & Target, 2002).

A long line of studies by Kochanska and colleagues (Kochanska, Coy, & Murray, 2001; Kochanska et al., 1996; Kochanska, Murray, & Coy, 1997; Kochanska, Murray, & Harlan, 2000) are relevant for testing the hypothesis that self-regulatory aspects of a child’s temperament (referred to as *effortful control*; see the detailed explanation in the next section) are influenced by the context of the mother–infant relationship, that is, by attachment processes. The pioneering studies of attachment in infants conducted by Ainsworth, Blehar, Waters, and Wall (1978) were based on a laboratory procedure known as the *strange situation*. This procedure tests the reaction of an infant to his or her mother in the presence of a stranger. Infants are observed when their mothers leave the room and when they are reunited with them, and the attachment style is classified as secure, resistant, avoidant, or disorganized (Main & Solomon, 1990). Kochanska, Coy, and Murray (2001) demonstrated that infants’ attachment classification in the strange situation at 14 months of age predicts their emotional regulation almost 2 years later, at the age of 33 months. This study found that insecure children were resistant, avoidant, and disorganized; had difficulties in regulating their affect; and showed more fear and anger in situations designed to elicit these emotions and more distress in situations designed to elicit joy than did secure children.

It is interesting to note that mother–child affect synchrony at infancy affects the emergence of self-control. This important concept refers to the early social caregiver–child interactions in humans, focusing on the temporal

coordination of nonverbal behaviors such as gaze, affect, vocalizations, body movements, and arousal. Although some initial hints of synchrony in the early interactions of the children with their human environment have been known for many years, this construct and its outcomes have only been systematically studied in recent years, mainly by Feldman and colleagues (see the reviews of this body of studies in Feldman, 2007a, 2007b). Feldman and colleagues have developed a time-based, microanalytic behavioral approach and found convincing evidence showing the long-term developmental outcomes of early synchrony experience, mainly in the domains of self-regulation and the capacity for empathy across childhood and adolescence. Synchrony is shown to depend on physiological mechanisms that support bond formation in mammals—particularly physiological oscillators and neuroendocrine systems such as those involving the hormone oxytocin.

Feldman (2007b) summarized the developmental course of synchrony: Its initial hints can be observed already in newborns as they engage in sporadic alert-scanning behaviors, and mothers target their stimulation to the infant's alert state. This provides the first contingency between the infant's internal state and the caregiver's behavior. Mothers seem to use such contingencies to augment infant alertness, usually by providing vocal and tactile stimulation. This kind of behavior at the neonatal period has been found to predict infant–mother and infant–father synchrony at 3 months (Feldman & Eidelman, 2007). According to Feldman, the temporal relationship between the social behavior of the caregiver and that of the child may take different forms: Some of them are concurrent behaviors, whereas others are more sequential and organized in an ongoing patterned format. *Concurrent relations* refer to co-occurrences of specific behaviors in parent and child, such as the co-occurrence of social gaze, vocalizing together, the matching of arousal level, or the coordination of parental affectionate touch with infant social gaze. *Sequential patterns* refer to chains of behaviors, for instance, maternal positive affect that precedes infant babbling, which precedes maternal gaze. These patterns are described as an ongoing “dance” between partners as they move together toward higher or lower affective involvement. During the second half-year of life, important developments occur in all forms of synchrony, and synchronic sequences begin to consolidate. In several longitudinal studies, Feldman, Greenbaum, and Yirmiya (1999) found that mother–infant synchrony at these early ages has critical long-term developmental implications. They found that mother–infant synchrony at 3 and 9 months predicts self-regulation at 2, 4, and 6 years, as assessed in tasks that required children's compliance with maternal requests and prohibitions; IQ measured at 2 and 4 years; the complexity of symbolic expressions during play at 3 years; and the child's use of words that reflect internal states at 2 years. For example, Feldman, Greenbaum, and Yirmiya found that higher levels of maternal synchrony with

infant affect at 3 months of age (infant-leads–mother-follows relation) and higher levels of mutual synchrony at 9 months (cross-dependence between maternal and infant affect) were each related to better self-control of the child at 2 years of age. These relations were found even after differences in temperament, IQ, and maternal style were partialled out.

It should be noted that some parameters of synchrony seem to be sensitive to specific maternal conditions and in these cases enhance the developmental risk. For instance, Feldman and colleagues found fewer moments of shared gaze and fewer patterned sequences among child–mother dyads of clinically depressed mothers (Feldman, 2007a). On the other hand, infant temperament seems to moderate the relations of synchrony and self-control, that is, closer associations were found between mutual synchrony and self-control for difficult infants, suggesting that mutual regulation of affect in infancy, as moderated by temperament, is important to the emergence of self-regulation (Feldman et al., 1999).

Feldman and colleagues traced the consequences of early synchrony up to adolescence: In a follow-up from 3 months to 13 years, they found correlations between synchrony in infancy and adolescents' capacity for empathy, which suggested that synchrony sensitizes infants to the emotional resonance that underlies human relationships across the life span (Feldman, 2007a). Hence, early relations with caregivers provide the immediate microsystem (Bronfenbrenner, 1979) within which children begin to develop their regulating skills. For instance, when faced with frustration, young children lean on their parents to provide them with support, empathy, and more important, guidance and strategies for coping with distress and self-regulation. Parents who allow autonomy facilitate their children's ability to regulate their own behavior. According to this view, children will most likely be able to internalize aspects of their social surroundings when there are opportunities for them to autonomously initiate and maintain behavior. Thus, although recognizing the importance of parents' responding to children's distress, it seems that parents who are too active and do not provide opportunities for autonomous regulation most likely undermine children's capacity to self-regulate.

Parenting

Quality of parenting contributes to the development of self-regulation. In general, evidence shows that parental supportive directives, behaviors, positive discipline, and expression of positive emotions have been correlated with better self-regulation of their children (N. Eisenberg, Smith, Sadovsky, & Spinrad, 2004). Mothers' and fathers' responsiveness to their child's distress has been found to predict better negative affect regulation (Davidov & Grusec, 2006), although a recent meta-analysis indicates that the associations between

child negative emotionality and parenting are moderated overall (Paulussen-Hoogbeem, Stams, Hermanns, & Peetsma, 2007).

The general notion that parental behaviors and strategies influence the development of self-regulation has been known for many years and has been extensively studied using Baumrind's concept of parental styles (Baumrind, 1972; Baumrind & Black, 1967). According to her classification, an authoritative rather than alternative style supports the child's internalization of social guidelines. A balance of warmth and firm guidance that is appropriate for the child's age and understanding and supports in developing inner control leads to both independence and sociability. More current research on parenting tends to focus on the effects of specific parental dimensions, such as warmth, emotional availability, punitive discipline practice, and intrusiveness (Nachmias, Gunnar, Mangelsdorf, Parritz, & Buss, 1996), instead of the broader classification used by Baumrind. The empirical data reviewed below imply that the most effective parenting behavior is the one that engages the child in a positive, warm, affective and guiding, but not intrusive, attitude while encouraging autonomous regulation (Calkins & Johnson, 1998). This, combined with adequate demands and avoidance of parental power-assertive discipline (Krevans & Gibbs, 1996), seems to foster the highest levels of self-regulatory capacity.

Parental Emotional Attitude Can Encourage Self-Regulation

A specific parental dimension that is gaining increasing research interest is parental warmth and positive expressivity (i.e., parents' tendencies to be supportive and affectionate, to express approval, and to direct positive emotion and behaviors toward the child; N. Eisenberg et al., 2003). Evidence shows that this dimension strongly affects the development of self-regulation (N. Eisenberg et al., 2003, 2005), although structural equation modeling (which is a statistical method for determining the extent to which data on a set of variables are consistent with hypotheses about causal association among the variables) of longitudinal data shows that this connection is moderated by the individual child's temperamental characteristic of effortful control that will be described in more detail in the next section (N. Eisenberg et al., 2005). A further illustration of the influence of parental warmth on the development of self-regulation can be found in the study by Colman, Hardy, Albert, Raffaelli, and Crockett (2006). They examined the contribution of caregiving practices at ages 4 to 5 years to children's capacity for self-regulation at ages 8 to 9 years. A large multiethnic sample indicated that high levels of maternal warmth at preschool ages were associated with a greater capacity for self-regulation at the subsequent elementary school ages. The researchers found that low levels of physically punitive discipline at preschool ages were also associated with a greater capacity

for self-regulation at the subsequent elementary school ages. Both associations remained significant when initial levels of self-regulation were also taken into account. In this sample, neither child gender nor ethnicity moderated the effects of early parenting practices on later self-regulation. Davidov and Grusec (2006) found that maternal warmth is linked to better regulation of positive affect and, at least in boys, to greater peer acceptance.

Overall, accumulating evidence indicates that gentle parental discipline strategies that rely on inductive methods and thus deemphasize power assertion, as well as responsive, sensitive caregiving, foster children's willingness to cooperate with parental agendas and increase children's prosocial behavior (Krevans & Gibbs, 1996). A reciprocal, positive, interpersonal orientation between the parent and the child is a critical factor in the development of conscience or autonomous self-regulation (Kochanska & Aksan, 2006).

Parental Strategies Can Foster Self-Regulation

As for parental strategies that foster self-regulation, many studies using laboratory tasks in which self-regulation of the child was measured in parallel to the behavior of the mother support the importance of providing opportunities for autonomous regulation (Calkins & Johnson, 1998; Houck & Lecuyer-Maus, 2004; Silverman & Ragusa, 1990; Spinrad et al., 2004). Calkins and Johnson (1998) observed mothers and their toddlers in a series of laboratory procedures designed to assess the relation among physiological arousal, frustration distress, emotion regulation, and maternal interactive style. They found that maternal interference style was related to the child's level of distress in response to the frustrating events, whereas maternal positive guidance was related to the use of distraction and mother-oriented regulating behaviors. Maternal preemptive behavior (e.g., carrying out activities for their children rather than allowing the children to do the activities for themselves) was related to a higher tendency of toddlers to display distress in response to a frustrating task. The researchers offered two plausible interpretations for this finding: (a) mothers may do things for their children to avoid negative outbursts, which may be a characteristic of the child's personality; and (b) children may develop a low tolerance for frustration because their efforts to do things independently are continually being frustrated. It is interesting to note that toddlers whose mothers tended to provide positive feedback and guidance tended to use distraction and constructive coping behaviors when confronted by frustration. As such, mothers' positive behavior was not related to the child's tendency to become distressed but rather related to the emotion-regulating behaviors the child displayed in situations that elicited distress.

Parental intrusiveness has the undesirable outcome of preventing the child from having the opportunity to exert and practice self-regulation. For

example, Nachmias et al. (1996) found that children of mothers who were more intrusive with their wary children in a novel situation had more regulatory difficulties.

On the other hand, providing opportunities for autonomous regulation is a parenting strategy that has a positive influence on the child's development of self-regulation. Silverman and Ragusa (1990) used compliance tasks (e.g., cleanup) and tasks requiring delay of gratification. The researchers found that mothers who were more active in the compliance situations had children who performed more poorly on the delays, even controlling for performance on the compliance tasks. Moreover, mothers' tendencies to encourage independence, as assessed through questionnaire measures, were associated with better ability of their children to perform under conditions of delayed reward.

Further interesting evidence for the effects of early maternal interactive style on the development of self-regulation can be found in the study by Spinrad et al. (2004). This study provides a longitudinal perspective on this developmental process. The specific strategies that mothers use to help their young children regulate their emotional responses were examined within a longitudinal design. Mother-toddler pairs were observed when toddlers were 18 and 30 months of age during several emotion-eliciting situations—for example, in a cleanup procedure in which mothers were instructed to direct their child to pick up toys and place them in a basket; in a frustrating toy-removal task in which toddlers were presented with an attractive toy and afterward mothers were asked to place the toy in a plastic jar so that the toy was within sight of the infants but not obtainable; and so forth. When the children were 5 years old, their responses to a disappointment task were observed.

Several interesting results came out of this study. First, consistent with Kopp's (1989) idea that mothers serve as a mechanism for regulating their children's affect until they acquire the necessary skills for regulation, the proportion of mothers' overall regulation attempts decreased when their children were between 18 and 30 months of age, while their use of explanation as a strategy increased. The researchers suggested that mothers may have responded to this increased capacity of their child by decreasing their own regulation attempts and leaning more on explanations that required cognitive and linguistic sophistication. Second, a predictive correlation was found between mothers' regulation strategies in toddlerhood and children's facial and behavioral responses to the disappointment task measured at 5 years of age. Mothers' use of regulation strategies at 30 months was positively related to children's appropriate emotional displays in response to disappointment. Third, two strategies appeared to specifically impact children's responses to disappointment negatively: granting the child's wish and questioning the child's emotions. Mothers' use of granting the child's wish at 18 months predicted the child's negative affect at age 5 years. Spinrad et al. (2004) suggested that when the mothers

“give in” to their children’s requests during emotion-eliciting contexts, children are actively reinforced in their expression of negative emotions and use this strategy to get what they want both in the specific context and also in future challenging situations. An additional interesting finding in their study was that mothers’ use of soothing and acceptance was not necessarily a successful strategy in the long run. Its effect depended on the age of the child: Mothers’ use of this strategy at 18 months was predictive of children’s use of distraction as a strategy at 5 years; however, mothers’ use of soothing and acceptance at 30 months was related to children’s unregulated facial responses at age 5 years. One possible explanation Spinrad et al. proposed for these results is that by 30 months of age children already have a number of self-regulation skills and therefore actually perceive those comforting reactions as frustrating and prefer more cognitively advanced input from their mothers, such as explaining the situation or cause of emotion.

Maternal strategies when setting limits have an additional impact on the child’s self-regulation. For example, Houck and Lecuyer-Maus (2004) examined self-regulation at the age of 5 years in relation to maternal limit setting during toddlerhood. The pattern of maternal control strategies was assessed in a 3-min limit-setting situation in which the mother was asked to prevent her child from touching or playing with a novel object while all other toys, books, and other potential play items were removed from the room. Only basic furniture remained. Self-regulation was assessed by using the self-imposed delay-of-gratification paradigm (Shoda et al., 1990). Maternal limit-setting patterns in toddlerhood differentiated the subsequent duration of self-imposed delay. The less effective maternal strategy in the long run was the power-based maternal pattern in limit setting, that is, strategies that asserted power and control. Mothers with this pattern primarily used commands and physical directs, and they offered little empathic reasoning or sensitive support. The results of this study indicated that this strategy was not adequate to facilitate the toddler’s internalization of external control. The children of these mothers demonstrated only a very limited ability for self-regulation (delay of gratification) without maternal supervision. The longitudinal perspective indicated that the most effective maternal strategy was the *teaching-based* limit-setting pattern, which provided both firm control and sensitive support for the child’s developing self-control. These were mothers who were relatively clear about prohibition, using occasional commands, and did not avoid their children’s persistence or the potential for a control struggle. Moreover, they were contingently responsive to child cues, evidenced by their empathic reflection of their perceptions of their children’s feeling, states, or goals in relation to the prohibited object. They provided reasons, explanations, or both about the prohibition, and they used developmentally appropriate distracting activity. Mothers with a teaching-based pattern seemed to facilitate their children’s internalization of self-control

and provide a basis for the negotiation of control rather than assert power to gain compliance. This pattern seemed representative of Baumrind's (Baumrind & Black, 1967) authoritative parental style, adapted for toddlers. Consistently, children of authoritative parents tend to be able to control behavior in accordance with adults' expectations and exhibit little antisocial behavior. In addition, they are self-assured and competent in their social skills. These characteristics have been found not only in childhood but also in adolescence, where a low incidence of drug abuse has also been documented (Baumrind, 1991a, 1991b, 1991c). However, Florsheim, Tolan, and Gorman-Smith (1996) emphasized that drawing conclusions about how parental control and adolescent autonomy relate to behavioral problems without also considering the degree of warmth or hostility in the parent-child dyad is likely to produce an incomplete understanding of the process through which families and individuals develop.

Among the parenting strategies that seem to have a negative impact on the ability of the child to develop self-regulation, one can also speak of those that do not encourage the child to practice self-regulation. This can occur, in one extreme, in a too permissive discipline that does not set boundaries and requirements to which the child has to adjust. Indeed, a permissive style has been found to have negative long-term impact on the development of self-regulation (Baumrind, 1972, 1991b; Baumrind & Black, 1967). In families with permissive parents who are lax in discipline and allow children to express their impulses, children tend to engage in undercontrolled behavior. Thus, by indulging children during challenging situations, parents may fail to take advantage of opportunities for their children to learn ways of dealing with future emotions. Low self-regulation has been also found in some more negative parenting styles, such as the authoritarian (strict but arbitrary and inconsistent) and the rejecting styles. These styles, in combination with familial adversity and stress, predict the enhancement of early behavior problems in preschool and their continuation in childhood years (Campbell, 1995).

However, parenting as has been detailed so far in this chapter must interact with the individual characteristics of the child, as different children react differently to the same parenting according to their individual temperament. I focus on this interaction in the next section.

Parental Effect on Self-Regulation Can Depend on the Child's Temperament

When examining the parental strategies that seem to provide the best conditions for the development of conscience and moral conduct, a complex interaction between parenting and the child's temperament is revealed (N. Eisenberg, 2000; Kochanska & Aksan, 2006; see more details about temperament and self-regulation in the Temperament section in this chapter). This interaction indicates that the effect of parental strategies on the development

of the child's self-regulatory mechanisms is not absolute and may vary according to the child's characteristics. Kochanska and colleagues (Fowles & Kochanska, 2000; Kochanska, 1991, 1997; Kochanska & Aksan, 1995, 2006) suggested and showed that for fearful children, gentle parental discipline would be particularly effective because it elicits just the right amount of apprehension and promotes behavior change and internalization. In contrast, for fearless children, similar gentle discipline may not create sufficient arousal, yet increasing power assertion to the point at which a fearless child begins to respond would likely undermine internalization because of anger and resentment toward the parent. Fearless children seem to be more dependent on a positive, interpersonal orientation inherent in secure, mutually responsive parent-child bonds. Such positive relationships may provide an alternative motivational basis for children's willingness to embrace parental values and agendas (Maccoby & Martin, 1983). Indeed, cumulative empirical evidence shows that gentle maternal discipline practices that deemphasize power assertion predict internalized conduct for fearful children in particular, whereas attachment security and maternal responsiveness predict internalized conduct for fearless children in particular (Fowles & Kochanska, 2000; Kochanska, 1991, 1997; Kochanska & Aksan, 1995, 2006).

Effects of Parental Influences on Self-Regulation Seem to Be Culture Dependent

An important caveat worth keeping in mind in regard to parental influences on the development of self-regulation is that some of the effects seem to be culture and ethnicity dependent (Florsheim et al., 1996; Keller et al., 2004). Moreover, the associations between negative emotionality and parenting seem to be also dependent on socioeconomic status (Paulussen-Hoogeboom et al., 2007).

Home Environment Affects the Child's Self-Regulation

In addition to the direct relation between the caregiver and the child, an important environmental factor that seems to influence the development of self-regulation is the overall home atmosphere. Studies that use the measure of chaos show that a chaotic home environment is associated with elevated behavior problems, limited attentional focusing, and reduced ability to understand and respond to social cues in children (Dumas et al., 2005). These correlations could be explained, at least partially, by the kind of parental factors that we described above, because home chaos tends to be related to less effective parental discipline. However, parenting does not explain the whole effect of the chaotic home environment. Chaos is predictive of children's problem behavior over and above parenting, exacerbating the effect of poorer quality parenting on children's behavior (Coldwell, Pike, & Dunn, 2006).

TEMPERAMENT

The concept of temperament refers to the core individual differences around which the personality of a child eventually develops. These differences are related, at least partially, to genetic allelic variations (Auerbach et al., 2001). Although researchers differ in regard to the exact definition of this construct (Bates, 1989), most agree that *temperament* refers to those innate individual differences in behavioral tendencies and style that appear early in life and remain relatively stable across situations and time (Goldsmith et al., 1987). Some of those behavioral tendencies seem to have a stronger genetic origin than others; some are present early after birth (Buss & Plomin, 1984), whereas others emerge during childhood and develop as a function of brain maturation (Posner & Rothbart, 1998). Children differ along temperamental dimensions, such as the tendency to display positive emotionality, the tendency to approach novel stimuli, and so forth, which can be rated either through parental reports (Rothbart, Ahadi, Hershey, & Fisher, 2001) or through direct systematic laboratory observations (Lab-Tab; Goldsmith & Rothbart, 1996). Temperamental characteristics also potentially buffer the ways in which parental practices affect a child. For instance, fearful and non-fearful children are oppositely affected by the same type of parental practice in their development of self-regulation and prosocial behavior (N. Eisenberg, 2000; Kochanska & Aksan, 2006).

According to Rothbart and colleagues (Ahadi, Rothbart, & Ye, 1993; Rothbart, 1989c; Rothbart & Bates, 1998; Rothbart et al., 2001), factor analyses of parental reports of children's temperament reveal two types of higher order factors. One type is a reactive factor that begins to emerge already in the early months and includes aspects such as activity level, sociability, impulsivity, enjoyment of high-intensity pleasures, and tendency to negative affectivity. The other type is a self-regulation factor that seems to emerge later and has been termed *effortful control* and depends heavily on executive aspects of attention (Posner & Rothbart, 2000; Rueda, Posner, et al., 2005; Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005).

Fear as a Regulatory and Reactive Dimension

Individual differences in fearfulness emerge as early as within the first year of life and remain quite stable (Caspi & Silva, 1995; Kagan, 1998). This developing fearful inhibition can be considered a reactive early inhibitory control of behavior mechanism (Rothbart, Ellis, & Posner, 2004) and has been found to be positively involved in the development of conscience (Rothbart, Ahadi, & Hershey, 1994). On the other hand, lack of fear at preschool age has been found to predict aggression at the age of 11 years (Raine, Reynolds, Venables,

Mednick, & Farrington, 1998). As pointed out in the section about the effects of parenting, for fearful–anxious children, gentle maternal discipline that deemphasizes power results in an optimal, moderate level of anxious arousal and provides optimal conditions and motivation for the processing of information in the disciplinary encounter (N. Eisenberg, 2000; Fowles & Kochanska, 2000; Kochanska & Aksan, 2006). This evidence shows that there are critical interactions between this regulatory dimension of temperament and parental strategies. Rearing influences seem to be particularly important for highly reactive and fearful children. Specifically, it has been found that these children are more susceptible to the quality of the relationship they have with their parent (Van IJzendoorn & Bakermans-Kranenburg, 2006).

Fear inhibits behavior and might help the child avoid negative outcomes and “stay out of trouble.” In other words, children with strong approach tendencies who are also fearful, may inhibit approach tendencies in the face of negative cues, while under the same circumstances, less fearful children might not be able to inhibit their approach tendency (Rothbart et al., 2004).

