The Development of Effortful Control

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Chapter 9
The Development of Effortful Control

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Michael Posner is one of the most creative and influential psychologists of the past century. He has been a pioneer in cognitive science and is one of the founders of the field of cognitive neuroscience. The experimental paradigms he has developed have provided a major foundation for the imaging of the human brain. It is our great honor and pleasure to work with him as he continues his pioneering efforts, now focusing on attentional development and its relation to education. Our development of marker tasks based on patterns of adult brain activation has allowed us to study infant and child development in neuroscientifically informed, yet nonintrusive ways. Together with Posner, we have been studying temperament in infants and young children in relation to underlying neural networks for self-control.

Our effort began with the study of temperament and proceeded to making links between temperamental dimensions and neural circuitry using marker tasks derived from adult imaging studies. The levels of analysis available for this exploration now range from molecular genetics to the socialization of behavior. We hope that by furthering methodological links between different levels of analysis, a basis will be provided for examining the many exciting questions at their interface. This chapter examines parallel developments of executive attention and self-regulation, as well as the genetic and experience-related factors that influence the functioning of this system.

Defining Temperamental Effortful Control

Temperament refers to individual differences in reactivity and self-regulation assumed to have a constitutional basis (Rothbart & Derryberry, 1981). The term *constitutional* refers to the relatively enduring biological makeup of the organism, influenced over time by heredity, maturation, and experience. Reactivity refers to the excitability, responsivity, or arousability of the behavioral and physiological systems of the organism, whereas self-regulation refers to neural and behavioral processes functioning to modulate this underlying reactivity (Rothbart & Derryberry, 1981).

Infants come into the world with a set of reactions to their environment that include activity, emotion, and attention. Infants in turn differ greatly in their reactions to events. One child is easily frustrated, has only a brief attention span**,** and cries with even moderate levels of stimulating play; another child enjoys rough play and seeks out exciting events. These reactions to the environment, together with the mechanisms that regulate them, constitute the child's temperament.

Identifying parameters of temperamental reactivity (response latency, rise time, intensity, and recovery time) allows the study of temperament at behavioral, psychophysiological, endocrine, and neural levels (Rothbart & Derryberry, 1981). Although**,** to date**,** these parameters have chiefly been used in laboratory studies assessing general dimensions of temperament (e.g., Lemery, Goldsmith, Klinnert, & Mrazek, 1999; Rothbart, Derryberry & Hershey, 2000), they may in the future allow for more dynamic study of temperament and developmental processes. Distinguishing between reactive and self-regulative characteristics has also been useful in thinking about development generally, in that much of early behavior can be seen as reactive to immediate stimulus events and to endogenous changes in infant state. Later, more self-regulatory

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systems, particularly the executive attention system, will develop to modulate this reactivity (Derryberry & Rothbart, 1997; Rothbart & Derryberry, 1981).

Temperament arises from our genetic endowment, but it both influences and is influenced by the experience of the individual. Figure 9.1 describes three broad factors of temperament in childhood, with associated lists of lower level temperament dimensions whose scales load on each factor. Their interrelations within two cultures are also described. Extraversion and negative affect are early developing dimensions of temperament that are present within all cultures studied to date. Effortful control is a later-developing dimension that also appears within all cultures studied.

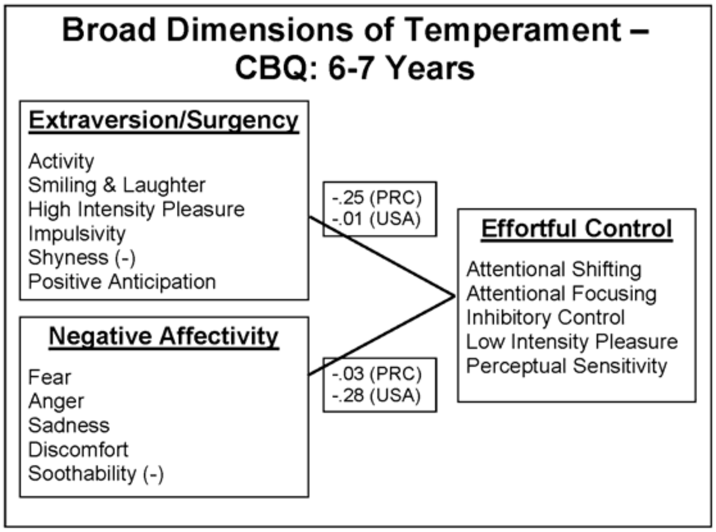

Figure 9.1
Broad dimensions of temperament from the Children’s Behavior Questionnaire