Extreme fear–avoidance temperament has been termed behavioral *reactivity* (Kagan, 1997) or *inhibition* (N. A. Fox, Henderson, Rubin, Calkins, & Schmidt, 2001). Inhibited toddlers and preschool children are characterized as displaying vigilant behaviors and motor quieting when confronted with novelty (N. A. Fox et al., 2001). These extremely shy children also show high reactivity in physiological measures of stress in novel situations, such as levels of saliva cortisol and heart rate (Kagan, Reznick, & Snidman, 1989). Similar physiological correlates have also been found in high reactive primates (Higley & Suomi, 1989). At the other extreme of the approach–avoidance axis, researchers have found highly approachable children. N. A. Fox et al. (2001) introduced the term *exuberant* for these uninhibited children, indicating unrestrained joy. These children show high drive for rewards, excited anticipation for pleasurable activities, behavioral approach to novelty (Derryberry & Rothbart, 1997), and might respond with greater distress when rewards are blocked or lost. In other words, they might have more difficulty regulating distress during frustrations and disappointments (Putnam & Stifter, 2005). N. A. Fox et al. found that exuberance is quite stable over development. In a longitudinal study, they found that about half of the infants who were high in motor activity and positive affect at 4 months of age maintained a profile of exuberance across a period of 4 years and displayed high sociability and high approach to novelty and social interactions.

Relevant to the present discussion, some links have been found between approach reactivity and emotion regulation, although this temperamental style and its implications have not been much studied. For example, Rydell, Berlin, and Bohlin (2003) found that exuberance as well as high anger

emotionality and low regulation of positive emotions predicted externalizing problem behavior. The relation between exuberance and externalizing behavior was demonstrated also by Putnam and Stifter (2005). A plausible framework for understanding such association was proposed by Derryberry and Rothbart (1997): Children with strong approach tendencies and relative lack of fear might have a biased representation that emphasizes rewards and positive consequences of approach at the expense of plausible negative consequences and punishment. In the more extreme cases, this representational bias could impair the ability to predict negative outcomes of their behavior and lead to “disinhibited” externalizing problems.

Both extremes of the avoidance–approach temperamental axis seem to have characteristic electrophysiological patterns. N. A. Fox et al. (2001) reported evidence for an opposite pattern of electroencephalogram (EEG) asymmetry between right and left frontal areas in inhibited versus exuberant children. This finding is connected to an interesting body of literature that provides hints to the early biological bases of temperamental differences, especially those related to regulation. This literature brings evidence for the relation between brain functioning and regulatory temperamental characteristics, specifically, between electrophysiological left–right frontal asymmetry and regulatory aspects of temperament and affective styles. This relation has been observed as early as the first year of life (Bell & Wolfe, 2004; Wolfe & Bell, 2004). For example, infants who cry at maternal separation are more likely to show right frontal brain electrical activation at rest (N. A. Fox, 1994; N. A. Fox, Calkins, & Bell, 1994). Moreover, infants who display more negative affect and more motor activity at the age of 4 months tend to show right frontal activation at 9 months and inhibited behavior at 14 months (Calkins, Fox, & Marshall, 1996). Individual differences in temperament and frontal asymmetry in brain activity are likely to be relatively stable throughout the preschool years (Bell & Wolfe, 2004; N. A. Fox & Calkins, 2003; N. A. Fox et al., 2001). Evidence based on EEG asymmetry also supports a relation between attention and emotional regulation. It was found that children having greater attentional focus and lower distractibility show greater self-control of emotion and increased left–right frontal EEG asymmetry (Perez-Edgar & Fox, 2000).

Executive Control as a Voluntary Regulatory Dimension

Effortful control (EC) develops later and allows voluntary control of behavior and emotion (Rothbart et al., 2004). *Effortful control* can be defined as the capacity to modify reactivity tendencies by purposely engaging behavioral strategies and exerting self-control. This factor mainly includes inhibitory control, the ability to focus attention, and the ability to shift attention. Factor analyses in parental report questionnaire studies indicate that this broad fac-

tor is defined in terms of scales that measure attentional focusing, inhibitory control, low-intensity pleasure, and perceptual sensitivity, and negatively correlates to children's scores on negative affect tendency (Posner & Rothbart, 2000). Attention skills help to attenuate the tendency to express negative affect (Gerardi-Caulton, 2000; Rothbart et al., 2001), although whether negative emotionality is inhibited may depend on culture (Ahadi, Rothbart, & Ye, 1993).

Moreover, individual differences in inhibitory control correlate in children with the ability to regulate their emotions, even after controlling for age and verbal ability (C. M. Carlson & Wang, 2007). This relation was found for controlling negative emotions (i.e., when the child is given a disappointing gift) as well as positive emotions (i.e., when the child is required to keep an exciting secret).

An impressive structural magnetic resonance imaging study carried out in Australia provided evidence supporting the relation between temperamental EC and the brain areas related to executive aspects of attention. In a sample of 155 individuals, it was found that larger paracingulate regions predicted greater temperamental EC (Whittle et al., 2008).

According to Rothbart's model, infants are not born with mature EC, but it matures and develops progressively. Although children differ already at infancy in the initial self-soothing behaviors, such as finger sucking (Rothbart, Ziaie, & O'Boyle, 1992), individual differences become clearer as the more effortful self-regulatory and self-monitoring processes begin to emerge at preschool age. In other words, EC develops relatively late and continues to develop during childhood. The timing of this maturation is considered to be constrained by the maturation of the executive control of attention (Posner & Rothbart, 1998; Rueda, Posner, et al., 2005).

It is interesting to note that there are indications for some degree of heritability in the individual characteristics of self-regulation, based on greater similarity between identical twins than between fraternal twins. This has been demonstrated both in measures of emotional regulation (Goldsmith, Buss, & Lemery, 1997; Goldsmith & Davidson, 2004) and executive aspects of attention (Fan, Wu, et al., 2001). Moreover, empirical evidence supports the notion that individual characteristics in EC are stable. This stability has been found across time and across different types of measurements. For instance, longitudinal studies show that sustained attention at the age of 9 months predicts EC at the age of 22 months (Kochanska et al., 2000; Kochanska, Tjebkes, & Forman, 1998). Moreover, in these longitudinal studies, children performed consistently across different tasks within the battery designed for assessing EC. Children were also stable in their performance across time. Moreover, individual differences in performance of EC tasks were found to be stable in toddlers between ages 24 and 39 months (S. M. Carlson, Mandell, & Williams, 2004). Stability

in performance in tasks requiring working memory (WM) and inhibitory control was also reported by Diamond, Prevor, Callender, and Druin (1997) in their longitudinal study on children treated for phenylketonuria and a comparison group of siblings.

Further convincing evidence for the stability of EC can be found in a series of studies by Mischel and Shoda, sometimes nicknamed the “marshmallow studies,” which are summarized in their *Science* article (Mischel, Shoda, & Rodriguez, 1989). To begin with the bottom line of this work, the length of time that preschoolers successfully waited for a reward predicted not only their self-control but also their cognitive and social competence when these children reached adolescence. The importance of this work is that it clearly shows the long-term broad consequences of being able to self-regulate as well as the persistence of individual differences during an impressively long period of time. Therefore, this series of studies deserves a closer look and a more detailed description.

Mischel et al. (1989) began their experimental procedure by showing the child some toys he would be allowed to play with at the end of the session. In this way they created a positive uniform ending to the experiment. The child was then shown a pair of treats (e.g., one vs. two marshmallows) and told that he could receive the preferred treat if he waited until the experimenter came back into the room. Moreover, he was free to end the waiting at any time. However, in such case, he would get the less preferred treat. In other words, the researchers created a conflict between the child’s desire to obtain the “better” treat and his temptation to end the delay. After the child understood the terms of the task, he was left alone while his behavior was observed unobtrusively until he terminated the delay period or for a maximum of 15 min, when the experimenter returned and gave him the treat. A follow-up of their sample more than 10 years later showed that the children who waited longer in the experimental situation were rated by their parents as more attentive and better able to concentrate, to resist temptation, and to cope with frustration. Moreover, they were rated as being more academically and socially competent. Under some variations of their original experimental task, these researchers found in one of their samples that the delay time that a child was able and willing to wait at the age of 4 years later correlated with his Scholastic Assessment Test (SAT) score at entrance to college.

One of the most interesting but less often cited findings of this series of studies was the relation between the ability to exert executive control of attention by shifting attention away and the length of delay the child could wait (i.e., his self-regulation). Contrary to the researchers’ original hypotheses, attention to the rewards substantially decreased delay times. Children succeeded in waiting markedly longer when they paid less attention (either by physically looking away or by distracting their attention) to the rewards during the delay (in

different variations of the procedure, the experimenters systematically tested the effects of covering or uncovering the rewards during the delay period, encouraging the child to think about the rewards or about something else). Their observation about the spontaneous behavior of the children during the delay in the classical experimental task showed individual differences and pointed toward the strategies that were most effective for their preschool children: The children who were more successful in waiting seemed to deliberately avoid looking at the reward, some helping themselves by literally covering their eyes with their hands. Although these researchers did not link this finding to the concept of EC, this clear relation between the ability to exert volitional control over attention and success in a self-regulation challenge is fully consistent with the idea that one of the main and meaningful components of EC is executive attention (Posner & Rothbart, 1998, 2000; Rothbart, Sheese, & Posner, 2007).

Regarding sex differences in EC, Goldsmith et al. (1997) found that at toddler age, boys were rated as higher than girls on anger proneness and activity level, whereas at childhood age, boys were rated higher than girls on activity level and high pleasure scales. Girls, on the other hand, were rated higher on inhibitory control and perceptual sensitivity scales and overall got higher scores on EC. The overall trend seems to be that sex effects on temperament begin to emerge and become more salient during the preschool years (Rothbart, 1989b), resulting in girls tending to demonstrate better self-regulation than boys in early childhood (Rothbart et al., 2004).

GENES

Understanding how the cognitive and emotional networks carrying out mental processes are related to individual genetic differences is a major challenge in current research (Posner, Rothbart, & Sheese, 2007). A method of discovering relevant genes looks for the relation of different versions of a gene (alleles) to individual differences in personality, in behavioral tendencies, and in specific cognitive functions such as attention. Thus, specific genes and their alleles become a physical substrate that connects individuality to general features of the mind (Posner et al., 2007). An example of these kinds of variations across individuals, discussed below in detail, is found in the dopamine receptor D4 gene (*DRD4*). In this gene, a specific 7-repeat allele has been associated with, among other things, the personality trait of novelty seeking (Ebstein et al., 1996). In this section, I review the gene variations that, according to current molecular genetic research, have implications for self-regulation. But before I continue with this discussion, I will make a small detour and first clarify some basic concepts of genetics.

Genetics for Beginners

A *gene* is a portion of the deoxyribonucleic acid (DNA) molecule that codes for a protein. The genetic code is composed of *codons*, which are trinucleotide units, each one coding for a single amino acid. One can think of a codon as the minimal meaning unit in the genetic “language.” If the codons are the words, the letters are the nucleotides, G, C, T, and A. DNA does not usually exist as a single chain of molecules but instead as a tightly associated pair of long strands entwined like vines in the shape of a double helix. The nucleotide contains both the segment of the backbone of the molecule, which holds the chain together, and a base, which interacts with the other DNA strand in the helix. Each type of base on one strand forms a bond with just one type of base on the other strand. This is called *complementary base pairing*, with A bonding only to T and C bonding only to G. This arrangement of two nucleotides binding together across the double helix is called a *base pair*. The “recipe” for the preparation of a protein is embodied in the sequence of the nucleotides along a strand. This recipe determines the protein through a complex multistep process. The first is called *transcription*, which is the synthesis of a messenger RNA (ribonucleic acid). The mRNA in turn undergoes translation, through which it specifies the synthesis of polypeptides, which ultimately go on to form proteins. The boundaries of a protein-encoding gene are defined as the points at which transcription begins and ends. The core of the gene is the *coding region*, which contains the nucleotide sequence that is eventually translated into the sequence of amino acids in the protein. The coding region begins with the initiation codon, which is normally ATG. It ends with one of three termination codons: TAA, TAG, or TGA. On either side of the coding region are DNA sequences that are transcribed but are not translated. These untranslated regions or noncoding regions often contain regulatory elements that control protein synthesis. Most human genes are divided into exons and introns. The exons are the sections that are found in the mature transcript (mRNA), whereas the introns are not.

There is some individual variability within these sequences that compose the different genes. A specific form of a gene is called an *allele*. In other words, individuals differ in the specific alleles they carry. One of the most common forms of variability is related to the number of repetitions that a certain portion of the code has. This is called a *variable number of tandem repeats* (VNTR). There are other types of variations that are not related to repetitions but to changes or deletions of a part of a sequence. The specific effects of the genetic endowment depend on the DNA sequences that specify what is inherited. This cannot be altered by the environment. On the other hand, it should be kept in mind that the functional effects of those DNA sequences are entirely

dependent on gene expression, which can be influenced (sometimes in a major way) by environmental features (Rutter, 2007).

Human DNA is organized in 23 pairs of chromosomes. Chromosomes 1 through 22 (the autosomes) are designated by their chromosome number. The sex chromosomes are named X or Y. The structure of each chromosome includes a centromere and two pairs of arms: a pair of short arms usually referred to as *p* and a pair of long arms referred to as *q*.

Geneticists use a standardized way of describing a gene's cytogenetic location. The location describes the position of a particular band on a stained chromosome. The gene "address," for example, *7q21*, provides the following information: (a) the first number indicates the chromosome on which the gene can be found—in this case, it is chromosome 7; (b) the letter indicates the arm of the chromosome—in our example, the gene is located on *q* (i.e., the long arm); (c) the position of the gene on the arm. The position is usually designated by two digits (representing a region and a band), which are sometimes followed by a decimal point and one or more additional digits (representing sub-bands). The number that indicates the gene position increases with distance from the centromere. In our example the gene is located at position 21.

Returning to the theme of our discussion, several specific allelic forms of dopamine genes show associations with behavioral tendencies and disorders related to executive attention and self-regulation. The reader might recall that, as described in Chapter 3, the brain circuitry of self-regulation seems to heavily rely on dopamine.

Dopamine Genetic Variations Implicated in Self-Regulation

Several types of dopamine genes are related to attention and self-regulation. The list includes genes related to the different dopamine receptors, genes related to the dopamine transporter, and more.

Dopamine Receptors

DRD4. The first gene I focus on is *DRD4*. The dopamine D4 receptor is located on chromosome 11p15. The most studied polymorphism is in exon III, where there is a VNTR of the base-pair sequence (Fossella et al., 2002; LaHoste et al., 1996; Lakatos et al., 2002), although some additional polymorphisms of this gene have been also studied (McCracken et al., 2000). The number of repeats can vary between 1 and 11 (Mill et al., 2002), the most frequent variants being the 4-repeat and the 7-repeat alleles, with the 2-repeat allele being the second most frequent. The frequency of the different alleles is unevenly distributed around the world (Harpending & Cochran, 2002).

The association between the 7-repeat allele and specific behavioral tendencies has been found early after birth (Ebstein et al., 1998). In this study, 2-week-old neonates who were homozygous for the 4-repeat *DRD4* allele had lower scores on a measure of visual and auditory orientation than did infants who had at least one copy of the 7-repeat allele. Consistently, 12-month-old infants with the 7-repeat allele showed higher levels of activity and lower interest in a block play situation than infants with the shorter form of the allele (Auerbach et al., 2001). In adults, as mentioned previously, this polymorphism has been associated with risk taking and tendency to seek novelty (Ebstein et al., 1996).

An interesting series of studies related the variations in *DRD4* to effectiveness of executive attention (Posner et al., 2007). These studies were based on a computerized task for studying the networks of attention (Attention Network Task or ANT). First, the ANT in monozygotic and dizygotic same-sex twins was used to assess heritability of the different aspects of attention (Fan, Wu, et al., 2001). Heritability was found for the executive network. At the next step, Fossella et al. (2002) found a relation between the *DRD4* and the efficacy of executive attention, as measured with the ANT. Last, this group conducted a neuroimaging study in which groups of carriers of different alleles of the gene were compared while they performed the ANT (Fan et al., 2003). Group differences were found in the ability to resolve conflict as measured by the ANT and also significantly different activations in the anterior cingulate cortex (ACC).

An impressive body of research supports the relation between this gene and self-regulation disorders, most of it focused on attention-deficit/hyperactivity disorder (ADHD; Diamond, 2007; Durston et al., 2005; Faraone et al., 1999, 2005; Grady et al., 2003; Li, Sham, Owen, & He, 2006; Maher, Marazita, Ferrell, & Vanyukov, 2002; Rowe et al., 2001; Swanson, Flodman, et al., 2000). This literature is further discussed in Chapter 5.

An additional interesting piece of support that adds to the body of evidence linking risk of maladaptive behavioral problems in children with the 7-repeat allele of the *DRD4* is the relation between this allele and nonsecure disorganized attachment. As I discussed earlier in the Temperament section, early attachment to the caregiving figure provides a widely used framework for explaining the influences of early social experiences on normal and problematic development of personality. The studies by Lakatos and colleagues (Lakatos et al., 2000, 2002) suggested that having a 7-repeat allele predisposes infants to attachment disorganization. Lakatos et al. (2000) found an association between the 7-repeat allele and disorganization of infants' attachment behavior toward their mother in a low-social-risk group of 1-year-old infants. Some hints to the fact that the relation between this gene and attachment is probably quite complex can be found in this group's additional finding that *DRD4* interacts with

an additional polymorphism found in the upstream regulatory region of this gene—the -521 C/T single nucleotide polymorphism. Lakatos et al. (2002) found that having both alleles together increased ten-fold the odds ratio for disorganized attachment.

DRD5. An additional dopamine receptor gene that has been related to ADHD is the *DRD5*. This relation was first suggested by Daly, Hawi, Fitzgerald, and Gill (1999). The literature in this case is somewhat less abundant than in the case of the *DRD4*. However, it includes some meta-analyses (Li et al., 2006; Maher et al., 2002) that confirmed that the *DRD5* 148-bp allele of this gene is related to increased risk of ADHD, whereas the 136-bp allele may actually have a protective effect.

Catechol-O-Methyltransferase Gene

The second type of dopamine genes that has been related to attention and self-regulation concerns the catechol-O-methyltransferase gene (*COMT*). This gene codes for one of the most important mechanisms for clearing released dopamine from extracellular space—the *COMT* enzyme (Egan et al., 2001). The prefrontal cortex (PFC) is more dependent on the *COMT* enzyme than other neural regions; therefore, variations in the *COMT* gene may disproportionately affect the PFC, leaving other brain regions (e.g., the striatum) relatively unaffected (Diamond, 2007). The *COMT* gene is located within the q11 band of human chromosome 22. A common variation in the *COMT* gene is a single change in the pair-base G/A at codon 158 of the gene. This variation has implications for the activity of the enzyme, that is, this variant of the *COMT* gene leaves dopamine longer in the extracellular space, especially in the PFC (Lachman et al., 1996). It has been shown in adults to result in better performance on prefrontal cognitive tasks that require WM and inhibition (Egan et al., 2001). In children, this allele has been associated with better executive function, better performance on a cognitive task requiring WM, and inhibition skills that rely on the PFC (dot-mixed task; Diamond, Briand, Fossella, & Gehlbach, 2004). This effect seems to be stronger in males than in females (Diamond, 2007). In adults, it was related to performance on the Wisconsin Card Sorting Test of executive cognition (Egan et al., 2001). The alternative allele of this gene—the valine allele—was shown to be preferentially transmitted in ADHD and was associated with impulsive false alarm errors on a continuous performance task (J. Eisenberg et al., 1999). Moreover, in males, associations have been reported between *COMT* variations and obsessive-compulsive disorder (Karayiorgou et al., 1997).

Dopamine Transporter

A third dopamine gene that has been related to self-regulation is the gene that codes for the dopamine transporter—the *DAT1*. The relevant VNTR is a

40-bp repeated region situated in the 3' untranslated region (chromosomal location 5p15.3), and the "risk" allele is referred to sometimes as the 480-bp allele (Cook et al., 1995; Curran et al., 2001; Daly et al., 1999; Gill, Daly, Heron, Hawi, & Fitzgerald, 1997) and other times as the 10R allele (Swanson, Flodman, et al., 2000; Yang et al., 2007). At the end of the 1990s, several studies related this allelic variation with hyperactivity (Cook et al., 1995; Daly et al., 1999; Gill et al., 1997; Waldman et al., 1998). Some of the studies reported later led to inconsistent findings; although some studies failed to establish an association between this gene and heritability of ADHD (i.e., Swanson, Flodman, et al., 2000), others did find support for such an association (i.e., Curran et al., 2001; Kirley et al., 2002; Maher et al., 2002).

The *DAT1* gene, expressed predominantly in the basal ganglia, and its polymorphism preferentially influence caudate volume (Durston et al., 2005). In a positron emission tomography study, Jucaite, Fernell, Halldin, Forssberg, and Farde (2005) examined the nigrostriatal dopamine system in adolescents with ADHD and young adult control subjects. The study included quantification of dopamine markers in the midbrain, the site of dopaminergic cell bodies, and their projection region, the neostriatum. One of the main findings in this study was reduced dopamine transporter binding in the midbrain in adolescents with ADHD. The authors suggested that this might reflect lower endogenous dopamine levels, which leads to reduced autoinhibition of dopaminergic cells, which in turn results in increased signaling in projection areas such as the striatum. However, no direct effect was established in this study between *DAT1* binding in the midbrain and behavior in a continuous performance task, nor with a measure of motor hyperactivity based on head movements.

As described so far, the association between *DAT1* and ADHD has been found predominantly with the hyperactive-impulsive symptoms of ADHD but not for inattentive symptoms. There are some reported associations between this gene and executive attention, as measured with the computerized ANT (Fossella et al., 2002; Rueda, Rothbart, et al., 2005), where the homozygous 10/10 genotype was actually associated with better scores. For example, in the Rueda, Rothbart, et al. (2005) study, the participant group showed not only reduced conflict (as measured by the ANT) and higher EC scores (as measured by the temperament parental report questionnaire, CBQ) but also more "normative" effects in the brain activity recorded on the scalp, that is, a mediofrontal effect of negative voltage known as the N2, which, as mentioned in Chapter 2 in this volume, is usually found in conflict situations.

Monoamine Oxidase Gene

The fourth gene that I mention in this respect is the monoamine oxidase (MAOA) gene. The MAOA gene is located on the X chromosome (Xp11) and

codes for enzymes that catalyze biogenic amines, including the neurotransmitters norepinephrine, dopamine, and serotonin. MAOA is expressed primarily in neurons. Its expression is affected by the number of VNTR at the promoter of the gene (Caspi et al., 2002). This expression has been linked to susceptibility to violence and antisocial behavior. Moreover, several MAOA polymorphisms have been associated with executive attention. For instance, Fossella et al. (2002) linked two additional polymorphisms of the MAOA gene to executive attention: (a) a gene-linked polymorphic region (MAOA-LPR), which is a 30-bp repetitive sequence that resides 1.2 kb upstream of the start codon, for which 4-repeat were compared with 3-repeat alleles; and (b) a “C to T” base change at position 1460 in exon 14 of the gene. Executive attention scores for participants carrying the T and the 3-repeat LPR alleles were somewhat higher compared with executive attention scores for participants who were carrying the C and 4-repeat LPR alleles (Fossella et al., 2002). In the study by Fan et al. (2003) that was mentioned above this effect was replicated. In addition, their participants were scanned with functional magnetic resonance imaging during performance of the computerized ANT. It was found that individuals with the 4-repeat LPR allele showed more activation in the ACC while performing the ANT than those with the 3-repeat LPR (see Color Plate 5). As mentioned, a similar effect was also found in this study for polymorphisms in the *DRD4* gene.