Our factor analyses of the Children’s Behavior Questionnaire (CBQ; Rothbart, Ahadi, Hershey, & Fisher, 2001) identified a general factor of **e**ffortful **c**ontrol (attentional shifting, attentional focusing, inhibitory control, and perceptual sensitivity) distinct from factors of **s**urgency (activity level, positive anticipation, high intensity pleasure/sensation seeking, impulsivity, smiling and laughter, and a negative loading from shyness) and negative emotionality (shyness, discomfort, fear, anger/frustration, sadness, and a negative loading from soothability/falling reactivity). We have also found intercorrelations among measures of attentional focusing, attentional shifting, and inhibitory control in adults (Derryberry & Rothbart, 1988).

These factors map conceptually and empirically onto the extraversion/positive emotionality, neuroticism/negative emotionality, and conscientiousness/constraint dimensions found in Big Five and Big Three studies of adult personality (Ahadi & Rothbart, 1994; Rothbart, Ahadi, & Evans, 2000). These broad temperament constructs suggest that temperament goes beyond either a set of unrelated traits or generalized characteristics of positive and negative emotionality. Important are interactions between the child’s motivational impulses and his or her efforts to control them.

We used oblique factor rotations allowing us to look at correlations among these broad factors. In U.S. adult as well as child samples, effortful control measures are not related to measures of positive emotionality but are inversely related to negative emotionality. In the People's Republic of China, we found a highly similar factor structure but different relationships between the reactive factors and **e**ffortful **c**ontrol (Ahadi, Rothbart, & Ye, 1993; see Fig. 9.1). In the United States, but not China, children higher in effortful control showed lower negative affectivity. In China, but not the United States, children higher in effortful control were less surgent and extraverted. These findings suggest differences between cultures in the behaviors seen as worthy of control (negative affect in the United States; outgoing behavior in China), and these in turn may be related to cultural values. An important goal of temperament research is to specify processes at the levels of biology and social development that may link the child's early endowment to later expression.

Linking Effortful Control and Executive Attention

Effortful control, defined as the ability to inhibit a dominant response to perform a subdominant response, to detect errors, and to engage in planning, is a major form of self-regulation, and self-regulation has been a central concept in developmental psychology and in the study of psychopathologies. Self-regulation refers to children's ability to control reactions to stress, maintain focused attention, and interpret mental states in themselves and others (Fonagy & Target, 2002) and is a feature of normal child development (Bronson, 2000).

In two large longitudinal studies (32 to 66 months and 9 to 45 months), Kochanska and her colleagues have assessed five skills involving the capacity to suppress a dominant response to perform a subdominant response (Kochanska, Murray, & Coy, 1997; Kochanska, Murray, & Harlan, 2000; Kochanska, Murray, Jacques, Koenig, & Vandegeest, 1996). These include delay (e.g., waiting for candy displayed under a transparent cup), slowing motor activity (drawing a line slowly), suppressing and initiating responses to changing signals (go-no-go games), effortful attention (recognizing small shapes hidden within a dominant large shape), and lowering the voice. Laboratory batteries were designed for developmental periods ranging from 22 to 66 months. Beginning at age 2.5 children's performance was highly consistent across tasks, indicating they all appeared to measure a common underlying quality that had developed over time. Measures also showed stability for children across time, with correlations across repeated assessments ranging from .44 for the youngest children (22 to 33 months) to .59 from 32 to 46 months, and to .65 from 46 to 66 months (Kochanska et al., 2000).

What does effortful control mean for temperament and development? It means that unlike early theoretical models of temperament that emphasized how people are moved by the positive and negative emotions or level of arousal, people are not always at the mercy of affect. Using effortful control, people can more flexibly approach situations they fear and inhibit actions they desire. The efficiency of control, however, will depend on the strength of the emotional processes against which effort is exerted (Rothbart, Derryberry, et al., 2000).