I should mention that in spite of the accumulating evidence relating the aforementioned genes to ADHD, there is also contradicting evidence of studies that failed to find connections regarding each one of the polymorphisms. For example, when Payton et al. (2001) looked for associations between ADHD and alleles of several dopamine-related candidate genes by using a family-based association approach, they did not find an association between ADHD and the *DRD4* and *COMT* genes, and only a trend for the associations between ADHD and the MAOA and *DRD5* genes. In the meta-analysis of Li et al. (2006) that was mentioned previously, although associations were found with *DRD4* and *DRD5*, their results failed to support an association with *DAT1*. Moreover, Mill et al. (2002) found no evidence for biased transmission of the 7-repeat allele in a family-based 20-year longitudinal study, although they found that individuals with a 7/7 genotype did score higher on quantitative measures of hyperactivity at some assessment ages and a trend toward an association between this allele and impulsivity; however, these effects were small and nonsignificant. Most important, the effects did not replicate across different ages.

Moreover, it should be noticed that I have limited the discussion in this chapter to the most studied and known genetic polymorphisms. Readers can refer to Faraone et al. (2005) for a much more detailed and extensive review of the molecular genetics of ADHD.

Gene \times Gene Interactions

The etiological complexity of psychological disorders, including ADHD, has led to increasing recognition of the importance of examining gene–gene interactions (Rutter, 2007). In other words, the effects of an allelic variation of a specific gene may depend on additional allelic variations that the individual carries in other genes. There is some accumulating evidence showing gene–gene interactions of serotonin and dopamine that relate to self-regulation. Specifically, interactions have been found between the serotonin transporter gene (*5-HTT*) and the various dopamine genes that were mentioned in the previous section. These interactions are linked both to variations in temperament and to childhood behavior problems (Auerbach et al., 1999, 2001; Benjamin et al., 2000; Ebstein et al., 1998). The relevant allelic variation in the *5-HTT* is a repetition in the gene promoter regulatory region, sometimes appearing in the literature as *5-HTTLRP* short-versus-long alleles.

Ebstein et al. (1998) reported that 2-week-old neonates with both the short forms of the *DRD4* (3 or 4 repeats) and the short homozygous (*s/s*) *5-HTT*, meaning two copies of the short-form genotypes, received the lowest scores on a neonatal measure of visual and auditory stimulation than any other allelic combination of these two genes. When these infants were 2 months old, there was again an interaction between the *DRD4* and *5-HTT* alleles in mother reports of their infant temperament. The infants with both the short *DRD4* and the *s/s 5-HTT* alleles showed the most extreme scores on negative emotionality and distress to daily routine situations (Auerbach et al., 1999). Auerbach et al. (2001) performed a further follow-up of these infants when they were 12 months old. The infants were observed in a series of standard temperament episodes, which elicited fear, anger, pleasure, interest, and activity (Lab-TAB; Goldsmith & Rothbart, 1996). Infants with the long *DRD4* showed less interest in the structured block play and more activity during free play. They also displayed less anger in the episode of mild physical restraint. Infants with the *s/s 5-HTT* showed less fearful distress to stranger approach and less pleasure during play. Most important to note is that there was an interaction between *DRD4* and *5-HTT* and infant performance on a measure of duration of looking, with the shortest duration of looking being shown by infants with the long alleles of *DRD4* and *s/s 5-HTT* genotype combination.

The interaction between the serotonin transporter gene and dopamine genes has been found not only in infants but also in children. In a longitudinal study that followed children since birth, Schmidt, Fox, and Hamer (2007) found that 7-year-old children with higher internalizing and externalizing scores on a behavior problem checklist were those children with the long *DRD4* alleles and at least one short *5-HTT* allele.

The interaction among the *5-HTT*, *DRD4*, and also *COMT* alleles has been found also in adults in relation to the novelty seeking personality trait (Benjamin et al., 2000).

GENE \times ENVIRONMENT INTERACTIONS

One reason for the relatively modest effect of genetic alleles in accounting for behavioral differences may be that they interact with experience during development of the brain networks (Posner & Rothbart, 2005). Indeed, empirical findings are now accumulating on the interactions between identified single genetic variants and the operation of environmentally mediated risks (Bakermans-Kranenburg & van IJzendoorn, 2006; Caspi et al., 2005; N. A. Fox et al., 2005; Rutter, 2007; Sheese, Voelker, Rothbart, & Posner, 2007). These types of interactions once were thought to be rare in psychopathology, but they have turned out to be common (Moffitt, Caspi, & Rutter, 2006) and are found in primates as well (Suomi, 2003). In other words, biological and environmental factors seem to influence the development of self-regulation in an interactive fashion. On one hand, the environment can shape the epigenetics (Meaney, 2010) and the expression of the individual genotype; on the other hand, gene variations may increase vulnerability to certain environmental pathogens (Caspi et al., 2005).

In regard to self-regulation, evidence suggests that the impact of the genetic variability described earlier in the Genes section might not be direct. Instead, it can be moderated by temperamental–genetic individual differences, which can create differential susceptibility to environmental influences (Belsky, Bakermans-Kranenburg, & van IJzendoorn, 2007). The child degree of risk might result from complex Gene \times Environment ($G \times E$) interactions that involve biological vulnerability and the immediate caregiving environment. This potentially has great importance because this type of environment can be relatively easily manipulated or improved, because it can be targeted by early interventions and parent training.

$G \times E$ supporting evidence has been recently found regarding the *D4DR* allelic variations, specifically, the 7-repeat *DRD4* allele. Bakermans-Kranenburg and van IJzendoorn (2006) found that children's externalizing behaviors (e.g., aggressive behavior) were interactively affected by the specific *DRD4* polymorphism and maternal sensitivity. Their study involved 47 twin pairs and their mothers. Maternal sensitivity was coded from videotapes of mothers and each of their 10-month-old twin infants' dyads, which were filmed during normal unstructured activities around the home and during feeding and free play. They used the Ainsworth's 9-point rating scale (Ainsworth, Bell, & Stayton, 1974), which includes four aspects of the mother's behavior:

(a) mother's awareness of her baby's signals, (b) accurate interpretation of them, (c) appropriateness, and (d) promptness of response. The final score represents the extent to which all four of these components of sensitivity were evident during the observations for a specific mother–infant dyad. Mothers were median split to more sensitive mothers and less sensitive mothers. Mothers completed the Child Behavior Checklist (CBCL/2–3 years; Achenbach, 1992) for each twin when the children were 39 months old. Analyses were done on a sample, including one of the twins of each pair (randomly selected), and then replicated for the other half of the sample. They found that only for those children with a 7-repeat allele of the *DRD4*, maternal sensitivity at 10 months was associated with lower externalizing behavior at 39 months. They did not find an effect of maternal sensitivity at 10 months on the externalization symptoms of those children without the 7-repeat allele. This effect was replicated in the second half of the sample. Their finding suggests that those children with the 7-repeat *DRD4* allele might be more sensitive to environmental risk factors (although some caution should be taken in this interpretation as the CBCL questionnaire was filled by the mothers themselves, who clearly differed in their sensitivity toward their child, which means that some alternative explanations of the findings could also be feasible). This research group also found that this same genetic polymorphism may play a role in the development of attachment disorganization, making some children more susceptible to the influence of “disorganizing” environments than other children. Van IJzendoorn and Bakermans-Kranenburg (2006) found that maternal, unresolved loss or trauma was associated with infant disorganization, but only in the presence of the *DRD4* 7-repeat polymorphism.

The overall idea that genes influence the relation between parenting and temperament, and the specific idea that children with the 7-repeat *DRD4* allele might be more sensitive to environmental risk factors, are both further supported by Sheese, Voelker, Rothbart, and Posner (2007). In this study, children 18 to 21 months of age were genotyped for the *DRD4* 48 base-pair repeat polymorphism. The children also interacted with their caregiver for 10 min in a laboratory setting, and these videotaped interactions were coded for parenting quality by using an observational rating procedure. Parenting quality was assessed by using a videotaped free-play procedure and a rating scheme adapted from the National Institute of Child Health and Development's Early Child Care Research Network (1993). In this method, raters watched the entire interaction and then used 7-point Likert scales to rate the parent on different quality aspects of the mother's interaction with her child, such as emotional support, intrusiveness, hostility, and so forth. The mothers were asked to report their child's temperament by filling out the Early Childhood Behavior Questionnaire (Putnam, Gartstein, & Rothbart, 2006). Results showed that the presence of the *DRD4* 7-repeat allele was associated with differences in the influence of

parenting on a measure of temperamental sensation seeking, which was constructed from caregiver reports on children's activity level, impulsivity, and high-intensity pleasure. Children with the 7-repeat allele were influenced by parenting quality. Those who were exposed to poor-quality parenting showed the highest levels of sensation seeking, whereas infants with that allele who received high-quality parenting showed the lowest levels of sensation seeking. In contrast, for the children without the 7-repeat allele, there were no effects of parenting quality on the sensation-seeking temperamental scores (see Figure 4.1). In this study, neither *DRD4* nor parenting quality was related to EC.

There are different plausible ways to interpret this pattern of interaction between the 7-repeat *DRD4* allele and parenting factors. As I explain in more

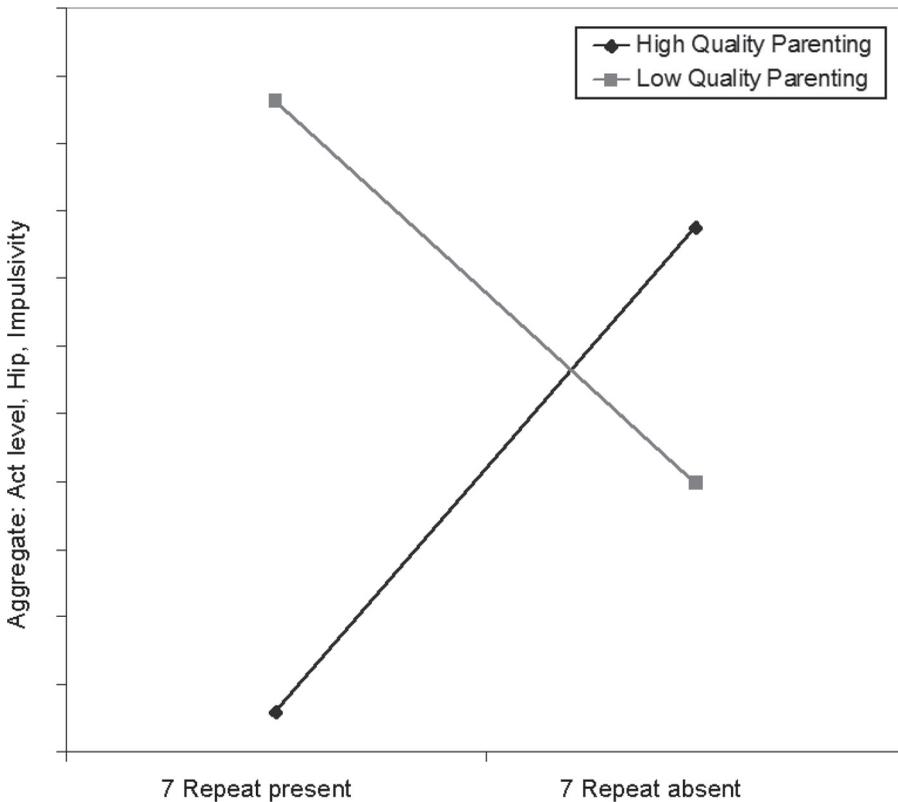


Figure 4.1. The presence of the *DRD4* 7-repeat allele and quality of parenting interaction determined activity level, impulsivity, and high-intensity pleasure, which aggregate to a measure of sensation seeking. Reprinted from "Parenting Quality Interacts With Genetic Variation in Dopamine Receptor D4 to Influence Temperament in Early Childhood," by B. E. Sheese, P. M. Voelker, M. K. Rothbart, and M. I. Posner, 2007, *Development and Psychopathology*, 19, p. 1043. Copyright 2007 by Cambridge University Press. Reprinted with permission.

detail later in this chapter, some of these interpretations challenge the simpler, common interpretation of correlations between this specific genetic variation with ADHD and other externalizing disorders mentioned in the Genes section. One possibility is that having the 7-repeat *DRD4* polymorphism puts a child at risk of developing externalization problems; however, this genetic liability can be moderated by the environment. An alternative interpretation would be that the 7-repeat *DRD4* allele provides higher sensitivity to environmental influences. This sensitivity could be a double-edged sword, having advantages as well as disadvantages. On one hand, if this genetic variation increases flexibility in response to environmental demands, it would allow the environment to shape the child's behavior; therefore, this would serve as a mechanism for culture influences on behavior. On the other hand, under aversive environmental conditions, cultural demands, or both, this sensitivity could place the child at a higher risk.

The last alternative is consistent with the current scientific understanding of the origin of the 7-repeat allele of the *DRD4* and the fact that it is under positive selective pressure (Ding et al., 2002; Wang et al., 2004). In other words, this allele originated as a rare mutational event, but its occurrence became more and more frequent throughout evolution, as the result of its adaptive value. Calculations of the allele's age, based on observed intra-allelic variability in the DNA of individuals from Africa, Europe, Asia, North America, South America, and the Pacific Islands, led to the estimation that this allele arose 40,000 years ago (Ding et al., 2002; Wang et al., 2004). Harpending and Cochran (2002) speculated that the increase in the frequency of the 7-repeat allele could be related to the major expansion in the numbers of humans that occurred at that time and the appearance of the radical new technology of the Upper Paleolithic era. They mentioned two hypotheses to explain the world distribution of the 7-repeat allele. The first is that the allele increases the likelihood that its bearers migrate. As humans colonized the earth in the past, bearers of the 7-repeat allele were more likely to be movers, so that populations far away from their ancient places of origin have higher incidences of this allele. This might explain the uneven current distribution of this allele around the world; it is quite common in some populations (e.g., South American Indians), it has an intermediate frequency in others (e.g., Europeans), and is extremely rare in others (e.g., East Asians). The second hypothesis is that 7-repeat allele carriers enjoy a reproductive advantage in male-competitive societies, either in competition for food as children or in face-to-face and local group male competition. Societies in which this advantage would be present were rare before the spread of agriculture but common after it. This hypothesis links the changes in the frequency of the 7-repeat allele with key changes in human ecological history around 40,000 years ago. Under such conditions, individuals with personality traits such as novelty seeking might

have had some survival advantage, and therefore this allele was preserved and became more frequent, following the Darwinist principle of natural selection.

If this evolutionary perspective of the 7-repeat allele is true, then the question that arises is, of course, why would an allele that has been positively selected in human lineage currently be found to be disproportionately represented in individuals diagnosed with ADHD and other externalization disorders? One of the plausible explanations suggested by Wang et al. (2004) is that when a common genetic variation is related to a common disease, it might be because the disease is a product of a change in the environment. This would mean that the same traits that may have enhanced the selection of the 7-repeat allele under some circumstances may have harmful effects when combined with other environmental–genetic factors. For example, they may predispose behaviors that might be inappropriate in the typical classroom setting and other cultural requirements in modern times.

It has been suggested that the D4 dopamine receptor (*DRD4*) locus may be a good model system for understanding the relationship between genetic variation and human cultural diversity (Harpending & Cochran, 2002; Wang et al., 2004). Even though extensive research is still required, the evidence described above in regard to interactions between the 7-repeat allele and parenting characteristics begins to open a window on the complex interplay between genes and environment for complex developmental processes such as the development of self-regulation.

G × E interactions have also been found regarding proneness to violence and antisocial behavior. In this case, the relevant gene that has been found to interact with the environment is the MAOA. As explained in the Genes section, MAOA expression is known to depend on tandem repeats at a specific location of this gene. According to Caspi et al. (2002), the MAOA level of expression moderates the effects of maltreatment during childhood. Caspi et al. found that an aversive early environment had a significant effect on those individuals with low MAOA activity. Adolescents with low MAOA activity who were maltreated in childhood showed significantly more antisocial behavior than adolescents with low MAOA activity who were not maltreated. In contrast, in adolescents with high MAOA activity, this early environmental effect of maltreatment did not increase their antisocial behavior.

An additional example of G × E interaction related to self-regulation has to do with the opposite of externalization, that is, internalization disorders, such as extreme behavioral inhibition. Caspi et al. (2003), for instance, found that adults who had the short 5-HTT allele and reported high levels of stressful life events were more likely to show major depressive disorder than individuals who had two long alleles. N. A. Fox et al. (2005) focused on the same polymorphism within a longitudinal framework and tested its interaction on fear-related behaviors in young children. They found that those children with the combi-

nation of the short *5-HTT* allele and low social support had increased risk for behavioral inhibition in middle childhood.

To summarize, we have reviewed environmental and genetic factors that influence the development of self-regulation. Among environmental factors, we have focused mainly on diverse aspects of the relation between the child and the caregiver, beginning already at early infancy.

Environmental and genetic factors have direct, long-lasting influences on the development of self-regulation. In addition, these factors seem to have critical interactions. Most of the current empirical evidence suggests that the impact of the environment on the development of self-regulation is at least partly dependent on the specific allelic combinations that the individual child carries. According to this view, it is plausible that individual genetic structure can increase the child's risk through an increased sensitivity to environmental factors.

5

SELF-REGULATION IN SOCIAL CONTEXTS

The development of self-regulation has important implications for a child's functioning in social contexts. In this chapter, I review supporting evidence for this relation.

The initial social scene that is affected is the relation with caregivers, as effortful control (EC) influences the ability to comply with parental demands (Kochanska et al., 2001). Later on, high levels of EC have been related both to less aggression and fewer behavioral problems and to higher levels of conscience, empathy, and prosocial behavior (Kochanska et al., 1996, 1997, 2001; Kochanska & Knaack, 2003; Kochanska & Murray, 2000). As a result of this, individual EC also has a strong impact on the child's relation with peers and his or her social competence (N. Eisenberg et al., 2004).

In addition, aspects of EC at preschool, mainly inhibitory control, delay gratification, and working memory (WM), strongly predict academic success in elementary school (Blair & Razza, 2007) and many years later (Shoda et al., 1990).

COMPLIANCE

“Don’t touch the television.” “Don’t climb on the table.” “Don’t run into the street.” Compliance with caregivers’ instructions and requirements is one of the first self-regulation challenges with which young children need to cope. The term *compliance* refers to the child’s ability to cooperate with daily requirements and to accept behavioral standards imposed by the caregiving environment. It is considered to be a crucial developmental achievement during the process of socialization (Kaler & Kopp, 1990) and a first step toward the internalization of behavioral standards and rules (Kochanska et al., 1997).

According to Kochanska, the individual degree and quality of compliance depend, on the one hand, on the quality of the mother–child interaction and the socialization process (Kochanska et al., 1997) and, on the other hand, on the temperamental individual characteristics, especially in terms of self-regulation (Kochanska, 1993). This hypothesized relation between self-regulation and compliance is based on the temperamental concept of EC presented in Chapter 4 in this volume (Rothbart, 1989c; Rothbart & Bates, 1998; Rothbart et al., 2001). When referring to qualities of compliance, it is useful to differentiate between committed compliance versus situational compliance. *Committed* compliance refers to children’s more mature responses in which they embrace the maternal agenda, accept it as their own, and willingly follow instructions. *Situational* compliance refers to a scenario in which children cooperate without sincere commitment (Kochanska et al., 2001). Committed compliance relates to internalization, whereas situational compliance does not (Kochanska & Aksan, 1995).

Moreover, the need to comply seems to impose different levels of self-regulatory challenge for young children, depending on the requirement context. Two broad categories that have been studied are *don’t* versus *do* requirements (Kochanska & Aksan, 1995). *Don’t* requirements include inhibition or avoidance of a forbidden behavior. In contrast, *do* requirements involve the initiation of a new desirable behavior, according to the parent–educator instruction. The many *do* examples include doing homework, cleaning up the toys, and all kinds of household chores. Whereas *don’t* requires stopping or inhibiting a current behavior, *do* requires both—stopping a current behavior and initiating a new one according to the request (Kochanska & Aksan, 1995). Therefore, compliance with *do* requirements is more challenging than compliance with *don’t* ones. Indeed, empirical evidence indicates that the percentage of compliance with *don’t* requirements is usually higher than the percentage of compliance with *do* requirements in both toddlers and preschoolers (Kochanska et al., 1998, 2001).

A nice empirical illustration of the relation between self-regulation and the different types of compliance within the *do* and *don’t* contexts can be

found in the study by Kochanska et al. (2001). The researchers examined the development of self-regulation in 108 young children during their first 4 years of life. Children were tested at ages 14, 22, 23, and 45 months. Inhibitory control was assessed in a battery of tasks designed for toddlers and preschoolers, including delayed response to an offering of candy, motor control when moving a toy animal (turtle or bunny) on a track, a turn-taking game, and so forth. Compliance with a *don't* requirement made by the mother was assessed in a situation in which attractive toys were placed in a laboratory room while the child was forbidden to touch them and was given boring or broken toys to play with instead. Children's cooperation with an adult other than the mother (i.e., the experimenter) was also observed at the age of 33 months. Compliance and internalization were assessed in the same situations, depending on whether the mother was present while the compliance behavior was measured or was instructed to leave the room and leave the child alone. EC was assessed by using Rothbart's parental report temperament questionnaire, the Children's Behavior Questionnaire (CBQ; Rothbart et al., 2001).

The most relevant result of this study was the connection between EC and committed compliance, although in this study this relation was found only for *don't* requests. In this type of situation, children who received high scores in inhibitory control showed higher compliance with parental requirements. In addition, committed, but not situational, compliance during interaction with the mother was associated with children's internalization when left unsupervised. This finding supported Kochanska et al.'s (2001) view that committed compliance is an early form of the emerging internalization of rules of behavior. Moreover, there was a positive moderated correlation between child compliance with a maternal request and cooperation with another adult. This finding only partially supported the idea of a general compliance construct, which reflects the child's overall compliance tendency beyond the specific dyadic relation with the parent.

An additional interesting finding by Kochanska et al. (2001) was that girls generally showed more committed compliance than boys. This is consistent with previous studies (Kochanska & Aksan, 1995) and has been reported especially from the preschool years and onward. Girls tend to show more compliant behavior than boys regarding the requests and demands of parents and adults in general (Eaton & Enns, 1986; Feingold, 1994; Maccoby & Jacklin, 1974; Ruble & Martin, 1998).

The concept of committed compliance was later broadened and renamed *receptive cooperation*. Receptive cooperation includes the child's social eager responsiveness and harmonious cooperation with the parent in a broad range of settings and interactive contexts, beyond the previously studied discipline situations (Kochanska, Aksan, & Carlson, 2005). Attachment and quality of the relationship with the parent influence receptive cooperation

of toddlers. However, this relation is not straightforward and might depend on additional variables, such as the child's temperament and the parent's gender. For example, results showed that the combination of a high propensity to anger at the age of 7 months and nonoptimal early care was associated with impaired willingness to cooperate with the parent in the second year of life. Secure attachment with the father or responsive care of the mother appeared particularly important for angry infants. The specific relations were slightly different for mother-child and father-child dyads, but they supported the same general pattern. In mother-child dyads, maternal responsiveness in infancy and child attachment security at 15 months were associated with the child's high receptive cooperation with the mother. Mother responsiveness was specifically critical for infants with high temperamental proneness for anger; in cases of highly responsive mothers, angry infants became highly cooperative toddlers, but in cases of unresponsive mothers, angry infants were very uncooperative at 15 months. One plausible interpretation of Kochanska et al.'s (2005) results is that parental behavior can moderate infant temperamental proneness to negative affect and help the child to develop better self-regulated behavior; however, it can also enhance the uncooperativeness of the child. Mothers' negative maternal control strategies that are intrusive and high in power assertion are typically ineffective in achieving a satisfactory resolution. Toddlers' noncompliance and defiance are related to negative maternal control, and more specifically, to maternal high illusion and overestimation of control (Donovan, Leavitt, & Walsh, 2000), and maternal intrusiveness (van der Mark, Bakermans-Kranenburg, & van IJzendoorn, 2002). Although van der Mark et al. (2002) found this relation when both measures were obtained at the same timepoint, they failed to establish a longitudinal effect when testing it in girls 16 and 22 months of age. The relation between mother sensitivity and compliance is also supported by Lehman, Steier, Guidash, and Wanna (2002). In their study, maternal emotional availability (Biringen, Robinson, & Emde, 1994) was found to strongly predict compliance, especially on the scales of maternal variables of sensitivity and structuring.

Moreover, according to Strand, Wahler, and Herring (2001), maternal reinforcements, related both to the specifically maternal request and generally praising prosocial behavior, enhance the child's compliance. Furthermore, Strand (2002) indicated that a "coaching" intervention designed to improve maternal coordination with the child in a joint problem-solving task (i.e., giving the mother some specific tips and instructions about the best way to respond to the child's successes and failures during the task) was a successful way to improve the child's compliance.

A caveat that should be kept in mind is that at younger ages (i.e., around 2 years) resistance to control and defiant behavior might actually be related

to a healthy emerging sense of autonomy and self-efficacy (Erikson, 1964). Consistently, Dix, Stewart, Gershoff, and Day (2007) found that at 14 to 27 months, resistance was linked to maternal supportive behavior, autonomy-granting control, and low-depressive symptoms. They found that high-defiant children also initiated more positive interaction with mothers than did low-defiant children. They concluded that early active resistance to parents may reflect children's motivation to control events, rather than strained parent-child relationships. This issue again raises the difficulty of disentangling self-regulation from motivation.

AGGRESSION AND OTHER BEHAVIORAL PROBLEMS

Problematic emotion regulation, especially anger management problems, seems to be linked to externalization behavior problems, mainly to aggressive behavior. N. Eisenberg, Fabes, and colleagues (N. Eisenberg et al., 1993, 1994, 1996; Fabes & Eisenberg, 1992) have studied the role that anger and the regulation of anger reactions might play in the development of social behavioral competence. They found that individuals who are highly emotional in response to anger-inducing events and low in regulation are likely to display aggression. Their hypothesis was that intensity of anger is related to a loss of behavioral control. Strategies such as attentional control, avoidance, and instrumental coping may be useful in dealing with anger (N. Eisenberg et al., 1993, 1994). Children who fail to use such strategies tend to vent their emotions and may become aggressive. In contrast, children who are able to control their attention and behavior are expected to manage their emotions and plan their behavior; therefore, they get to practice and use the skills needed to get along with others and to engage in socially appropriate behavior (for a comprehensive review, see N. Eisenberg et al., 2004).

Indeed, negative correlations have been found between EC and aggression, and positive correlations have been found between aggression and surgency and aggression and negative affect, especially anger (Rothbart et al., 1994). Posner and Rothbart (2000) suggested that EC regulates aggression indirectly by controlling reactive tendencies, underlying surgency, and negative affect. For example, children high in EC may be more able than others to direct attention away from the rewarding aspects of aggression by shifting attention away from negative cues related to anger. Supporting evidence for this relation can also be found in additional studies (Calkins & Dedmon, 2000; see a review of this line of evidence in Fox & Calkins, 2003). EC negatively correlates with concurrent measures of externalization problems (Spinrad et al., 2007; although in their structural equation model there was no significant predictive correlation from EC at age 18 months to externalization at 28 months).

Longitudinal studies have revealed supporting evidence for a prospective, predictive relation from weak emotional regulation at preschool years to behavioral problems at school age (Bierman, Nix, Greenberg, Blair, & Domitrovich, 2008; N. Eisenberg et al., 1997; N. Eisenberg, Fabes, Guthrie, & Reiser, 2000). N. Eisenberg et al. (2000) showed that children high in negative emotionality seem to be more at risk of externalizing behavioral problems, depending on their attentional control (as reported by teachers who used a temperament questionnaire). Among these children, those prone to externalizing problems were those lacking attentional control. In addition, they found that the predicting relation between behavioral self-regulation and externalization behavioral problems was not moderated by negative emotionality. In other words, low behavioral regulation at preschool age predicted higher levels of externalization behavioral problems at school age, both for children high and low in negative emotionality.

The relationship between weak self-regulation of negative affect and behavioral problems, such as aggressive behavior toward peers, has also been found in adolescence (Caspi, Henry, McGee, Moffitt, & Silva, 1995; Krueger, Caspi, Moffitt, White, & Stouthamer-Loeber, 1996). For example, in a sample of young teenage boys, half of whom were known to manifest symptoms of behavioral disturbance, Krueger et al. (1996) found that low self-control was a risk factor specific to externalizing (aggressive and delinquent) disorders: Boys who showed signs of externalizing disorders tended to seek immediate gratification in a laboratory task more often than both nondisordered boys and boys who showed signs of internalizing (anxious and depressed) disorders. The relation between self-regulation and externalization behavioral problems has also been found in longitudinal studies. Caspi and Silva (1995) found that lack of control as reported by parents when children were 3 and 5 years old moderately predicted internalization problems (i.e., anxiety, fearfulness, and withdrawal) at adolescence and more strongly predicted externalization problems (i.e., hyperactivity, inattention, antisocial behavior, and conduct problems). This was found both for boys and girls.

As described in Chapter 4 of this volume, parental strategies and home environment can heavily influence this relation, causing the persistence and even enhancement of behavior problems across ages.

PEER RELATIONS AND SOCIAL COMPETENCE

An increasing body of empirical evidence supports the idea that self-regulation, especially regulation of negative emotional reactivity, affects children's functioning within their peer groups. N. Eisenberg and colleagues

have studied this relation for many years (N. Eisenberg et al., 1993, 1995, 1997, 2000; Maszk, Eisenberg, & Guthrie, 1999; Murphy & Eisenberg, 1997; Spinrad et al., 2004, 2007). In one of their earlier studies, N. Eisenberg et al. (1993) examined the relations between frequency and intensity of negative emotion, attentional control, and coping behavior, with preschool and kindergarten children's sociometric status and social behavior. They studied this relation by using direct sociometric scales and adults' estimations (parents and teachers) of sociometric status. They found that emotional intensity and aggressive coping behavior, as reported by teachers at school, were related in boys to their sociometric status, that is, high emotional intensity and aggressive coping behavior (as opposed to more constructive coping strategies) were associated with low levels of social functioning and with low sociometric status; high attentional control and constructive coping strategies were associated with positive social functioning (see also N. Eisenberg et al., 1994).

The predictive relation between self-regulation and later low social functioning has also been found in longitudinal designs (N. Eisenberg et al., 1995, 1997, 2000; Mischel et al., 1989), although in some of these studies this relation has been found to be stronger in boys than in girls (for a more extensive review of this literature, refer to N. Eisenberg et al., 2004).

Although the actual relationship between emotional regulation and social functioning turns out to be more complex than the above schema, children who are better able to inhibit inappropriate behaviors, delay gratification, and use cognitive methods of controlling their emotion and behavior tend to be socially competent overall, liked by their peers, and well-adjusted (Calkins & Dedmon, 2000; N. Eisenberg et al., 1996, 1997, 2001; Gilliom et al., 2002; Lemery et al., 2002; Lengua, 2002). In contrast, intense, emotionally negative children are less popular with peers (Stocker & Dunn, 1990).

Denham et al. (2003) also found that children showing higher scores of emotional understanding and regulation at preschool ages later showed higher levels of social competence (rated by teachers as well as by peers). Consistent with the aforementioned studies by Eisenberg, Denham et al. found that emotion regulation aids those who most need to regulate, meaning children who are temperamentally more prone to negative emotionality. In other words, the ability to refrain from disregulated venting was more predictive of social competence in children high in negative emotionality.

It is interesting to note that this study also found that emotional regulation at ages 3 to 4 years actually predicted social competence more strongly for girls than boys. Children who were less likely to vent their emotions, especially girls, were evaluated as more socially competent. The researchers' interpretation of these findings was that uncontrolled expression of negative emotions might contradict stereotypical views of girls' social competence,

and thus when a girl behaves less positively, this negative behavior may be more salient.

CONSCIENCE AND EMPATHY

Conscience and empathy are key aspects of prosocial behavior. As is reviewed in this section, self-regulation seems to play an important role in this important aspect of development.

Conscience

The ability to regulate attentional processes also seems to play an important role in the development and enactment of morally relevant behavior (N. Eisenberg, 2000). More specifically, temperamental–personality traits such as impulsivity and voluntary behavioral inhibition appear to be intimately related to the development of conscience (N. Eisenberg, 2000). According to Kochanska and Aksan (2006), conscience is a personality system that gets coherently organized early in life and is relatively stable over time. Individual differences in conscience emerge as a result of a complex interplay between children’s temperamental individuality and socialization in the family. This research indicates that both inhibitory systems of temperament—fearfulness and EC—are associated with more mature moral conduct, although the main effects of EC appear to be more pronounced (Kochanska & Aksan, 2006). In an impressive line of studies, Kochanska and colleagues (Kochanska et al., 1996, 1997, 2001; Kochanska & Knaack, 2003; Kochanska & Murray, 2000) have consistently found that children’s EC predicts conscience and internalized conduct, both concurrently and longitudinally, from toddler age to early school age.

Moreover, EC seems to mediate the relation between less efficient child-rearing styles, such as maternal power assertion and impaired conscience development in children. Kochanska and Knaack (2003) assessed EC at 22, 33, and 45 months of age with a battery of laboratory tasks. The compound measure of EC at these different ages was found to predict the child’s conscience at the age of 56 months. The measure of conscience in this study included ratings on items that reflected “moral self” (e.g., concern about others’ wrongdoing, guilt or affective discomfort after transgression), internalization of their mother’s rules (not cheating while left alone in the room after the mother forbade them to touch an attractive toy), and internalization of the experimenter’s rules (not cheating at a game while the experimenter was not in the room). The researchers also looked for a negative influence of maternal

power-assertive child-rearing style on the development of conscience. This relation was indeed found, and it is interesting that it was found to be mediated by the child's EC. In other words, this study suggested that maternal power-assertive discipline may impair the child's development of EC, which in turn may impair his or her development of conscience. The relation between EC and conscience has also been reported in adolescence. For example, in the study by Krueger et al. (1996), mentioned in the Aggression and Other Behavioral Problems section, young adolescents who were able to delay immediate gratification in a "delay gratification" laboratory task were described by their mothers as ego-controlled, ego-resilient, and also more conscientious (for a more comprehensive review of this literature, see N. Eisenberg, 2000; and N. Eisenberg et al., 2004).

Empathy

Empathy is the ability to experience and understand what others feel, and it plays a fundamental role in interpersonal interactions (Decety & Lamm, 2006). This ability seems to involve both emotion sharing (bottom-up information processing) and executive control to regulate and modulate this experience (top-down information processing; Decety & Lamm, 2006).

Interesting links have also been found between EC and empathy. According to N. Eisenberg and colleagues (N. Eisenberg, 2000; N. Eisenberg et al., 1994, 2004; Gurthrie et al., 1997), empathy is the affective response that stems from the apprehension or comprehension of another's emotional state or condition and is similar to what the other person is feeling or would be expected to feel. With further cognitive processing (assuming that the individual is old enough to differentiate between one's own and others' internal states), an empathic response usually turns into either sympathy or personal distress. Sympathy, according to this view, is an emotional response stemming from the apprehension or comprehension of another's emotional state or condition, which is not the same as what the other person is feeling (or is expected to feel) but consists of feelings of sorrow or concern for the other. Personal distress, on the other hand, is a self-focused, aversive, affective reaction to the apprehension of another's emotion (e.g., discomfort, anxiety), such as the distress of a person feeling anxious when viewing someone who is sad.

N. Eisenberg et al. (1994) suggested that people who can maintain their emotional reactions within a tolerable range (within a level that does not become aversive) are prone to be sympathetic because they can experience how others feel without being overwhelmed by their emotion and becoming self-focused. In other words, people who are well regulated are more likely to experience sympathy.

In contrast, N. Eisenberg et al. (1994) suggested that people who are prone to intense negative emotions and have difficulty regulating themselves—particularly their emotions—would also be prone to personal distress (focusing on their personal negative experience instead of feeling sympathy toward the negative experience of the other). Empirical findings in studies of adults have been somewhat consistent with this prediction (see the review of this line of literature in N. Eisenberg, 2000). Somewhat more consistent relations between situational sympathy and dispositional regulation have been found for children (N. Eisenberg, 2000). For example, Gurthrie et al. (1997) videotaped 5- to 8-year-olds while they watched an empathy-evocative film. Their parents rated the children's effortful regulation, using items from the CBQ questionnaire (Rothbart et al., 2001). The children themselves self-reported their sadness and sympathy feelings on watching the film. The findings for self-report measures were consistent with expectations, at least for girls. Girls' (but not boys') reports of sympathy were positively related to teachers' ratings of attentional control. The researchers raised two possible explanations. One possibility was that girls who are more regulated are more comfortable expressing emotions verbally, whereas such a relation does not hold for boys. Alternatively, it could have been that although regulation is associated with sympathy for both sexes, boys' reports are often contaminated by the desire to appear masculine to themselves and others. Gurthrie et al. also found that children who were rated high on effortful regulation exhibited greater facial sadness during the film than children who were rated low on effortful regulation.

Gurthrie et al. (1997) also found that children rated by their parents as low in effortful regulation were prone to experience personal distress. However, contrary to their predictions and to the findings of N. Eisenberg et al. (1995), they did not find that sympathy, as measured by facial expressions of concerned attention, was related to regulation measures.

The new approach of social neuroscience has recently provided evidence consistent with the model described above. This new scientific discipline combines research designs and behavioral measures used in social psychology with neuroscience markers, and it has begun to unravel the neural systems that underpin the processes involved in the experience of empathy, including emotion sharing, perspective taking, and emotion regulation (Decety & Lamm, 2006; Lamm, Batson, & Decety, 2007). It has been found, for instance, that empathy-related processing of emotional facial expressions recruited brain areas involved in mirror neuron and theory-of-mind mechanisms (Schulte-Ruther, Markowitsch, Fink, & Piefke, 2007). Moreover, it has been found that adopting a self-perspective when observing others in pain results in stronger feelings of personal distress and activates the pain-brain circuitry, including the amygdala, to a larger extent. Such a complete self–other merging seems to be detrimental to empathic concern. The best response to another person's plight may not

be distress but efforts to soothe that distress. Conversely, when participants take the other's perspective, there is less overlap between the neural circuits involved in the processing of firsthand experience of pain, and they indeed report more feelings of empathic concern (Decety & Lamm, 2006).

The relation between EC and empathy is in line, from a developmental perspective, with the coincidence in age between the maturation of EC and theory of mind, and with findings showing a positive correlation between them in children; that is, preschool children showing higher levels of EC also tend to do better on tests tapping theory of mind (S. M. Carlson & Moses, 2001).

ACADEMIC COMPETENCE AND ACHIEVEMENT

EC seems to be related to academic competence. Among the plausible reasons for this relation, Valiente, Lemery-Chalfant, Swanson, and Reiser (2008) suggested that the more cognitively oriented components of EC, such as planning and attention allocation, may be directly related to academic competence. Some evidence indeed supports the idea that components of EC (e.g., attentional regulation, persistence, delay of gratification) are positively related to reading, math, and linguistic abilities, as well as teachers' reports of competence (Fabes, Martin, Hanish, Anders, & Madden-Derdich, 2003; National Institute of Child Health and Development Early Child Care Research Network, 2003). Blair and Razza (2007), for example, examined the role of self-regulation in emerging academic ability in 3- to 5-year-old children from low-income homes. They found that measures of EC (e.g., inhibitory control, attention shifting) in preschool were related to measures of math and literacy ability in kindergarten. Results indicated that the various aspects of child self-regulation accounted for unique variance in the academic outcomes, independent of general intelligence. Moreover, they found that the inhibitory control aspect was strongly correlated with both early math and reading ability (see also Bierman et al., 2008). Similar results were reported by Bull and Scerif (2001), who found that lower mathematical ability in first- to third-grade children was correlated with lack of inhibition and poor WM, resulting in problems with switching and evaluating new strategies while dealing with tasks; and by Checa, Rodríguez-Bailón, and Rueda (2009), who found in young adolescents that EC, as measured with the Attention Network Task, was related to academic outcomes, particularly in mathematics, as well as to aspects of social adjustment.

More recently, Ponitz, McClelland, Matthews, and Morrison (2009) used the head-toes-knees-shoulders task to study self-regulation in kindergarten children. Performance of this task requires (a) focusing on instructions and commands, (b) using WM to remember and execute new rules while pro-

cessing commands, and (c) inhibiting the automatic response while responding correctly. This measure of self-regulation has construct validity with parent ratings of kindergarteners' attentional focusing and inhibitory control and teacher ratings of behavioral regulation. They found that participants with higher levels of behavioral regulation, as measured with the head-toes-knees-shoulders task at the beginning of the kindergarten year, reached higher levels of mathematics, literacy, and vocabulary skills in their second assessment, which took place in the spring of that year.

Moreover, there is some evidence that the relations between regulatory abilities and academic competence persist over time. For example, preschoolers' delay of gratification has been found to predict adolescents' verbal intellectual ability and Scholastic Assessment Test (SAT) scores (Rodriguez, Mischel, & Shoda, 1989; Shoda et al., 1990).

In addition, it has been hypothesized that the inhibitory aspects of EC may influence academic performance while being mediated by constructs such as social competence, the teacher-child relationship, and classroom participation. Valiente et al. (2008) studied the relations among children's EC, school relationships, classroom participation, and academic competence with a sample of 7- to 12-year-old children. Parents and children reported on children's EC, and teachers and children reported on children's school relationships and classroom participation. Children's grade point averages and absences were obtained from school-issued report cards. Significant positive correlations existed between EC, school relationships, classroom participation, and academic competence. Moreover, the teacher-child relationship, social competence, and classroom participation partially mediated the relation between EC and change in grade point average from the beginning to the end of the school year. The teacher-child relationship and classroom participation also partially mediated the relation between EC and change in school absences across the year. Consistently, also in the study by Checa et al. (2009), this variable mediated the relationship between social adjustment and schooling outcomes.

To summarize, I have reviewed the extant empirical evidence in regard to the impact of self-regulation on the adjustment and functioning of the child in the social and academic worlds. Readers have seen that individual differences in EC are connected to individual differences in the quality of social interactions. This relation seems to be explained through more than one mechanism. For example, children who can regulate their negative emotionality and become less overwhelmed with these feelings probably can find less aggressive and more socially appropriate ways to cope with frustrating situations. Moreover, children who are well regulated are more likely to experience sympathy, probably because they can experience how others feel without being overwhelmed by their emotion and becoming self-focused.

EC has an important impact on the child's academic achievements. This relation seems to be persistent and has longitudinal predictive outcomes from preschool year through childhood and adolescence. This relation, again, can be explained through more than one mechanism. First, better EC indicates that the child has a higher control over his or her attention and possibly better overall executive functions. This predicts better ability to cope with academic workload, resist distraction, and so forth. In addition, the relation between EC and academic achievements is achieved through the higher social skill variables, and the teacher–child relationship and classroom participation seem to be important variables that affect academic competence.

6

ILLUSTRATING A DEVELOPMENTAL PATHOLOGY OF SELF-REGULATION: THE CASE OF ADHD

Beyond the continuum of individual differences in self-regulation capacities, or maybe at the edge of it (E. Taylor, 1999), one can find children who are suffering from a diverse range of developmental disorders that involve impairments of self-regulation. This chapter illustrates the consequences of failure in self-regulation by focusing on one such developmental pathology, attention-deficit/hyperactivity disorder (ADHD). Current views of this syndrome conceptualize it primarily as a disorder in key aspects in the development of self-regulation (Nigg, 2005).

First, I provide a brief general introduction to this syndrome. Then, each of the issues that have been covered in the previous chapters of this book is illustrated in the case of ADHD. In this sense, I treat this syndrome as an extreme case for looking at the causes and consequences of dysregulation. Moreover, I look at the underlying brain mechanisms that are considered to be deficient in the syndrome, including brain anatomy, brain functioning, neurodevelopment, and genetics.

In addition to reviewing relevant research literature about this syndrome, many of the sections of this chapter present findings from the longitudinal study on children at familial risk for ADHD that my colleagues and I have conducted for the past 8 years; therefore, it is worth offering a few words of introduction

about this study. The Ben-Gurion Infant Development Study (BIDS), under the principal investigators Auerbach, Landau, Berger, and Atzaba-Poria, has been following a sample of children at familial risk for ADHD since birth. In this study, risk for ADHD has been defined as ADHD symptoms in the fathers (\leq three vs. \geq seven symptoms). Auerbach and Landau began this study in 1999, recruiting participants from the maternity ward of the Soroka Medical Center, Beersheba, Israel. The sample was limited to boys because the ratio of boys to girls with ADHD ranges from 3:1 to 9:1 (American Psychiatric Association, 1994; Dankaerts & Taylor, 1995; Gross-Tsur, Shalev, & Amir, 1991). Moreover, our sample was chosen based on fathers' symptoms because of evidence that children are more affected when the affected parent is of their gender (Minde et al., 2003), and exposure to maternal ADHD is not associated with more impairment than exposure to paternal ADHD (Biederman, Faraone, & Monuteaux, 2002). All children were from two-parent families. The parents were native-born Israelis or immigrants who had studied in Israel and spoke Hebrew. Initial recruitment was done on the basis of an ADHD symptoms questionnaire, using a yes–no format, that the father completed at the hospital at the time of the child's birth (see Auerbach, Atzaba-Poria, Berger, & Landau, 2004). When the children in the study were between 2 and 6 months old, the parents were more fully assessed by a psychiatric interview (see more details in Landau, Amiel-Laviad, Berger, Atzaba-Poria, & Auerbach, 2009). In addition, both parents completed the Conners Adult ADHD Rating Scale (CAARS; Conners, Erhardt, & Sparrow, 1999), about both themselves and their spouses. Our initial publications were based on a dichotomous split between risk and comparison groups as determined by the recruitment questionnaire. Later analyses used the CAARS questionnaires, which produced a continuum range of risk scores. We have assessed this sample periodically during home and lab visits. Our measures include parent-report questionnaires as well as systematic behavioral laboratory measures. The BIDS sample provides a unique opportunity for tracing the risk for developing ADHD and looking for its developmental pathways.

GENERAL INTRODUCTION TO ADHD

ADHD is a prevalent, child-onset disorder that is characterized by age-inappropriate levels of inattention, hyperactivity, and impulsivity (American Psychiatric Association, 1994). These behavioral deficits arise relatively early in childhood, typically before the age of 7 years, and are fairly persistent over the course of development (Barkley, Fischer, Edelbrock, & Smallish, 1990; Hinshaw, 1994; Weiss & Hechtman, 1993). It is one of the most common disorders of childhood, having a prevalence of about 3% to 5% (American Psychiatric Association, 1994) and is more common in boys

than in girls, both in epidemiological and in clinical populations (Breton et al., 1999).

As I present in detail below, evidence suggests that the disorder has both genetic and environmental underpinnings. First-degree relatives of children with ADHD are 7.6 times more likely to have the disorder than are relatives of normal children (Biederman et al., 1992). Furthermore, 60% of children having a parent with ADHD are likely to be diagnosed as having ADHD (Biederman et al., 1995). The high heritability estimates (75%–90%) for ADHD in twin studies support a strong genetic contribution (Goodman & Stevenson, 1989; Larsson, Larsson, & Lichtenstein, 2004; F. Levy, Hay, McStephen, Wood, & Waldman, 1997; Rietveld, Hudziak, Bartels, van Beijsterveldt, & Boomsma, 2004), especially for hyperactivity symptoms (Kuntsi & Stevenson, 2001). As readers will see in this chapter, environmental factors also seem to have some contribution to the syndrome; for instance, family relationships, parent–child interaction, and family adversity are associated with the development and severity of the disorder (Biederman et al., 1995; Jacobvitz & Sroufe, 1987).

ADHD is viewed as comprising three primary symptoms: poor sustained attention, impulsiveness, and hyperactivity. These three major impairments have currently been reduced to two, with hyperactivity and impulsivity constituting a single impairment, encompassing three subtypes of the disorder, classified by the *Diagnostic and Statistical Manual of Mental Disorders* (4th ed.; *DSM-IV*; American Psychiatric Association, 1994), as the predominantly inattentive type, the predominantly hyperactive–impulsive type, and the combined type. In this chapter, I mostly refer to the combined type, which is the most common and on which most of the studies in the literature have been conducted. However, it is important to keep in mind that there is also great heterogeneity within each of these subtypes. For example, within the combined subtype there are individuals who have prominent mood or anxiety problems, whereas others have abnormal low anxiety and are at risk of severe antisocial behavior (Manassis, Tannock, Young, & Francis-John, 2007; Nigg & Casey, 2005). There is also much heterogeneity in the executive–cognitive profile (Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005). Furthermore, there are some claims in the literature that inattentiveness–attention deficit disorder (ADD) should be considered a completely separate syndrome instead of an ADHD subtype (Diamond, 2005; Milich, Balentine, & Lynam, 2001).

HOW DISREGULATION DEVELOPS IN ADHD

Self-regulation seems to be compromised in ADHD. Some indices of such deviation from normal development can even be found at very early stages of life.

Disregulation During Infancy and Early Childhood: Early Markers of Self-Regulation in Children at Risk for ADHD

It has been suggested that there are many pathways to ADHD and that certain temperamental characteristics may provide the behavioral early markers for some of these pathways (Auerbach et al., 2008; Nigg, Goldsmith, & Sachek, 2004). Some of these temperamental difficulties seem to show up already at early infancy and be preliminary manifestations of disregulation. For example, Wolke, Rizzo, and Woods (2002) found correlations between (a) persistent crying at 3 to 4 months of age and hyperactivity, (b) parent-reported conduct problems and negative emotionality, and (c) teachers' reports of lower academic achievements in middle childhood.

In the BIDS, the infants were first assessed during the neonatal period. The infants were assessed with the Neonatal Behavioral Assessment Scales (NBAS; Brazelton & Nugent, 1995). The risk and comparison groups did not differ by birth weight or parental demographic characteristics. As reported by Auerbach et al. (2005), the infants at familial risk for ADHD exhibited subtle signs of higher vulnerability in the neonatal period; difficulties in state organization and regulation were more apparent in the ADHD risk group than in the comparison group. The ADHD risk group scored less optimally on the neurodevelopmental immaturity factor, which consists of items that measure both motor maturity and autonomic stability. This result was consistent with our predictions, which were based on the findings of the Minnesota High Risk Study (Jacobvitz & Sroufe, 1987) that revealed low scores on the NBAS motor maturity factor differentiated hyperactive from nonhyperactive kindergarteners.

There was also a marginal difference for activity level, where the ADHD risk group showed a higher level of activity than the comparison group. This difference later became stronger as the infants grew up and became fully mobile. At the 7-month assessment, the risk group was significantly rated by mothers as being higher on activity level than the comparison group. In addition, neonatal activity was positively correlated with 7-month activity level (Auerbach et al., 2004). At the 7-month laboratory assessment, using the Laboratory Temperament Assessment Battery (Lab-TAB-Prelocomotor version; Goldsmith & Rothbart, 1996), our risk group differed significantly from the comparison group on measures of activity level, interest, and anger.

Furthermore, when our sample reached toddlerhood, we analyzed the stability of the between-groups differences, in the temperament ratings at 7, 12, and 25 months of age (Auerbach et al., 2008). The results of this analysis showed that the risk group had higher ratings of negative emotionality (anger), and lower ratings of attention, inhibitory control, and effortful control (EC). All these group differences were stable but small. The strongest and most stable difference between the groups was on activity level, which seemed to

emerge as a strong candidate as an early marker of risk for ADHD. Consistently, Sonuga-Barke, Auerbach, Campbell, Daley, and Thompson (2005) have found that extreme levels of high activity at the age of 4 years predicted the early onset and persistence of ADHD.

The differences that we found between the risk and comparison groups at toddlerhood in EC, and its components, attention and inhibitory control, provide support for this construct as an additional potential liability marker of risk for ADHD. Low EC has continued to be related to ADHD risk further on in BIDS. For instance, EC negatively correlated with symptoms of ADHD as measured by the DuPaul, Power, Anastopoulos, and Reid (1998) scale that parents completed when the children were 4.5 years old (see compatible results also in Nigg, 2006).

An additional early marker found in the BIDS as well as in the literature is difficulties in regulating negative emotionality. Goldsmith, Lemery, and Essex (2004), for example, found in a longitudinal study that maternal rating of hostile and aggressive behavior when children were in preschool predicted symptoms of ADHD in kindergarten. Also, Nigg et al. (2004) found correlations between early measures of emotional regulation and later symptoms of attention deficits.

Disregulation in Children, Adolescents, and Adults With ADHD

At school age, the characteristic disregulation in children with ADHD, especially those having the combined subtype, is still expressed in excessive activity; impulsivity; and disorganized, off-task behaviors. They do not seem to pay attention to what is being said or done, they show reckless play, and are at higher risk for accidents and physical injuries (Nigg & Casey, 2005). These children have trouble coping with the requirements of the school environment, tend to go off task, and have trouble finishing their homework and staying organized. There is also substantial comorbidity with anxiety problems, which seems to reflect poor emotion regulation rather than fear or panic (Barkley, 2002). It has been suggested that in children with ADHD plus anxiety, the frontal lobe deficits might affect both their ability to inhibit negative affect as well as their ability to inhibit responses to stimuli, resulting in their comorbid symptomatology (Manassis et al., 2007).

Most of the children with ADHD are diagnosed at school entrance, and most of the cognitive and motivational phenotypes described in the following section have been studied in elementary school children with the syndrome. However, it is now well established that ADHD can persist into adolescence and adulthood (Thapar, Langley, O'Donovan, & Owen, 2006). The persistence rate varies among studies, probably due to differences in the measurement tools, and can be as high as 57% (Biederman et al., 1995). In their meta-analysis of

follow-up studies, Faraone, Biederman, and Mick (2006) found that about 15% of children with ADHD still meet the full *DSM-IV* criteria for having “persistent ADHD” at adulthood, and about 65% still show symptoms of ADHD that meet the definition of “ADHD in partial remission.” Furthermore, Faraone, Biederman, Feighner, and Monuteaux (2000) claimed that from a familial perspective, the assessment of ADHD may even be more valid in adults than in children.

In the long run, ADHD is associated with greater risks for low academic achievement, poor school performance, retention in grade, school suspensions and expulsions (Barkley, 1997; Barkley et al., 1990), poor peer and family relations, anxiety and depression, aggression, conduct problems and delinquency, early substance experimentation and abuse (Biederman et al., 1992), driving accidents and speeding violations (Barkley, 2002; Barkley, Murphy, & Kwasnik, 1996). When it persists into adulthood, it is associated with difficulties in adult social relationships, marriage, and employment (Barkley, 1990; Hinshaw, 1994; Mannuzza & Klein, 2000; Nadeau, 1995; Weiss & Hechtman, 1993). Comorbidity of ADHD with aggression-conduct disorder tends to aggravate the symptoms of both and to be associated with poorer outcomes (Thapar et al., 2006).

COGNITIVE AND MOTIVATIONAL DISREGULATION IN ADHD

Different models have been proposed that define the underlying deficits behind the behavioral symptoms of ADHD or what are sometimes called the *behavioral phenotypes* (Castellanos & Tannock, 2002; Nigg, 2001; Russell et al., 2006; Sagvolden, Johansen, Aase, & Russell, 2005; Sergeant, 2005; Sonuga-Barke, 2003; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Today, most researchers would agree that there is a complex chain of deficits in response inhibition, delay aversion, and executive functioning (EF; Kieling, Goncalves, Tannock, & Castellanos, 2008) and that at least two (Sonuga-Barke, 2003), three (Nigg & Casey, 2005), or more brain networks are compromised in this syndrome and involved in multiple developmental pathways (Sonuga-Barke, 2005). As summarized by Nigg (2005),

Neuropsychologic studies of ADHD have generated several now well-established findings in ADHD-C [ADHD-combined]. These findings have been used by theorists in models that emphasize particular components of a unified self-regulatory system, which emerges from the infant to toddler years, consolidates from the preschool to early childhood years, and continues to mature through adolescence. (p. 1432)

However, it should be noted that there are also alternative approaches. For example, Halperin and Schulz (2006) suggested that ADHD is actually the

result of an early and possibly genetically mediated noncortical insult, involving mechanisms of alertness, and that later development of the prefrontal cortex (PFC) and EF are related to diminution of core symptoms with age, which is commonly seen in children with ADHD.

In the following section, I cover each of the different cognitive and motivational processes involved in self-regulation mentioned in Chapter 2, illustrating the consequences of their deficiency as found in individuals with ADHD.

Attention in ADHD

Contrary to initial speculations and the name of the syndrome, ADHD seems not to involve core deficits in orienting of attention. Although there was interesting initial evidence for lateralized orienting deficits (Sheppard, Bradshaw, Mattingley, & Lee, 1999; Swanson et al., 1991), results in this area of research have not been consistent. In 2000, Berger and Posner arrived at the conclusion that evidence in ADHD was mostly consistent with difficulties in two of the attentional networks—EF–EC, and vigilance and alerting regulation—but there was little empirical support for the involvement of the orienting network in this pathology. Deficits in executive attention and vigilance monitoring could explain the vast deficits usually found in ADHD, including impaired adaptation to task demands and diminished posterror slowing (Sergeant & van der Meere, 1988). This conclusion is strengthened in light of the studies that have been conducted in the past 10 years (see the meta-analysis in Huang-Pollock & Nigg, 2003). Overall, there is no evidence that consistently supports the notion of impaired engaging or disengaging of spatial attention in this syndrome (Nigg, 2005). That said, there are interesting findings coming from the event-related-potential (ERP) literature (see more details in the later section on functional brain abnormalities), indicating that children with ADHD do have impairments in some early stages of stimulus evaluation, which seem related to attention orienting (Banaschewski & Brandeis, 2007).

A recent study with the Attention Network Task (ANT; Johnson, Robertson, et al., 2008), which compared children with ADHD and controls, revealed exactly this pattern of results: Performance on the ANT clearly differentiated the children with and without ADHD in terms of mean and standard deviation of reaction time (RT), the number of incorrect responses made, and the number of omission errors made. The ADHD group demonstrated deficits in the conflict network in terms of slower RT and a higher number of incorrect responses; moreover, the ADHD group showed deficits in the alerting network in terms of the number of omission errors made. No deficit in the orienting network in ADHD was found (K. A. Johnson, Robertson, et al., 2008).

In the BIDS, children performed an adapted version of the child Attention Network Task (cANT; Rueda, Fan, et al., 2004) during the lab assessment at the age of 4.5 years. The conflict effect in RTs in this task correlated with concurrent inattention symptoms, as measured by the DuPaul, Power, Anastopoulos, and Reid (1998) questionnaire, and with performance on additional tasks that the children performed in the lab, tapping inhibitory control (Farbiash, Berger, Atzaba-Poria, Landau, & Auerbach, 2009).

An additional aspect of attention in which children with ADHD show poor performance is sustained attention over time, as required in the Continuous Performance Test (CPT; e.g., Chae, Jung, & Noh, 2001; Epstein, Goldberg, Conners, & March, 1997; Weyandt, Mitzlaff, & Thomas, 2002). Several tests of this sort have been developed and commercialized, for example, the Conners CPT II (Conners & MHS Staff, 2000) and the Test of Variables of Attention (TOVA; L. M. Greenberg, 2007), and they are widely used around the world to provide supporting information for the diagnosis of ADHD. The TOVA, for example, uses geometric stimuli and contains two test conditions—target infrequent and target frequent conditions. The first part of the test is boring and fatiguing, and participants must pay close attention to respond to the infrequent target correctly. When participants do not respond to the target, it is called an *error of omission* and is a measure of inattention. In the second part of the test, participants expect to respond most of the time but occasionally must inhibit the tendency to respond. When participants respond to the nontarget, it is called an *error of commission* and is a measure of impulsivity. Thus, the ability to pay attention to a boring, repetitive task is best measured in the first part of the TOVA, whereas the ability to inhibit oneself is best measured in the second part (Lark, Greenberg, Kindschi, Dupuy, & Hughes, 2007). The relevant measures in this type of test include variability of response time, response time, commission (false alarms) and omission errors (misses), postcommission response times, anticipatory responses, and usually also an ADHD score based on age–gender norms. High false-alarm rates are considered to reflect impulsivity and inhibition problems, that is, a sort of deficit that will be detailed in the next section.

A characteristic aspect in the performance of this type of tasks that is receiving increasing attention in the ADHD literature is the *increase variability*, sometimes called *reaction time variability* (RTV) and other times called *intra-subject variability* (ISV). High RTV is actually found in ADHD children not only in CPT tasks but also in additional tasks that require sustained attention and effort. For example, Kuntsi, Oosterlaan, and Stevenson (2001) found that RTV in the primary discrimination task in a stop-signal task was what best discriminated between the hyperactive and control groups. This finding seems to be quite consistent and has been replicated in many other studies. Sixteen of the 22 studies reviewed by Klein, Wendling, Huettner, Ruder, and Peper

(2006) found that the ISV measure discriminated between the ADHD group and controls. It is interesting to note that methylphenidate administration seems to reduce RTV as well as normalize levels of commission in sustained attention tasks (K. A. Johnson, Barry, et al., 2008). Moreover, RTV has been linked to genetic risk, as it is found to be higher in individuals who carry the 10-repeat allele of the *DAT1* gene and the 7-repeat allele of the *DRD4* (Bellgrove, Hawi, Kirley, Gill, & Robertson, 2005; Kebir, Tabbane, Sengupta, & Joobar, 2009), and it has been estimated to have shared familial effects of around 60% to 70% in a large, international sibling-pair sample (Andreou et al., 2007).

A recent direction of research focuses on the frequency of such attentional lapses in ADHD. Di Martino et al. (2008) found that fluctuations of RT in low frequencies are correlated with the diagnosis of ADHD beyond the global effect of RTV. An intriguing question for future research is whether these spectrally specific fluctuations in behavioral responses are linked to the intrinsic regional cerebral hemodynamic oscillations, in what is called the *default-mode network*, that occur at similar frequencies (M. Fox & Raichle, 2007; Raichle et al., 2001).

Inhibition in ADHD

ADHD has been repeatedly linked to deficits in inhibitory control (Berger et al., 2007). Barkley (1990, 1997) proposed that a primary deficit in inhibitory control is the core deficit that underlies the development of broader deficits in EF, accounting for the wide range of dysfunctional behavior in ADHD. According to this view, the deficit in inhibitory control explains cognitive difficulties and causes problems in self-regulation of affect. Nigg (2001) reviewed the data in regard to inhibition and ADHD that were available at that time and arrived at the conclusion that for the ADHD-C type, the data support a deficit in executive motor control. However, at that time his review indicated the existent data were mixed and too limited with regard to interference control and cognitive inhibition. In a more recent meta-analysis, Willcutt et al. (2005) reviewed 83 studies that administered EF measures to groups with ADHD ($N = 3,734$) and without ADHD ($N = 2,969$). They found clear differences between groups in many EF measures. One of the most consistent effects was obtained on measures of response inhibition. Response-inhibition deficits have been found in ADHD using a variety of paradigms, such as antisaccades, go/no-go, and so forth (see the detailed review in Nigg, 2005). However, it should be kept in mind that inhibition deficits might not characterize all but only a portion of children with ADHD. For example, Nigg et al. (2005) estimated that 35% to 50% of cases of ADHD-C type have this kind of impairment. Kuntsi et al. (2006) showed that there is a moderate degree of heritability of this disability (18%–45%), which in their study was estimated on the basis of

commission errors in go/no-go tasks with a large, population-based twin sample. Moreover, when Sonuga-Barke, Dalen, Daley, and Remington (2002) tested a sample of preschoolers, looking for early individual differences related to ADHD symptoms, they found that response inhibition (measured in a "Puppet say . . ." task), but not planning and working memory (WM), were correlated with ADHD symptoms even after controlling for IQ and age.

One of the specific aspects of response inhibition that has been repeatedly shown to be impaired in ADHD is the ability to interrupt an about-to-be-executed response, as measured by the stop-signal task (J. Stevens, Quittner, Zuckerman, & Moore, 2002). This deficit, indeed, has been suggested to be an endophenotype of the disorder (Castellanos & Tannock, 2002). The inhibition slopes obtained from these children are flatter than those of controls (Schachar & Logan, 1990), and their stop-signal reaction times (SSRTs) are longer (Bedard et al., 2002; Pliszka, Liotti, & Woldorff, 2000; Schachar et al., 2000, 2004); that is, to be able to not respond, ADHD participants need to get the stop signal close in time to the go stimulus. This finding was reconfirmed in a meta-analysis of 33 studies (Lijffijt, Kenemans, Verbaten, & van Engeland, 2005). Moreover, the SSRTs of children with ADHD have been found to correlate with their ratings of hyperactivity (Pliszka, Borchering, Spratley, Leon, & Irick, 1997). Tillman, Thorell, Brocki, and Bohlin (2008) showed that SSRT and inhibition ratio significantly relate to teacher ratings of inattention as well as to performance on other tasks that tap inhibition, such as the day-night Stroop-like task (Gerstadt, Hong, & Diamond, 1994).

In the BIDS, participants performed a staircase dynamic-tracking adapted version of the stop-signal paradigm, suitable for preschoolers (Berger & Alyagon, 2004). The task was presented to the participants as a set of computerized games. Because children at these ages cannot perform a task with too many trials, the trials were divided into three different stories or games. All of the games had the same basic structure: The child discriminates between two stimuli according to their color. For example, in the apples game, the child was to help Little Red Riding Hood sort apples for Grandma into the corresponding baskets according to their color. If the apple was then replaced by a worm (i.e., the stop signal), the child had to refrain from responding, or otherwise "the worm would be able to eat the apples in the basket."

At age 5 years, we found that the child's SSRT was correlated with his concurrent symptoms of hyperactivity measured by the DuPaul rating scale, and even predicted later on, at the age of 7 years, symptoms of hyperactivity measured by the Conners ADHD Rating Scales (CAARS), parent version. More important, paternal inattentiveness as measured with the CAARS at the child's birth predicted the child's SSRT in the stop-signal task, even after controlling for any possible effects of the child's inhibition ratio and the efficiency of the tracking paradigm. We did not find evidence that RT variability, per se,

was related to paternal risk or to concurrent ADHD symptomatology (Berger et al., 2010).

Working Memory in ADHD

WM impairments have been suggested as one of the endophenotypes of ADHD (Castellanos & Tannock, 2002). In the already mentioned meta-analysis conducted by Willcutt et al. (2005), the authors concluded that although not many studies have examined WM deficits in ADHD, the results tend to be consistent and promising. Seventy-five percent of the studies they reviewed that compare ADHD participants and controls in spatial WM found significant group differences. This deficit has been demonstrated in tasks that require both storage and manipulation of information in memory, such as the Cambridge Neuropsychological Test Automated Battery (Owen, Doyon, Petrides, & Evans, 1996), in which participants search spatial locations, looking for tokens while remembering not to return to any locations where tokens were previously found. Children with ADHD tend to make more errors. Significant group differences were also found in 55% of the studies that included one of the verbal WM tasks, such as the Digit Span Backward, in which participants repeat a series of digits in the reverse order from which they were presented (Wechsler, 1991). Children with ADHD tend to show a smaller span (i.e., they are able to report only shorter series of the digits without erring).

Furthermore, the population-based twin study by Kuntsi et al. (2006) indicated that there is (a) a moderate degree of heritability (36%) and (b) a negligible shared environmental influence with WM deficits in ADHD, as measured by using the Digit Span Backward.

However, it should be remembered that there are also some contradictory findings in regard to the centrality of WM deficits to ADHD. For example, Sonuga-Barke et al.'s (2002) study revealed no association between ADHD and WM in preschoolers. Moreover, sometimes the differences in WM measures between the ADHD group and controls disappear after controlling for variables such as IQ (Kuntsi et al., 2001).

It has even been proposed that WM problems might be the core problem in the truly inattentive but not the combined subtype of ADHD (Diamond, 2005). Lui and Tannock's (2007) findings are consistent with this suggestion.

Task Switching in ADHD

A documented but much less studied EF impaired in ADHD is the ability to switch between tasks. Children with ADHD have been shown to have larger switching costs than controls (Cepeda, Cepeda, & Kramer, 2000). Medication seems to bring the ADHD children's switching performance to a

level comparable to that of control groups (Cepeda et al., 2000). An additional study of this same research group that tested the specific effects of the medication on the switching process (Kramer, Cepeda, & Cepeda, 2001) found that medication reduced the switching costs in the long response-to-cue interval condition. Kramer et al. (2001) suggested that the reason for this effect was related to the ADHD children's delay of aversion and difficulty with long delays under uncertain conditions. In addition, medication improved error rates in the response-incompatible trials. In other words, it aided the ADHD children in selectively ignoring the incorrect response on those trials in which the relevant and irrelevant task dictated different responses. It should be mentioned, however, that this pattern of results was not replicated in Oades and Christiansen's (2008) study.

Language-Related Self-Regulation in ADHD

In addition to the deficits in EF already mentioned, the developmental self-regulatory difficulties in children with ADHD are also related to their language capabilities (Nigg, 2005). In general, there is a high prevalence of comorbid linguistic impairments and reading disabilities with ADHD (Purvis & Tannock, 1997). Specifically, children with ADHD seem to show delays in their ability to use language to regulate and monitor their behavior. Consistent with the predictions of Barkley's (1997) model, children with ADHD show less mature private speech while confronting a challenging task, that is, later internalization of it. Berk and Potts (1991), Winsler (1998), and others have found that in comparison with controls, children with ADHD engaged in more externalized task-relevant speech and less relatively internalized task-relevant private speech. Children with ADHD do not exhibit more externalized task-irrelevant speech and display the same developmental stages for private speech as controls but with a noticeable delay in the transition toward internalization (Berk & Potts, 1991). At preschool age, Winsler, De Leon, Wallace, Carlton, and Willson-Quayle (2003) found that individual differences in children's private speech use was related to their observed and reported behavior at school and home; children whose private speech was more maturely, partially internalized had fewer externalizing behavior problems and better social skills as reported by parents and teachers. In contrast, children whose private speech was largely task irrelevant engaged in less goal-directed behavior in the classroom, expressed more negative affect in the classroom, and were rated as having poorer social skills and more behavior problems.

A study within the BIDS (O. Levy, 2006), conducted when the children were 3 years old, investigated the influence of children's ADHD symptoms on their language level, the influence of these two variables on the mother's scaffolding while tutoring them, the influence of these variables on the amount

and type of use the children make with private speech strategy, and the influence of all these variables on the children's task success as a measure of their self-regulation ability. During a home visit, child language was assessed with the Clinical Evaluation of Language Fundamentals–Preschool (Wiig, Secord, & Semel, 1992). During a laboratory visit, children were given two tasks: a puzzle task and a Lego task. Each task had a picture, and the child was asked to assemble the puzzle and the Lego model so that they would be identical to the picture. Results indicated that the child's ADHD symptoms were negatively correlated with his or her language level. Also, it was found that the child's language level predicted the suitability of the maternal scaffolding to his or her needs. In the Lego task, children with more ADHD symptoms who used less relevant private speech were less successful on the task. The child's ADHD symptoms were also found to be negatively correlated with language level. This variable in turn predicted maternal levels of scaffolding.

Delay Aversion and Temporal Discounting in ADHD

As reviewed in Berger et al. (2007), ADHD seems to involve motivational processes also. A motivational deficit explanation for ADHD implies that for children with this syndrome, threatening events, contextual cues for punishment, and so on, do not trigger the same motivational cascade as in other children, which in turn produces a failure to regulate normal social learning.

The relation between inattention symptoms and behavioral measures of choice impulsivity and delay aversion has also been documented in a general population study (Paloyelis, Asherson, & Kuntsi, 2009). In this study, more than 1,000 children were tested, making a fixed number of repeated choices between a smaller reward delivered immediately and a larger reward delivered after a delay (choice-delay task). There were two experimental conditions: including and excluding a postreward delay. Paloyelis et al. (2009) controlled for age and IQ in their analysis. The results indicated that inattention ratings predicted preference for smaller immediate rewards under both task conditions for both sexes. Hyperactivity–impulsivity ratings, on the other hand, were negatively associated with choice impulsivity in the post-reward delay condition, but only for girls.

BRAIN ABNORMALITIES IN ADHD

All the neuropsychological deficits mentioned earlier in this chapter that have been documented in ADHD are linked to structural and functional brain abnormalities in the frontal-striatal-cerebellar circuits detailed in Chapters 2 and 3 of this volume.

Structural

Pathologies of the brain frontal areas related to inhibitory control, executive attention, and vigilance have been extensively found in ADHD (Berger & Posner, 2000). Volumetric differences between children with ADHD and controls have been found mainly in those brain areas involved in inhibitory control of motor responses, such as the dorsolateral prefrontal cortex and the caudate nucleus of the basal ganglia (Berger et al., 2007). Children with ADHD have smaller frontal lobe gray- and white-matter volumes than controls do (Mostofsky, Cooper, Kates, Denckla, & Kaufmann, 2002). Additional volume reductions have been found in parietal, temporal, anterior cingulate, and cerebellar regions (Carmona et al., 2005).

Recent meta-analyses of structural neuroimaging in ADHD strengthen these observations (Seidman, Valera, & Makris, 2005; Valera, Faraone, Murray, & Seidman, 2007), confirming global brain reduction for ADHD participants compared with control participants, with the largest divergences observed in the cerebellar vermis, the corpus callosum, the total cerebral volume, and the right caudate. In the meta-analysis by Shaw et al. (2009), the abnormalities at the subcortical level were consistently found in the shape and volume of the basal ganglia, hippocampus, and amygdale. Structural developmental abnormalities in the size and shape of the basal ganglia were recently corroborated by Qiu et al. (2009). At the cortical level, the meta-analysis by Shaw et al. found consistent anomalies in the lateral prefrontal and parietal cortex, but they found less consensus on the exact location of these structural changes.

White matter abnormalities in ADHD were recently demonstrated by using diffusion tensor imaging. Silk, Vance, Rinehart, Bradshaw, and Cunnington (2009b) found differences between adolescents with ADHD and controls in the pathways that connect prefrontal and parieto-occipital areas with the striatum and the cerebellum. Silk et al. (2009b) suggested that these differences could be related to a lesser degree of neural branching within key white matter pathways in the ADHD group. Moreover, analysis of age effect indicated that these were developmental abnormalities in the connectivity of the basal ganglia (Silk, Vance, Rinehart, Bradshaw, & Cunnington, 2009a).

Cortical thinning in the cortical network that supports attention and EF (i.e., the right inferior parietal, dorsolateral prefrontal, and anterior cingulate cortices) was also found in adults with ADHD (Makris et al., 2007). Longitudinal studies of cortical thickness (a process that I explain in more detail in Chapter 3) suggest that ADHD in childhood may be characterized by a delay in cortical maturation (Shaw, Eckstrand, et al., 2007), especially in prefrontal areas (see Color Plate 6).

It is worth mentioning that a study by van 't Ent et al. (2007) of structural magnetic resonance imaging (MRI) in monozygotic twins concordant or dis-

cordant for attention–hyperactivity problems indicated the possibility of differentiation between the brain-structure anomalies related to genetic versus environmental risk for ADHD.

Functional

Functional abnormalities have been found in ADHD by using imaging techniques such as functional MRI (fMRI), during performance of tasks that demand inhibitory control, such as the stop-signal and go/no-go tasks (Bush et al., 1999; Casey, 2001; Casey, Trainor, Orendi, et al., 1997; Durston et al., 2003; Rubia et al., 1999; Vaidya et al., 1998). For example, Vaidya et al. (1998) showed that children with ADHD had higher frontal activation and lower striatal activation than control children during response inhibition. Moreover, administration of methylphenidate led to improved performance associated with increased frontal activation for both groups and an increase in striatal activation for the children with ADHD. Durston et al. (2003), in part, replicated these findings in younger children with ADHD, showing that the striatum was the most robust region of difference between children with and without the disorder (see Color Plate 7).

However, a recent comprehensive review of the extant literature arrived at the following conclusions (Paloyelis, Mehta, Kuntsi, & Asherson, 2007). First, when comparing brain activity related to successful inhibitory control, there are large inconsistencies among studies in the location of group differences. Some studies revealed less activity for the ADHD group in the right prefrontal areas and anterior cingulate cortex, other studies revealed the difference to be lateralized actually on the left, and others revealed bilateral differences. There are also some inconsistencies in the direction of the differences, with some studies revealing more activity in these areas for the ADHD group. According to Paloyelis et al.'s (2007) review, the direction was found to be more systematic when comparing activity in tasks that tap error detection, attention processes, motor functions, and WM. In these cases ADHD groups showed lower activity; in attentional tasks the differences tended to be temporal and parietal; and in motor tasks the differences were over frontal areas. A further conclusion of their review was that the most consistent finding in the fMRI studies comparing ADHD participants and controls was lower activity in the striatum.

In a recent and interesting fMRI study, Rubia et al. (2009) compared brain activation among healthy, ADHD, and obsessive–compulsive disorder (OCD) groups of boys during a tracking stop task as well as a visual–spatial switching task. Results indicated that both patient groups shared brain dysfunction compared with healthy controls in right orbitofrontal (successful inhibition) and left dorsolateral prefrontal cortices (failed inhibition). Moreover,

Rubia et al. found that the right inferior prefrontal dysfunction was specific to the ADHD group during both tasks. In addition, during the switch task the ADHD group showed dysfunction in the left basal ganglia and cingulate gyri. Left inferior prefrontal dysfunction during the switch task was significant in the children with ADHD relative to controls but only marginally so in the OCD group.

In addition to the fMRI evidence related to inhibitory control, Cao et al. (2008) demonstrated reduced activations in frontal and parietal areas related to intrinsic (tonic) as well as phasic alertness. These children tended instead to recruit occipital areas and the cerebellum. This study also calculated the correlations between these activations and ADHD symptoms. It was found that for intrinsic alertness, the signal changes in the right precuneus were negatively correlated with scores of inattention symptoms; the more severe the inattentive symptoms, the less activation in the right precuneus in the ADHD group. This correlation was reduced when partial correlations were calculated to control for hyperactivity–impulsivity symptoms.

A recently flourishing direction of research compares brain activity at resting stage, in the already mentioned non-goal-directed default-mode network. This seems to also be a promising approach for studying brain dysfunction in ADHD. Castellanos et al. (2008) compared adults with ADHD and healthy control participants and found decreased functional connectivity between the anterior cingulate and precuneus–posterior cingulate cortex regions and between the precuneus and other default-mode network components, including the ventromedial PFC.

Abnormalities have also been demonstrated in the electrophysiological brain functioning of children with ADHD, by studies that use EEG–ERP techniques. These studies demonstrated that the behavioral abnormalities of children with ADHD in inhibitory control coincide with deviations in electrophysiological measures, such as the frontal N2 latency and amplitude (Dimoska, Johnstone, Barry, & Clarke, 2003; Overtom et al., 2003; Pliszka et al., 1997; Pliszka, Liotti, & Woldorff, 2000). Moreover, these deviations have been found to be affected and, at least partially corrected, by stimulant medication (i.e., methylphenidate; Broyd et al., 2005). Reduced activity over frontal areas (i.e., reduced N2 amplitudes) has also been documented in adolescents with ADHD (Albrecht, Banaschewski, Brandeis, Heinrich, & Rothenberger, 2005; McLoughlin et al., 2009; Wild-Wall, Oades, Schmidt-Wessels, Christiansen, & Falkenstein, 2009).

ERP studies have found smaller amplitudes of error-related negativity effects (Liotti, Pliszka, Perez, Kothmann, & Woldorff, 2005; see Color Plate 8), as well as smaller amplitudes in the positive component related to conscious error processing (O’Connell et al., 2009) in boys with ADHD compared with healthy control subjects. However, some studies, such as Wild-Wall et al.’s

(2009) study, have not found group differences in error detection (nor in post-error behavioral slowing or in the error-related ERP components).

As already mentioned, ERP studies demonstrate that deficits in ADHD might not be expressed at later processing stages but at early perceptual and attentional processes that occur within the initial 150 ms of stimulus information processing (Banaschewski & Brandeis, 2007). Children with ADHD exhibit increased early automatic attentional orienting (increased N1) before failing to allocate sufficient attentional resources in further processing stages (Brandeis, van Leeuwen, Steger, Imhof, & Steinhausen, 2002). Impaired attention has also been shown as a reduction of the P300 to cues preceding a target (Banaschewski et al., 2003; Brandeis, Banaschewski, et al., 2002). This attentional deficit temporally precedes inhibitory or executive control and has been found to predict subsequent performance (Banaschewski et al., 2003). ERP studies also support impaired response-execution processes in ADHD (Banaschewski et al., 2004). Moreover, motor preparation as reflected in the lateralized readiness potential is also reduced in children with ADHD (Steger, Imhof, Steinhausen, & Brandeis, 2000).

As for the functional implications of the structural and functional disruptions of neural circuitry in ADHD that have been summarized in this section, Nigg and Casey (2005) raised a particularly interesting approach. They suggested that the neuroimaging findings indicate that there might be a disruption in three different neural circuits in this syndrome: the circuits involved in predicting *what* may occur in a given context and *when* it may occur, as well as then detecting a violation of those predictions and evaluating the emotional significance of an event or situation. These are the frontostriatal, front-cerebellar, and the frontolimbic circuits, respectively.

INDIVIDUAL DIFFERENCES IN SELF-REGULATION

As was described in Chapter 4, many factors affect the development of self-regulation of a child. The interaction among all these factors is reflected in the vast individual differences found in this ability. In this section, the different factors shown to affect self-regulation are reviewed in the context of ADHD.

Early Environment

The literature about early environmental risk for ADHD has focused mainly on the links between this syndrome and pre- and perinatal exposure to teratogens, such as nicotine, alcohol, and stress (see the review in Kieling et al., 2008), as well as on deficient fetal environment, resulting in low birth weight and small head circumference at birth (Schlotz, Jones, Godfrey, & Phillips, 2008). This literature indicates that such early environmental adversities might

induce vulnerability for ADHD, probably in interaction with the genetic liability (Brookes et al., 2006; Kieling et al., 2008). However, the question of early environmental risk is much broader and should especially include early interactions of the infant with caregivers and the effects of family atmosphere, as was described in detail at the beginning of Chapter 4. Therefore, in the next section, Early Interactions, I focus on these subtopics.

Early Interactions

Because ADHD is usually diagnosed at the beginning of elementary school, or the earliest, at preschool age, very early interaction with caregivers cannot be directly assessed on children with ADHD. Therefore, prospective longitudinal studies on children at risk for this syndrome constitute a feasible and very useful approach.

Within the BIDS, it was possible to assess early interactions with parents at very young ages. The first lab assessment of this sort took place when the children in our sample were 7 months old. We studied the patterns of interaction between 7-month-old boys with their mothers and fathers during a warm-up and two play episodes (Landau et al., 2010), using a coding system developed by Kochanska (Kochanska et al., 1997, 1998). Interestingly, infants in the risk group did not differ from the comparison group in the rate of emission of need-related events. However, they received less adequate responsivity from their parents to their total needs, and specifically to negative emotions or distress, than the comparison group. Maternal psychopathology did not account for these findings.

These patterns of results were confirmed and strengthened when the interaction of the 7-month-old boys with their parents was analyzed in a different task (blocks) and by using a different coding method (Landau et al., 2009). Again, infants in the risk group did not differ from those in the comparison group in frequency of needing help or involving parents in play. Nonetheless, they received adequate responsivity from their mothers less often than infants in the comparison group.

These results are at least suggestive that already at a very early age, children in a family in which one of the parents has ADHD symptomatology are at risk of receiving less optimal parenting than infants in the general population. This less optimal parenting could increase a genetic liability to ADHD or even constitute an additional mechanism by which ADHD risk is transmitted from generation to generation within families.

Parenting and ADHD

Longitudinal studies have found that intrusive, rejecting, and coercive parenting during infancy is associated with ADHD and with later hyperactive

symptoms in preschool children. For example, E. A. Carlson, Jacobvitz, and Sroufe (1995) found that in early childhood, quality of caregiving more powerfully predicted distractibility, an early precursor of hyperactivity, than did early biological or temperament factors (see also Jacobvitz & Sroufe, 1987; and Morrell & Murray, 2003).

Studies that compare dyadic parent–child interactions in children with ADHD, and comparisons at preschool and school age, have usually found that mothers of children with ADHD behave more intrusively, demandingly, negatively, and aversively than mothers of comparison children. Moreover, these mothers tend to be less approving and encouraging and to express less positive affect than comparison groups of mothers (Anderson, Hinshaw, & Simmel, 1994; Buhrmester, Camparo, Christensen, Gonzalez, & Hinshaw, 1992; Campbell, 1995; DuPaul, McGoey, Eckert, & VanBrakle, 2001; Keown & Woodward, 2002; Mash & Johnston, 1982). However, these findings should be interpreted with caution, as in this type of study it is very difficult to tease out from the equation the contribution of the child’s own temperament and behavior, which might be partially *driving* and partially *driven by* maternal behavior.

In BIDS, Gutwein-Mendlinger (2009) examined the relationship between parental intrusiveness, parental structuring, and turn-taking behavior in parent–child interaction at 2 years of age, and self-regulation abilities at 3 years of age. We observed a subsample of our 2-year-old boys in free-play interactions with their mothers and coded those interactions in regard to measures of maternal intrusiveness, maternal structuring and turn-taking behavior.

Results emphasized the complex relation among temperament, parenting, risk for ADHD, and self-regulation. The degree of maternal intrusiveness at 2 years of age was significantly related to the child’s level of inhibitory control and marginally related to the child’s impulsivity level at 3 years of age. The degree of maternal structuring at 2 years of age was significantly related to the child’s inhibitory control, attentional focusing, and impulsivity at 3 years of age. The rate of turn taking during the interaction at 2 years of age was marginally significantly related to the child’s attentional focusing and inhibitory control at 3 years of age. Moreover, at the age of 2 years, beyond groups, significant correlations were found between the degree of maternal intrusiveness and the structure to the turn-taking rate during mother–child interaction.

Between-groups comparison revealed that mothers of children at risk for ADHD were more intrusive and used lower structuring when interacting with their 2-year-old boys, relative to mothers of children in the comparison group. Unexpectedly, no difference in turn-taking rate was found between the groups. In addition, boys in the risk group were found to be significantly lower on measures of inhibitory control and attentional focusing, and marginally

significant higher on the impulsivity measure, relative to boys in the comparison group.

An additional study in BIDS further investigated the interaction between risk and parenting, this time looking for the contribution of dopamine genes, parental ADHD symptoms, and maternal negative and positive parenting styles, to the prediction of symptoms of inattention and hyperactivity in 4.5-year-old boys (Auerbach et al., 2009). In our sample, the environmental contribution to ADHD symptomatology was stronger for symptoms of inattentiveness, whereas the genetic contribution seemed stronger for hyperactivity. Regression analyses were conducted, predicting ADHD inattention and hyperactivity–impulsivity scores (measured with the ADHD Rating Scale–IV; DuPaul et al., 1998; completed by parents when the child was 4.5 years old), by paternal and maternal ADHD symptoms (measured with CAARS; Conners et al., 1999; completed when the child entered the study), positive and negative parenting styles (measured with the Parent’s Report; Dibble & Cohen, 1974; completed when the child was 4.5 years old), and the child’s dopamine genetic risk score (which combined the *DRD4* and *DAT1* genotypes risk).

Results showed that both negative and positive maternal parenting styles, together with maternal ADHD symptomatology, were predictive of inattentive symptoms. Although maternal negative parenting style was also a significant predictor for hyperactivity–impulsivity symptoms, cumulative dopamine risk contributed most heavily to the prediction of these symptoms. In this study, the interaction effects of Genetic Liability \times Parenting were not found to be significant.

Home Environment Effects on Self-Regulation

As was mentioned in Chapter 4, a chaotic home atmosphere is associated with elevated behavior problems, limited attentional focusing, and reduced ability to understand and respond to social cues in children (Coldwell et al., 2006; Dumas et al., 2005). In the BIDS, home CHAOS questionnaires were filled out by parents when the children were 4.5 years old. We found that this measure was correlated with concurrent scores of ADHD symptoms of the child assessed with the DuPaul et al. (1998) scale. It is more interesting to note that home chaos was found to mediate the relation between paternal symptoms of ADHD (as measured at entrance to the study, i.e., when the child was born) and the child’s symptoms of ADHD at 4.5 years of age. The direction of this mediating effect was that symptomatology in the child was highest when there was both high symptomatology of the father and a highly chaotic home environment. However, when the levels of home chaos were low, parental symptoms had no effect on the child’s symptoms (Mizrachi, 2009).

Temperamental Risk for ADHD

As summarized by Nigg et al. (2004), the temperament domains that emerge as correlates to externalizing behaviors in general, and ADHD symptoms in particular, are negative emotionality, poor self-regulation, and impulsivity. Difficulty in the regulation of anger has been associated with ADHD from preschool to adulthood (Douglas & Parry, 1994; Mash & Johnston, 1982; Ramirez et al., 1997). In Martel and Nigg's (2006) study, EC and reactivity were the dimensions most strongly related to teachers' ratings of ADHD. In BIDS, too, EC measured during toddlerhood positively predicted DSM ADHD symptoms at the ages of 4 and 7 years.

In addition, as mentioned at the beginning of this chapter, high activity levels at preschool have been found to predict early onset and persistence of ADHD (Sonuga-Barke et al., 2005). However, the relative relevance of this domain might decrease with age (Nigg et al., 2004).

An interesting model was recently suggested and tested by Martel, Nigg, and von Eye (2009) in regard to temperamental–personality traits and ADHD symptoms. They argued that top-down control, including traits such as conscientiousness and EC, are more strongly related to symptoms of inattention–disorganization, whereas reactive aspects of temperament and traits that reflect relatively more bottom-up processing, including negative and positive emotionality and hostility, are more strongly related to hyperactivity–impulsivity. Martel et al. (2009) found evidence confirming this idea in a sample of school-aged children and adolescents.

Genetic Risk for ADHD

Family, twin, and adoption studies provide compelling evidence that genes play a strong role in mediating susceptibility to ADHD (Faraone et al., 2005). Estimates of heritability in this syndrome range from 60% to 91% (Goodman & Stevenson, 1989; F. Levy et al., 1997; Thapar et al., 2006).

Probably the most extensively studied gene variation in this context is the *DRD4* 7-repeat allele. The original reports of an association between this gene and ADHD were found in the 1990s (Faraone et al., 1999; LaHoste et al., 1996), and many additional studies have been carried out since then. Some recent meta-analyses have confirmed this association (Faraone et al., 2005; Li et al., 2006), although there are also contradicting findings (Mill et al., 2002). There is some evidence that association with ADHD is more profound for cases of comorbidity with conduct disorder (Holmes et al., 2002).

DRD4 has been also associated with cortical development. Possession of the *DRD4* 7-repeat allele was associated with a thinner right orbitofrontal–inferior prefrontal and posterior parietal cortex. This overlapped with regions

that were generally thinner in participants with ADHD compared with controls (Shaw, Gornick, et al., 2007). It is interesting to note that this study revealed that participants with ADHD who carried the *DRD4* 7-repeat allele had a better clinical outcome and normalization of the right parietal cortical region.

Initially, the association between ADHD and *DRD4* was thought to be through the role dopamine plays in attentional functioning, but studies that used laboratory measures of attention failed to confirm such an association. In contrast, Fossella et al. (2002) and Swanson, Oosterlaan, et al. (2000) found poorer attentional performance for those individuals without the 7-repeat allele.

Diamond (2005, 2007) recently suggested the interesting hypothesis that *DRD4* may be more involved in ADD (i.e., the inattentive subtype) and may be related to prefrontal functioning but not in the subtypes that involve hyperactivity.

With regard to the association between *DAT1* and ADHD, it seems that the 10R genotype is related to increased risk for ADHD (Cook et al., 1995; Waldman et al., 1998). However, recent meta-analytic studies of *DAT1* have indicated that the findings are inconsistent. Li et al. (2006) found no association between 10R *DAT1* and ADHD, and Yang et al.'s (2007) meta-analysis reviewed 18 publications and concluded that there is a significant but small association between this polymorphism and ADHD. Waldman et al. (1998) found that the association of 10R *DAT1* was with hyperactive-impulsive symptoms of ADHD but not with inattentive ones. As mentioned previously, Diamond (2005, 2007) therefore proposed a differentiation between ADD and ADHD, according to which this gene (i.e., *DAT1*) is involved in ADHD but not in ADD and relates to striatal functioning rather than to prefrontal functioning.

In the BIDS, the relation between *DAT1* and ADHD has been replicated (Auerbach et al., 2010). In the 4.5-year-old children, an association was found between 10/10 *DAT1* and hyperactivity-impulsivity symptoms but not with the inattentive symptoms. Specifically, those children with the 10/10 *DAT1* risk genotype had significantly higher ADHD total scores and hyperactivity-impulsivity scores than children without that genotype. Moreover, in this study the *DAT1* effect also interacted with the 7-repeat allele of the *DRD4* gene. We (Auerbach et al., in press) found that a child who possessed the *risk alleles of both genes* had higher levels of ADHD symptomatology, in particular, symptoms of hyperactivity-impulsivity, at age 4.5 years than children who possessed any other combinations of the variants.

Additional candidate genes implicated in ADHD include genes related to dopamine as well as serotonin, for example, *DRD2*, *DRD3*, *DRD5*, *MAOA*, *COMT*, *DBH*, *5-HTT*, *HTR1B*, and *SNAP-25* (Faraone et al., 2005; see the review of genetic involvement in ADHD and a more extensive list of candidate genes in Durston, de Zeeuw, & Staal, 2009).

Gene × Environment Interactions in ADHD

In Chapter 4, I stressed the increasing interest in the interactions between genes and environment and the increasing empirical evidence for the importance of such interactions in the development of self-regulation. Here we illustrate this topic through specific studies that have demonstrated interactions of this sort in ADHD, despite the fact that longitudinal twin studies indicate that what is stable across development from parent-reported ADHD symptoms is mostly genetic (Price et al., 2005).

Environmental influences on genetic liability have been studied in ADHD in the context of dopamine dysfunction (see the review by Swanson et al., 2007). The effects of prenatal exposure to tobacco through maternal smoking were studied in the context of ADHD by Kahn, Khoury, Nichols, and Lanphear (2003). This study evaluated both maternal smoking and the *DAT* gene. It was found that child hyperactivity–impulsivity and oppositional behaviors were associated with a *DAT* polymorphism but only when the child also had exposure to maternal prenatal smoking. This line of research was somewhat extended in a twin study by Neuman et al. (2007). They found that gene–environment interactions modulated the risk for the ADHD-C subtype. Specifically, the strength of the associations between polymorphisms of the *DAT1* or *DRD4* genes and ADHD-C subtype were increased if the mother reported smoking during her pregnancy with the twins. However, the association found in this study with the dopamine transporter gene was with the 440 allele instead of the 480 allele, which was found to be the risk factor in Kahn et al.'s (2003) study and is usually considered the risk allele in candidate-gene studies of ADHD.

An additional teratogen that has been studied in this context is maternal alcohol consumption during pregnancy. Brookes et al. (2006) investigated Gene × Environment interaction between *DAT1* and maternal use of alcohol as well as tobacco during pregnancy in two different populations (i.e., an English and a Taiwanese sample). They found an interaction between the *DAT1* genotype and maternal use of alcohol during pregnancy, suggesting that *DAT1* moderates the environmental risk. Contrary to the above-mentioned studies, they did not find such an interaction in the case of smoking.

Environmental influences are not restricted to toxic exposure but of course also include psychosocial risk factors. Laucht et al. (2007) investigated whether psychosocial adversity moderated the effect of genetic variation in *DAT1* on ADHD symptoms in adolescents from a high-risk community sample that was followed longitudinally. Their definition of psychosocial adversity included marital discord, parental psychopathology, low maternal education, single parenthood, poor coping skills of a parent, and so forth. They found that psychosocial adversity moderated the impact of the *DAT1* gene on the

development of ADHD symptoms, revealing a *DAT1* effect only in those individuals exposed to this environmental adversity. Specifically, the results showed that 15-year-olds who grew up in greater adversity and were homozygous for one of the two risk alleles of *DAT1* that the authors studied exhibited significantly more inattention and higher hyperactivity–impulsivity than those with other genotypes or living in less adverse family conditions. Interestingly, they did not find significant main effects of genetic variants of *DAT1* on ADHD symptoms.

ADHD DISREGULATION IN SOCIAL CONTEXTS

As readers saw in Chapter 5, the development of self-regulation has important implications for a child’s functioning in social contexts. In this section, I review evidence that supports this relation in children with ADHD.

Compliance in Children With ADHD and in Children at Risk

Children with ADHD tend to show less compliance and be more negativistic during interaction with their mothers (DuPaul et al., 2001; Johnston & Mash, 2001). Compliance difficulties among children with ADHD can be explained by their significant deficit in inhibition control, as well as the nonoptimal interaction patterns they share with their mothers, or a combination of the two.

These possibilities were tested in BIDS, when the children came to the laboratory at the age of 3 years (Faroy, 2008). The children’s actual compliance behavior in *do* and *don’t* situations was measured (“toy cleanup” and “attractive toys prohibition,” respectively). The hypotheses were that the children at familial risk for ADHD would present less committed compliance and more situational compliance than the children in the comparison group in the more challenging situation. Specifically, in the *do* context the risk group would show more defiant behavior than the comparison group; mothers of children at risk would express lower levels of adequate responsiveness to their children’s signals and more control and intrusive behaviors than the mothers of children in the comparison group; also, there would be less shared positive affect in the mother–child interactions of the risk group.

Clear differences were found between the two research groups. Children at familial risk for ADHD displayed more situational compliance and less committed compliance in the *do* context than the children in the comparison group. However, no differences were found in the frequency of the defiant form of noncompliance between the groups. Mothers of children at risk for ADHD were more controlling and intrusive during free interaction and the *do* compli-

ance context as hypothesized but were also more adequately responsive to distress signals in the *don't* compliance context, contrary to the expectation. Moreover, there were no differences between the groups in shared positive affect. Faroy (2008) suggested a transactional interpretation for these findings: On the one hand, less committed compliance evokes more supervision from the mothers in the risk group; on the other hand, or possibly in interaction with the first pathway, the mother's intrusive and controlling behaviors may overstimulate the child and disrupt the development of self-regulation processes in children at risk.

Social Competence in ADHD

More than 20 years of research clearly indicates that children with ADHD often have conflicts with adults and peers and suffer from unpopularity, rejection by peers, and a lack of friendships (Nijmeijer et al., 2008). In social interactions they tend to show more hostile, disruptive, and impulsive behavior and have been characterized as talkative, loud, impulsive, commanding, and aggressive (Madan-Swain & Zentall, 1990). These poorly regulated social interactions have a heavy impact on their social partners, and therefore children with ADHD are often rejected by their peers (Hinshaw & Melnick, 1995), even after very short exposure (Erhardt & Hinshaw, 1994). For example, in a classic study by Pelham and Bender (1982), children with ADHD showed a bossy, aggressive interaction style and were already rejected by peers after 20 min of interaction. On sociometric measures, children with ADHD consistently receive lower scores on social preference and higher scores on social impact, they are more often in the rejected social status category, and they also have fewer dyadic friends (Hoza et al., 2005). Furthermore, in a recent study, Mrug et al. (2009) found that the variables that best discriminated between children with ADHD and their classmates were peer rejection and negative imbalance between given and received liking ratings (i.e., children with ADHD liked others more than they were liked).

It has been found that aggressive and noncompliant behaviors are strong predictors of peer rejection in children with ADHD (Erhardt & Hinshaw, 1994; Hinshaw & Melnick, 1995). Furthermore, co-occurrence with conduct disorder results in greater symptoms of both ADHD and conduct disorder and a poorer outcome (Thapar et al., 2006).

However, it is important to point out that children with the predominantly inattentive ADHD subtype are also rejected by peers (Hodgens, Cole, & Boldizar, 2000). It is possible that in these children anxiety, shyness, and withdrawal may all have a negative impact on their social functioning by diminishing the frequency of interaction with others.

Empathy and Conscience in ADHD

According to Barkley (1990, 1997), the deficit in inhibitory control explains cognitive difficulties and causes problems in self-regulation of affect. His model predicts that children with ADHD will also show (a) decreased empathy, (b) increased emotional responsivity to provoking situations, (c) diminished ability to anticipate emotional reactions to future events, (d) decreased capacity to regulate emotional states during goal-directed behavior, and (e) a greater reliance on externally based stimuli to provide the motivation and arousal needed to persist during goal-directed actions. Braaten and Rosen (2000) examined one of the hypotheses that emanated from Barkley's predictions: that boys with ADHD have a decreased ability to act empathically relative to those without ADHD. Empathy was measured by an empathy response task and through self- and parent-reports of emotion. On the empathy response task, children responded verbally to fictitious stories. Results revealed that boys with ADHD were less empathic than boys without ADHD. Boys with ADHD less frequently matched the emotion they identified in the character with the one identified in themselves, and they gave fewer character-centered interpretations in their descriptions of the character's emotion. Parent-report data revealed that boys with ADHD exhibited more behavioral manifestations of sadness, anger, and guilt than did boys without ADHD. Braaten and Rosen's results suggested that children with ADHD may be able to self-regulate their positive emotions but not their negative emotions, relative to the control group, which was comparable in variables such as age, verbal intelligence, and socioeconomic background.

Academic Competence and Achievement in ADHD

For many years, it has been known that ADHD is associated with greater risks for low academic achievement, poor school performance, retention in grade, school suspensions and expulsions (Barkley, 1990, 1997). These relations have been repeatedly confirmed. For example, in a population-based study, Barbaresi, Katusic, Colligan, Weaver, and Jacobsen (2007) compared the long-term school outcomes for children with and without ADHD. They compared the outcomes for 370 children with ADHD with those for 740 control participants from the same birth cohort, matched by gender and age. When the participants were about 18 years old, their full school records were inspected retrospectively. It was found that median reading achievement scores at age 12.8 years (expressed as a national percentile) were significantly lower for the ADHD group, with no gender differences. Moreover, the ADHD group had a higher percentage of days absent, was 3 times more likely to be retained a grade, and was 2.7 times more likely to drop out before high school graduation. The

data indicated that the association between ADHD and impaired school function increased as the children progressed from elementary school through high school.

Academic achievement outcome is especially compromised in those ADHD children who show EF impairments. This was demonstrated by Biederman et al. (2004), who compared four groups of children and adolescents: (a) control participants without EF deficits, (b) control participants with EF deficits, (c) ADHD participants without EF deficits, and (d) ADHD participants with EF deficits. They found that among the participants with ADHD, EF deficits increased the risk for grade retention and lower academic achievements. This relation was found even after controlling for gender, age, IQ, socioeconomic status, and learning disabilities. In contrast, they did not find evidence that EF deficits affected the functional outcome in the control groups.

There are firm indications that methylphenidate medication can markedly improve the academic outcomes of children with ADHD. Scheffler et al. (2009) analyzed data from a national American survey on children in kindergarten to fifth grade. They found that medicated children with ADHD had a mean mathematics score that was 2.9 points higher than the mean score of unmedicated peers with ADHD. Moreover, children who were medicated for a longer duration had a mean reading score that was 5.4 points higher than the mean score of unmedicated peers with ADHD. These results are consistent with a previous study by Hechtman et al. (2004) that demonstrated, in addition, that there was no advantage on any measure of academic performance or emotional status for the combination of medication combined with intensive multimodal psychosocial intervention, including academic assistance and psychotherapy, over methylphenidate alone. They found that significant improvement occurred across all the treatment groups and was maintained over 2 years.

SUMMARY

This chapter has illustrated the ideas presented in the previous chapters of this book, using one example of a developmental syndrome involving deficits in self-regulation, that is, ADHD. First, I described the nature of the self-regulation problems in this syndrome, including the developmental consequences of the deficit, which includes higher risk in the long run for low academic achievement, poor peer and family relations, anxiety and depression, aggression, conduct problems and delinquency, substance experimentation and abuse, driving accidents, and so forth. Second, I presented evidence in regard to specific deficits in ADHD within each of the underlying neurocognitive and neuromotivational mechanisms that subservise self-regulation, and these deficits have been found to be consistent with findings at the level of structural and

functional brain mechanisms. Third, I reviewed the factors that seem to contribute to individual differences in the development of self-regulation (e.g., parenting, genetics, $G \times E$ interactions) and showed their relevance in the case of ADHD. Last, I illustrated the specific implications of deficits in self-regulation within social and academic contexts in this syndrome.

The BIDS longitudinal study served to illustrate many of the above issues. The strength of this study is that it followed children from birth, identifying early risk factors, hoping to delineate the developmental pathways for this disorder. As readers have seen in this chapter, the main contributions of this study were in demonstrating the very early effects of the biological endowment of the child—including neonatal aspects such as neurodevelopmental maturity—persistent temperamental traits, and individual genotype. Such early characteristics of the infant predicted ADHD symptomatology at preschool age and lower performance in tasks that require inhibition and executive control.

Another important aspect of the BIDS findings that should not be overlooked is that parents not only contribute their genetic endowment to their offspring but also provide their rearing environment. When a parent has self-regulation deficits, this clearly affects the early parent–child interactions, as well as the overall home atmosphere. Parental characteristics and genetics might have different contributions depending on the type of outcome. In other words, risk factors may have different weights for different aspects of development. Specifically regarding ADHD symptomatology, BIDS demonstrated that the environmental contribution was stronger for symptoms of inattentiveness, whereas the genetic contribution seemed stronger for hyperactivity. As mentioned, we did not find indices for $G \times E$ interactions. More research with larger samples will be required to strengthen these findings.

7

FOSTERING SELF-REGULATION

As seen in Chapter 4, although the brain networks related to self-regulation are heavily shaped by genes, they can also be influenced by experience. In addition to the everyday life experiences provided by the caretaking and educational environments, it is possible that specific interventions can have a positive effect and foster the development of self-regulation.

In this chapter, I review recent accumulating evidence in regard to the influence of computerized training (Rueda, Rothbart, et al., 2005), as well as curriculum-based interventions (Bierman & Erath, 2004; Diamond, Barnett, Thomas, & Munro, 2007; Kam, Greenberg, & Kusche, 2004; Riggs, Greenberg, Kusche, & Pentz, 2006) designed to improve self-regulatory skills in developing children. The overall number of children who collectively participated in the reviewed studies is about 2,400. Different training programs approach self-regulation at different conceptual levels. Some of them focus directly on the underlying mechanisms that enable self-regulation (reviewed in Chapter 2), and in some cases, the interventions seem to have actually changed the underlying networks in ways that might lead to extensive generalization of the beneficial effect (Posner & Rothbart, 2005). Other training programs approach self-regulation in a more applied, emotion- and social relations–related sense.

The currently reviewed training literature is summarized and organized in Table 7.1. I have limited the review to studies of children. I have also limited the review to interventions that target attention, executive function (EF), and self-regulation. Additional rich literature can be found on interventions that target specific skills (e.g., literacy). Additional coverage of the brain networks involved in such school subjects and the plausibility of influencing those networks by specific training can be found in the groundbreaking book by Posner and Rothbart (2007), *Educating the Human Brain*, which was published as part of the American Psychological Association's Human Brain Development series.

Most of the intervention studies focused on preschoolers. This target age is of special importance because EF is more strongly associated with school readiness than is IQ or entry-level reading or math skills (Blair & Razza, 2007). Moreover, working memory (WM) and inhibition predict math and reading scores in preschool through high school (Blair & Razza, 2007; Bull & Scerif, 2001; Gathercole et al., 2007). Still, other training has been carried out during the elementary school years. It is not yet clear whether targeting preschoolers is indeed more efficient.

Many of the studies were designed for typically developing children. Some more specific intervention studies were tailored for children with conditions such as attention-deficit/hyperactivity disorder (ADHD; deBeus, Ball, deBeus, & Herrington, 2004; Klingberg et al., 2005; Klingberg, Forsberg, & Westerberg, 2002b; Shalev, Tsal, & Mevorach, 2007; Sohlberg & Mateer, 2001; C. Stevens, Fanning, Coch, Sanders, & Neville, 2008).

Furthermore, there is recent intriguing evidence concerning the efficacy of interventions based on training parents that seek to improve the attentional skills of their children (Fanning, Paulsen, Sunbord, & Neville, 2007). This idea is consistent with what was presented in Chapter 4 about the critical role of parents in the development of children's self-regulatory skills. Interestingly, a study by Bakermans-Kranenburg, van IJzendoorn, Pijlman, Mesman, and Juffer (2008) found that only those children with the 7-repeat allele of the *DRD4* gene showed the influence of a parent training intervention.

How efficient these interventions are in the long run, in regard to both typically developing children and children showing specific deficits in self-regulation, is still an open question. A further intriguing question for future research is how training interacts with medication to improve self-regulation in the case of syndromes such as ADHD.

TRAINING OF ATTENTION AND EXECUTIVE CONTROL

Several different approaches to training of attention and executive control can be found in the literature. I focus first on training based on comput-

erized technology. These training programs are usually presented to the participant as *computer games*.

Computerized Training

The first indication for the feasibility of improving attention by computerized training was obtained with monkeys. Rhesus monkeys can be trained to use a joystick to track objects (Rumbaugh & Washburn, 1995). After substantial training they can perform Stroop-like tasks (Washburn, 1994). Informal observations made by the researchers suggested that this kind of executive training influenced not only the monkeys' cognition but also their emotional regulation such that they became more social and less aggressive (Posner & Rothbart, 2007).

Posner and colleagues created a set of computerized training tasks, adapted from the original ones used for monkeys (Rueda, Posner, et al., 2005; Rueda, Rothbart, et al., 2005). This intervention was designed to train attention in general, with a special focus on executive control in children of 4 years of age and older.

To test its effectiveness, 4- and 6-year-old children played with these training computerized games for 5 days, 30 to 40 min each time. Control children of the same ages viewed interactive videos instead. Strong improvement in executive attention (i.e., conflict score that was obtained by subtracting congruent trial reaction time [RT] from incongruent trial RT) and intelligence (as measured by the Kaufman Brief Intelligence Test) was found from ages 4 to 6 years. Both 4- and 6-year-olds showed more mature performance after the training than did the control groups. This improvement was also found in event-related potentials (ERPs; mediofrontal N2) recorded from the scalp during Attention Network Test performance (Rueda et al., 2007).

Recently, Rueda, Checa, and Santonja (2008) replicated and extended these results. In their study, preschoolers went through 10 training sessions instead of five, some additional computerized games were added to the original battery, the pre- and post-battery included a "hot executive" task, and the lasting effects of the training were tested in a short-term (2 months) follow-up. The findings of Rueda, Rothbart, et al. (2005) were replicated in that the attention training had a beneficial effect on brain activation during performance of the conflict task and on the score of the abstract reasoning subscale of the Kaufman Brief Intelligence Test. They did not find an effect of training on the behavioral performance (Rueda et al., 2008). They found some marginal evidence that the effect of training on the intelligence score persisted 2 months after the intervention. Moreover, the trained children showed increased postintervention performance in the Children's Gambling Task (Kerr & Zelazo, 2004), whereas children in the control group did not. This finding is consistent with

TABLE 7.1
 Summary of Attention, Executive Function (EF), and Self-Regulation Training Studies Reviewed in Chapter 7

Name	Target	Intervention length	Sample type	Sample size	Outcome measures	Outcome timing	Study
Attention training	Executive attention	Five 45–60-min sessions	Normal developing preschoolers; training group + control	M	Computerized Flanker + ERP; Intelligence test (K-BIT); Parental report of Temperament (negative affect tendency); ERPs (evoked brain activity) during ANT	At end of intervention	Rueda, Rothbart, et al. (2005)
Attention training	Executive attention	Ten 35-min sessions	Normal developing preschoolers; training group + control	M	Computerized Flanker + ERP; Intelligence test (K-BIT); Delay of gratification	At end of intervention + follow-up 2 months later	Rueda et al. (2008)
CPAT	Sustained attention, selective attention, orienting of attention, and executive attention	Eight weeks, two 60-min sessions per week	ADHD, 6–13 years; training group + control	M	Academic grade-suitable tests of passage copying, math exercises, and reading comprehension; Parents' rating scale of inattention	At end of intervention (within 2 weeks)	Shalev, Tsai, and Mevorach (2007)
RoboMemo	WM	5 weeks, daily 40-min sessions	ADHD, 7 to 12 years; training group + control	L	Four EF tasks: (a) span-board—visuospatial WM, (b) Digit-span-verbal WM, (c) Stroop interference response inhibition, (d) Raven's Colored Progressive	At end of intervention + follow-up 3 months later	Klingberg et al. (2005)

FastForWord	Auditory attention	6 weeks, daily 100-min sessions	SLI + normal developing controls, 6–9 years	M	ERP measure of selective auditory attention–CELF-3 (a standardized language assessment)	At end of intervention	C. Stevens, Fanning, Coch, Sanders, and Neville (2008)
Neuropsychological rehabilitation							
APT	Visual and auditory focused, sustained, alternating, and divided attention	5 weeks of 120-min sessions, 4 days per week	ADHD 7–13 years; no controls	S	Measures of attention; Academic efficiency; Parent-reported measures of attention	At end of intervention	Williams (1989) as cited in Sohlberg and Mateer (2001)
APT + problem-solving strategies	Visual and auditory focused, sustained, alternating, and divided attention	18 weeks, two weekly 60-min sessions	ADHD, training group + controls; school-based sample	M	Measures of visual and auditory attention; Qualitative interviews with teachers	At end of intervention	Semrud-Clikeman et al. (1999)
Pay Attention!	Visual and auditory focused, sustained, alternating, and divided attention	8 weeks, two weekly 30-min sessions	ADHD 7–11 years; training group + controls	S	Coding, Digit Span, and Mazes subtests of the WISC–II; tests of sustained visual and auditory attention; Visual–spatial ability; Academic efficiency (age- and grade-appropriate arithmetic problems); Parent and teacher questionnaires	At end of intervention	Kerns et al. (1999)

(continues)

TABLE 7.1
 Summary of Attention, Executive Function (EF), and Self-Regulation Training Studies Reviewed in Chapter 7 (Continued)

Name	Target	Intervention length	Sample type	Sample size	Outcome measures	Outcome timing	Study
PIE	EFs: selective attention, inhibitory control, WM, planning and cognitive flexibility	16 weeks, twice a week, 30–40-min sessions	3–5 years, low SES individual cognitive training + iron, folic acid and environmental intervention vs. + iron, folic acid and environmental intervention without cognitive training	EL	Selective attention; Corsi blocks; Tower of London; FIST; A-not-B; Day–Night Stroop; Three–Four colors; card sorting (spatial and color); Delayed alternation	Pre- and post-intervention	Colombo and Lipina (2005)
PPEC	EFs: selective attention, inhibitory control, WM, planning and cognitive flexibility	16 weeks, twice a week, 30–40-min individual sessions vs. 30–50-min group sessions	3–5 years, low-SES preschoolers; individual vs. group cognitive training; both groups also received iron and folic acid	EL	Selective attention; Corsi blocks; Tower of London; FIST	Pre- and post-intervention	Martelli et al. (2007); Segretin et al. (2007)

TABLE 7.1
 Summary of Attention, Executive Function (EF), and Self-Regulation Training Studies Reviewed in Chapter 7 (Continued)

Name	Target	Intervention length	Sample type	Sample size	Outcome measures	Outcome timing	Study
Head Start REDI (Preschool PATHS)	EFs and school readiness	1 prekindergarten year	4-year-old children from Head Start + controls	L	Measures of EF (backward word span, peg tapping, DCCS); Walk-a-line slowly task; Examiners' rating of the child's capacity to sustain attention during the assessment; School Readiness (tests for language and emergent literacy) and teacher + observer ratings of social competence and aggressive-disruptive behaviors	At the end of the intervention	Bierman et al. (2008)
ICPS	Conflict resolution—interpersonal skills	1 or 2 school years; 12 weeks of intervention in each year	Normally developing kindergarten and 1st graders	L	Teachers rating Preschool Social Behavior Scale (PSBS); Teachers rating Hahnemann Behavior Rating Scale (HBRS)	At end of intervention + follow-up until 4th grade	Shure (1993)

ICPS	Conflict resolution— interpersonal skills	2 school years; 12 weeks of intervention in each year	Low SES nursery and kindergarten children; Four groups: 2 years of ICPS; ICPS in nursery school only; ICPS in kindergarten only; or no-instruction control	L	Teachers rating PSBS; Teachers rating HBRS	At end of intervention	Shure and Spivack (1982)
ICPS	Conflict resolution— interpersonal skills	2 school years; 4 months, twice a week	Low SES kindergarten and 1st graders; trained 2 years, kindergarten and first grade; trained 1 year, kindergarten or first grade	L	Teachers rating PSBS; Teachers rating HBRS	At end of intervention	Boyle and Hassel-Walker (2008)

Note. Sample size: small (S) = < 15 per group; medium (M) = 16–25 per group; large (L) = > 26 per group; extra-large (EL) = > 100 per group. ERP = event-related potential; K-BIT = Kaufman Brief Intelligence Test; CPAT = computerized progressive-attentional training; ADHD = attention-deficit/hyperactivity disorder; WM = working memory; DSM-IV = *Diagnostic and Statistical Manual of Mental Disorders* (4th ed.); SLI = specific language impairment; APT = attention process training; WISC-III = Wechsler Intelligence Scale for Children (3rd ed.); PIE = Programa de Intervención Escolar; SES = socioeconomic status; FIST = flexible item selection task; PPEC = Programa Piloto de Estimulación Cognitiva; PATHS = promoting alternative thinking strategies; CBCL = Child Behavior Checklist; DCCS = dimensional change card sort; ICPS = “I Can Problem Solve.”

the role attributed to executive attention in affective self-regulation in Posner's model—training of attention transferred to performance on tasks involving affective (motivationally relevant) regulation.

These important pioneer studies demonstrated that a short amount of specific computerized training can modify targeted cognitive processes such as executive attention and the activity at its relevant brain substrates and can even generalize to some intelligence measures. That said, it should be noted that the effects are of moderated sizes, as have been the samples tested so far. Moreover, the long-run effectiveness has not yet been tested beyond 2 months.

Additional evidence that some aspects of attention can be trained by using computerized games comes from intervention attempts in cases of attention impairments. For instance, Shalev et al. (2007) developed a computerized progressive-attentional training program for children with ADHD. This training program is composed of four sets of structured tasks meant to activate sustained attention, selective attention, orienting of attention, and executive attention. The tasks include a computerized continuous performance task, a conjunctive search task, a combined orienting and flanker task, and a shift Stroop-like task. In their study, they tested the efficacy of this training on a sample of twenty 6- to 13-year-old children with ADHD who were assigned to the experimental group and received the computerized progressive-attentional training program sessions twice a week over an 8-week period. Shalev et al. compared them with 16 age-matched control children with ADHD who participated in sessions of the same frequency, length, and format, except that instead of performing the training tasks, they played various computer games during the session. According to the authors, the children who received the computerized progressive-attentional training program showed a significant improvement in measures of reading comprehension and paragraph copying. Moreover, they found a significant reduction in parents' reports of inattentiveness. In contrast, no improvements were observed in the control group.

It is still unknown whether this kind of training could also have a beneficial effect for normally developing children because this has not been tested. However, based on the aforementioned results of Rueda and colleagues (Rueda et al., 2008; Rueda, Posner, et al., 2005; Rueda, Rothbart, et al., 2005) in preschoolers, such training could be possible, and the question is, what would be the optimal time frame? In other words, what is the window of opportunity for benefiting from such training?

Another example of computerized training of attention relates to auditory attention instead of visual. The FastForWord program was developed for children with specific language impairment and targets oral language skills through intensive, computer-based activities with acoustically modified speech and nonspeech sounds (Tallal, 2004). The program is based on the theory that language deficits arise from more basic perceptual deficits in processing and

specifically in processing sounds that are separated by brief durations or are themselves short in duration (Tallal, 2004; Tallal, Merzenich, Miller, & Jenkins, 1998). Children who receive the FastForWord intervention typically train with the software for 100 min per day, 5 days per week, for 4 to 6 weeks. Recently, C. Stevens et al. (2008) examined whether 6 weeks of such high-intensity training also influences neural mechanisms of selective auditory attention. Twenty children received computerized training, including eight children diagnosed with specific language impairment and 12 children with typically developing language. An additional 13 children with typically developing language received no specialized training but were tested and retested after a comparable time period to control for maturational and test–retest effects. Before and after training, children completed standardized language assessments and an ERP measure of selective auditory attention. Relative to the nontrained control group, trained children showed larger increases in the effects of attention on neural processing following training. The enhanced effect of attention on neural processing represented a large effect size (Cohen's $d = 0.8$) and was specific to changes in signal enhancement of attended stimuli. The ERP effects were found both for the specific language impairment children and the normally developing ones. This suggests, consistent with Rueda, Rothbart, et al. (2005), that the neural mechanisms of attention might be trainable. However, the children's gains in receptive language scores and electrophysiological measures of selective auditory attention were found immediately following the FastForWord training. It is unclear whether either effect persisted afterward because there was no longitudinal follow-up. In some of the longitudinal studies that followed children with dyslexia after the end of FastForWord training, it was found that standard scores on language assessments regressed back toward preintervention levels by the end of the second follow-up year (Hook, Macaruso, & Jones, 2001).

Noncomputerized Training

One example of a commercially available noncomputerized attention-training package is the Attention Process Training program (APT; Sohlberg & Mateer, 1987, 2001). This cognitive rehabilitation program is designed to remediate attention deficits in individuals with brain injury and is motivated by the assumption that discrete components of attention can be selectively rehabilitated through targeted stimulation. The APT materials consist of a group of hierarchically organized tasks that exercise different components of attention commonly impaired after brain injury, including sustained, selective, alternating, and divided attention. The program tasks place increasing demands on complex attentional control and WM systems. The training exercises include auditory attention tapes such as listening for descending number

sequences, detecting targets in the presence of distractor noise, and so forth. Some of the tasks combine auditory and visual activities.

The improvement in brain-injured patients following attention training has been found not only on measures of attention, memory, and learning but also on levels of independent living and returning to work (for a review of these studies, see Sohlberg & Mateer, 2001).

There are several reports of such attention training having positive effects in children with developmental attention disorders. D. J. Williams (1989) examined the effectiveness of attention training by using an adaptation of the APT on six children (ages 8–13 years) who were diagnosed with ADHD. He found significant improvements on the training materials as well as on untrained measures of attention. Moreover, Semrud-Clikeman et al. (1999) tested the efficacy of APT training combined with training in problem solving within a school setting, on children who were identified as having problems in attention and completing work. The children in the treatment group improved in visual cancellation and auditory attention. In the visual cancellation task, the ADHD group that received treatment performed more poorly than did the normal controls prior to treatment but did not differ from them following treatment. In the test of auditory attention, there was a significant improvement in the performance of the treated ADHD children following intervention, but there was no change in the ADHD controls. In addition, the authors commented informally that qualitative interviews with teachers revealed that children who had undergone the treatment seemed more attentive and showed improvement in completing tasks in class.

However, because the APT was developed for adults, many of the tasks were not engaging for children, relied on skills that were not expected to be well developed in younger children, or both. Therefore, K. A. Kerns, Eso, and Thomson (1999) developed a new version of the training adapted for younger children (“Pay Attention!”). The materials in this training program are based on the same hierarchical model of attention as the APT, which includes sustained, selective, alternating, and divided attention. To make the materials more engaging to young children, they were made more colorful and visually interesting, and they focused on familiar concepts, including the concepts of same and different, relative size, comparisons of visual features, and basic counting. As in the APT, they used both visual and auditory stimuli. Kerns et al. tested this program with a small sample of school-age children (ages 7–11 years). It was found that children who received the training performed better than matched controls on a number of untrained measures of attention, such as the day–night Stroop-like task and academic efficiency. In addition, they found that a marginally significant improvement in attention impulsivity was noted by teachers.

A very interesting approach to EF cognitive training has been developed by Lipina and colleagues (Colombo & Lipina, 2005; Martelli et al., 2007; Segretin et al., 2007) using large-scale interventions for children from poor, unsatisfied-basic-needs (UBN) homes. Lipina, Martelli, Vuelta, Injoque Ricle, and Colombo (2004) previously showed that UBN 3- to 5-year-old children are impaired in executive tasks tapping WM, inhibitory control, flexibility and planning (children from UBN homes made fewer correct trials before finding a hidden rule, fewer consecutive correct responses, and more perseverative errors in working spatial memory and delayed-response paradigms, and had less efficient achievement and decreased planning time in tasks that require planning).

The Programa de Intervención Escolar implemented a multimodular approach that included cognitive training, nutritional supplementation, teacher training, and health and social counseling for parents. The study was carried out with a sample of approximately 250 healthy children, 3 to 5 years of age from UBN homes in three public schools from the city of Buenos Aires, Argentina (Colombo & Lipina, 2005). It was designed as a controlled randomized trial, before and after cognitive intervention, in which children were administered a battery of tasks that demand executive processes. An intervention and a control group were both exposed to all of the modules of the program, except for the cognitive module, which was only for the intervention group. The program was implemented twice a week for 32 sessions. The children in the control group were exposed to activities without executive demands but of the same intensity and length. Pre- and postintervention assessments included tasks such as selective attention, Corsi blocks, Tower of London, A-not-B, delayed alternation, and more. The cognitive-training module consisted of individual exercising of these tasks, with progressively increased executive demands. Level of difficulty depended on the child's performance. Results showed that the cognitive training in combination with iron and folic acid supplementation was most effective in improving cognitive performance in healthy children from UBN homes in spatial WM and planning tasks (exercising effect). The same pattern of improvement was observed in attentional and flexibility task performances, suggesting a generalization effect (Lipina & McCandliss, 2007), although no generalized differences were found between the groups in the improvement of Wechsler IQ scores. No correlations were found between individual hemoglobin levels and test performance.

In a second study, named the Programa Piloto de Estimulación Cognitiva, the effectiveness of group (15 children each) versus individual cognitive training was tested within the same multimodular approach (Martelli et al., 2007; Segretin et al., 2007). In this case, both groups received the cognitive training, differing only in the group–individual mode of administration. In addition, both groups also received iron and folic acid supplements. The study was

carried out on a sample of approximately 540 healthy UBN children, 3 to 5 years of age, from the Salta and Buenos Aires areas in Argentina. In this study, none of the training tasks were used in the pre- and postassessments. The researchers found significant improvements following the intervention. The effect in the Tower of London task persisted even 6 months after the end of the intervention. However, similar improvements that followed the intervention were found for both groups. In other words, no special advantage was found for individual compared with group training.

TRAINING WORKING MEMORY

As detailed in Chapters 2 and 3 of this book, self-regulation seems to be influenced not only by attention and inhibitory control but also by WM. Therefore, an intriguing question is whether this function can be targeted through computerized training and whether such intervention could have an impact on other EFs and, more important, on the self-regulation of the child. Klingberg and colleagues (Klingberg et al., 2005; Klingberg et al., 2002b; Olesen, 2005) have indeed showed that this is possible in children with ADHD. In the more extensive of the studies, Klingberg et al. (2005) conducted a multicenter, randomized, controlled, double-blind trial with 53 children with ADHD, ages 7 to 12 years, without stimulant medication. Participants were randomly assigned to use either the treatment computer program for training WM or a comparison program. The training consisted of WM tasks implemented in a computer program named the RoboMemo (RoboMemo, Cogmed Cognitive Medical Systems AB, Stockholm, Sweden). The program was provided on a CD and used by the child on a personal computer either at home or in school. The program included visuospatial and verbal WM tasks. The children performed 90 WM trials on each day of training. The difficulty level was automatically adjusted, on a trial-by-trial basis, to match the WM span of the child in each task. The comparison condition was identical to the treatment except that the difficulty of the 90 WM trials remained at the initial low level. The children received 5 weeks of 40-min daily sessions. Analysis of the results was done for participants who completed the required minimum criteria of 20 days of training. Most of the participants were also evaluated at a follow-up 3 months later. The main outcome measure was the span-board task, a visuospatial WM task that was not part of the training program. For this task, the researchers found a significant treatment effect both postintervention and at follow-up. There were also significant effects for secondary outcome tasks that measured verbal WM, response inhibition, and complex reasoning. In addition, after training there was also a reduction of inattentive symptoms of ADHD according to parental ratings.

The question of whether normally developing children could also benefit from such training remains unanswered, although these researchers seem to have obtained some supporting evidence for this possibility (Olesen, 2005).

CURRICULUM-BASED INTERVENTIONS

Adele Diamond, from the University of British Columbia, Canada, led the first evaluation of a curriculum called Tools of the Mind (Tools), which focuses on EF (Diamond et al., 2007). The Tools program was developed by U.S. educational psychologists Elena Bodrova and Deborah Leong (Bodrova & Leong, 2007). The control group in Diamond's study received a curriculum called *balanced literacy* (dBL) that covered the same academic content as Tools but without a focus on EF. Children received either Tools or dBL for 1 to 2 years. Evaluation of outcome involved two computerized tests that measured EF (a dots task and a flanker task).

According to Bodrova and Leong (2007), the Tools curriculum is designed to help teachers create a positive classroom climate where self-regulation is learned in every activity, especially through dramatic play. Teachers are also trained to use activities specially designed to help children practice self-regulation. The activities are organized to promote self-regulation, aided by Vygotskian-oriented tools. For example, one activity in Tools is called *Buddy Reading*. The teacher pairs up the children and asks each child to select a book because children are to take turns reading to one another. Initially, all children prefer to read aloud and none want to sit and listen. The teacher gives one child a card with a drawing of lips and the other child a card with a drawing of an ear and explains that "ears don't talk; ears listen." The concrete drawing helps the child with the ear drawing to inhibit talking and to listen. The child with the "lips" reads the book and asks a question (given by the teacher), and the child with the "ear" listens and answers the question. Children then trade the lips-ear cue cards and roles. According to the authors, after several months the cue cards are no longer needed. Diamond's study included 147 preschoolers (62 in dBL and 85 in Tools), with an average age of 5.1 years. All of the participants came from the same low socioeconomic status (SES) neighborhood and were randomly assigned to one of the programs. The computerized outcome tasks that tap EF were the dots (Davidson et al., 2006) and a flanker task.

The results indicated that the Tools children outperformed the dBL children in tasks that require inhibition (i.e., the flanker task and the dots-incongruent condition). The task that also required WM and switching (i.e., the dots mixed) was found to be too difficult for most of the children. In this task, almost twice as many Tools as dBL children achieved more than 75%

correct in training trials. Moreover, in this study it was also found that tasks that were more demanding of EF correlated more strongly with standardized academic measures.

The Promoting Alternative Thinking Strategies (PATHS) is a curriculum originally designed for elementary school children with special needs. It focuses on promoting children's emotional development, self-regulation, and social problem-solving skills. It has been tested in several large-scale randomized field studies in special education as well as in regular schools (Conduct Problems Prevention Research Group, 1992; M. T. Greenberg, Kusche, Cook, & Quamma, 1995; M. T. Greenberg, Kusche, & Riggs, 2004; Kam et al., 2004; Riggs et al., 2006). The program is based on the affective-behavioral-cognitive-dynamic (ABCD) model of development created by M. T. Greenberg and colleagues (M. T. Greenberg & Kusche, 1993, 1998). A basic concept in this model is that young children experience emotions and react to them long before they can verbalize their experiences. Moreover, emotional development must be integrated with cognitive and linguistic abilities, which are slower to develop.

The curriculum includes several units: a self-control unit, a feelings unit, a general problem-solving unit, and a social problem-solving unit. Teachers receive special training and weekly consultations. The curriculum is implemented in class about three times a week and also generalized within the daily classroom atmosphere. For example, the self-control unit consists of a series of structured lessons in which children are told a metaphorical story of a turtle that has both interpersonal and academic difficulties because he doesn't "stop to think." With the assistance of a wise old turtle, the young turtle learns to develop self-control. Children practice "doing turtle" (i.e., going into the shell) by folding their arms and following simple steps of calming down and then calmly discuss the problem and their feelings with the teacher. Another example of the program is the control signal poster (CSP) modeled on the notion of a traffic light. The CSP has a red light to signal "stop—calm down," a yellow light for "go slow—think," and a green light to signal "go—try my plan." Children are encouraged to use these signals as a simple model of self-control and problem solving. They are also encouraged to think afterward and evaluate how the plan worked and how successful the model was for solving conflicts during the school day. An example of a randomized field test of the program can be seen in Kam et al.'s (2004) study. They tested the program in 18 special education classrooms, with a total of 133 children, which were randomly assigned to treatment and control conditions. The curriculum was implemented during one school year. The classes were mixed, including first through third graders with an average age of 8.8 years. Follow-up was done 2 years after the end of the intervention. Growth-curve analyses indicated that the intervention reduced the rate of growth of internalizing and

externalizing behavioral problems, as measured by teachers' CBCL questionnaire. Moreover, it was found that the intervention also reduced depressive symptoms, according to the children's self-report. In a previous large-scale randomized trial, 48 regular schools used PATHS as a prevention program (Conduct Problems Prevention Research Group, 1992). The program began at the beginning of first grade. Results after 6 months indicated reduced aggressive and disruptive behavior according to peer sociometric reports and improved quality of classroom atmosphere according to independent observers.

Greenberg and colleagues hypothesized that inhibitory control and verbal fluency were the neurocognitive functions that mediated the relation between the PATHS intervention and the behavioral outcomes (Riggs et al., 2006). In this study, the researchers reported the results of 318 second and third graders from regular schools with a mean age of 8 years, among whom 153 participated in PATHS and the rest were controls. They found that the PATHS intervention enhanced inhibitory control (performance in the Stroop task) and verbal fluency. Moreover, they found that inhibitory control mediated the effect of the intervention (measured by teacher reports of externalizing and internalizing behaviors). Although verbal fluency was related to internalizing behaviors, they did not find that this variable was related to externalizing behavior, nor did it mediate the efficacy of the intervention. The main limitation of this line of studies is that although the initial allocation of the subjects to the intervention and control groups was random, these were not blind or double-blind trials. Both the child and the teacher who rated the child's behavioral outcomes were aware of the intervention, and this may have had an effect on the results.

More recently, a randomized trial was implemented in preschool by using a version of the PATHS (the REDI [Research-Based, Developmentally Informed] program) within the U.S. Head Start program for low-income children (Bierman et al., 2008). The researchers followed 356 four-year-old children over the prekindergarten year. This study included objective EF tasks at the end of the intervention. The results confirmed, first of all, the predictive relation between preschool EF to cognitive and social-emotional school readiness, which was discussed in Chapter 5. For example, the researchers found that children's performance on the Dimensional Change Card Sort (DCCS) task (which assesses WM, cognitive inhibitory control, and set shifting) significantly predicted their acquisition of language-emergent literacy skills and also predicted teacher ratings of their end-of-year social competence (Bierman et al., 2008). Second, the results indicated that the REDI intervention promoted gains on two EF measures: the mentioned DCCS and the task-orientation measure, based on a rating of the child's capacity to sustain a focused task orientation (e.g., the child's capacity to sustain attention to the tasks; there were

items such as “pays attention to instructions and demonstrations,” “sustains concentration; willing to try repetitive tasks”). Third and most important, gains in EF seemed to have moderated the effectiveness of the intervention. For example, a child’s task orientation moderated the intervention effect on the teacher-rated social competence at the end of the intervention; performance on walk-a-line-slowly and task orientation moderated the intervention effect on observer-rated aggression, and so forth. In other words, the intervention appeared particularly beneficial to children who started the year with low levels of behavioral inhibitory control (e.g., difficulties delaying motor responding and sustaining effortful task engagement). According to the authors, the support provided by REDI may have compensated for these EF deficits, promoting social–emotional competence and aggression control in these less skillful children who struggled in “usual practice” classrooms (Bierman et al., 2008). These results seem interesting and promising, although an alternative explanation would be that they reflect regression to the mean. More research is needed to support the beneficial effects of this training program.

An additional school-based prevention program intended to improve self-regulation is the I Can Problem Solve (ICPS) program. ICPS focuses on helping children learn how to think through and resolve everyday conflicts. In this program, kindergarten, preschool, and elementary school children learn interpersonal cognitive problem-solving skills, including the ability to (a) identify a problem; (b) recognize thoughts, feelings, and motives that generate interpersonal problem situations; (c) generate alternative solutions to problems; and (d) consider the consequences of these solutions. ICPS is implemented through daily 20-min sessions for 12 intervention weeks. During the sessions, teachers use games, didactic discussion, role playing, and group interaction to teach children communication and problem-solving skills and the thought processes necessary for good decision making. The effectiveness of the ICPS in antisocial and socially withdrawn children has been tested in several large-scale studies, applying the program for 1 or 2 scholastic years (Boyle & Hasset-Walker, 2008; Shure, 1993; Shure & Spivack, 1982). In some of the studies, the children were also followed up for several years. Teachers’ ratings of the children’s social behavior supported the program’s success, especially when applied at the youngest ages. Moreover, it was found that it lowered the rates of behavioral problems and interpersonal maladjustment at least for a year following the intervention (a summary of the research related to the ICPS program can also be found at <http://www.thinkingchild.com/>). The relation between the effects of this program and the underlying EF mechanisms, such as inhibitory control, has not yet been studied.

SUMMARY

The extant literature includes several different approaches to the idea of fostering the development of self-regulation. First of all, as seen in this chapter, there have been several interesting attempts to use computerized training. These types of training usually focus on basic cognitive mechanisms that underlie self-regulation, such as executive attention. This feature is a major advantage for research into the nature of training effects, and computerized methods are well designed and controlled. Such training can be administered to children in a systematic and objective way. On the other hand, this type of training might be too narrow and its level of generalization to daily life might be limited, although there are some indications that training executive attention could generalize to measures of intelligence. Some of the computerized trainings were designed, at first, for the rehabilitation of impaired functions and could potentially be of use, also, for fostering development of those same functions within normative development.

I also reviewed noncomputerized training approaches, which focus more broadly on neurocognitive mechanisms, that is, EFs, and are based on specific tasks that involve them. Although only a limited number of studies have used such training, these attempts have involved impressive sample sizes, and their results look promising.

Curriculum-based interventions are probably the most applicable approach for large-scale changes within the educational system. Such interventions usually involve training the education staff and reaching the children through the staff and through the changes in the pedagogical atmosphere. These interventions can probably ensure that trained skills are more easily generalized and are therefore a major advantage of these interventions. The main weakness of the interventions, on the other hand, is that it is not clear what is being trained and which mechanisms mediate success and failure. Moreover, it is not clear to what extent the control groups are indeed comparable and to what extent the effects will prevail after the intervention is over.

In summary, although not yet very abundant, the reviewed extant literature in regard to training indeed supports the plausibility of improving self-regulation through relatively short-term interventions. There are still many open questions, but the basic idea of training seems possible. A separate conceptual question is whether better self-regulation is always desirable. The data reviewed in Chapter 5 support the idea that it is indeed beneficial for the child, in both the short and long run and in both the social and academic contexts. Still, it could be argued that at young ages, children perhaps benefit from their immaturity as a way to test boundaries and approach the world egocentrically. Furthermore, there might be no real consensus on what “healthy” self-regulation

looks like in the early developmental stages. In this sense, the best approach would probably be to aim at fostering the development of basic neurocognitive mechanisms, which would enable the child to develop the optimal level of self-regulation that is adaptive for his age and environment.

In addition to the literature reviewed in this chapter, an intriguing and interesting alternative approach has recently arisen in the literature (Tang et al., 2007, 2010), that is, improving self-regulation through mental training. One such training, based on traditional Chinese medicine (integrative body–mind training), was found to improve the efficiency of executive attention and alerting attention networks. Moreover, it was demonstrated that such training strengthens anterior cingulate cortex (ACC) connectivity. Specifically, it increased the integrity and efficiency of white matter in the anterior corona radiata, an important white matter tract that connects the ACC to other structures. Thus, *attention state training*, that is, training that modifies the brain state even without a task, could also provide an interesting means for improving self-regulation.