Effortful Control and Self-Regulation

Reasons for studying the emergence of executive attention are strengthened because cognitive measures of conflict resolution in laboratory tasks have been linked to aspects of children's effortful self-control in naturalistic settings. Children relatively less affected by spatial conflict also received higher parental ratings of temperamental effortful control and higher scores on laboratory measures of inhibitory control (Gerardi-Caulton, 2000; Rothbart, Ellis, Rueda, & Posner, 2003).

In Oregon, 6- to 7-year-olds high in effortful control have been found to be high in empathy, guilt/shame, and low in aggressiveness (Rothbart, Ahadi, & Hershey, 1994). Eisenberg and her colleagues have also found that 4- to 6-year-old boys with good attentional control tend to deal with anger by using nonhostile verbal methods rather than overt aggressive methods (Eisenberg, Fabes, Nyman, Bernzweig, & Pinulas, 1994). Effortful control may support empathy by allowing attention to the thoughts and feelings of another without becoming overwhelmed by one's own distress. To display empathy toward others requires that one interpret their signals of distress or pleasure. Imaging work in normals shows that sad faces activate the amygdala. As sadness increases, this activation is accompanied by activity in the anterior cingulate as part of the attention network (Blair, Morris, Frith, Perrett, & Dolan, 1999). It seems likely that this cingulate activity represents the basis for one’s attention to the distress of others.

Similarly, guilt/shame in 6- to 7-year-olds is positively related to effortful control and negative affectivity (Rothbart et al., 1994). Negative affectivity may contribute to guilt by providing strong internal cues of discomfort, increasing the likelihood that the cause of these feelings will be attributed to an internal conscience rather than external reward or coercion (Dienstbier, 1984; Kochanska, 1993). Effortful control may contribute also by providing the attentional flexibility needed to notice these feelings and relate them to feelings of responsibility for one's own specific actions and their negative consequences for another person (Derryberry & Reed, 1994, 1996).

Consistent with this analysis, effortful control also appears to play an important role in the development of conscience. The internalization of moral principles appears to be facilitated in fearful preschool-aged children, especially when their mothers use gentle discipline (Kochanska, 1991, 1995; Kochanska et al., 1997). In addition, internalized control is greater in children high in effortful control (Kochanska et al., 1996, 1997, 2000). Thus, two separable control systems appear to regulate the development of conscience. Although fear may provide reactive behavioral inhibition and strong negative affect for association with moral principles, effortful control provides the attentional flexibility required to link negative affect, action, and moral principles. In terms of neural systems, a strongly reactive amygdala would provide the signals of distress that would easily allow empathic feelings toward others, leading to children who might be relatively easy to socialize. In the absence of this form of control, development of the cingulate would allow appropriate attention to other signals.

Individual differences in effortful control are also related to some aspects of metacognitive knowledge, such as theory of mind, that is, knowing that people's behavior is guided by their beliefs, desires, and other mental states (Carlson & Moses, 2001). Moreover, tasks that require the inhibition of a prepotent response are correlated with performance on theory of mind tasks even when other factors, such as age, intelligence, and working memory are factored out (Carlson & Moses, 2001). Inhibitory control and theory of mind share a similar developmental time course, with advances in both areas between the ages of 2 and 5.

Marker Tasks

We have used model tasks related to brain function to assess the executive attention capacities likely to underlie effortful control (Posner & Rothbart, 1998). Monitoring and resolving conflict between incompatible responses requires voluntary and attentive control of action and is considered a function of executive attention. Cognitive tasks involving conflict have been extensively used to measure the efficiency with which control of action is exerted (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Posner & DiGirolamo, 1998).

A basic measure of conflict resolution is provided by the Stroop task. The original form of this task required research participants to report the color of ink a word was written in, when the color word, for example, red, might conflict with the color of ink, for example, blue. We know from adult brain imaging studies that Stroop tasks activate a midline brain structure, the anterior cingulate, which is also associated with other executive attention activities. In a meta-analysis of imaging studies, the dorsal section of the anterior cingulate was found to be activated in cognitive conflict tasks such as variants of the Stroop task (Bush, Luu, & Posner, 2000). An adjacent area of the anterior cingulate was found to be activated by emotional tasks and emotional states. The two divisions also seem to interact in a mutually exclusive way. For instance, when the cognitive division was activated, the affective division tended to be deactivated and vice-versa, suggesting the possibility of reciprocal effortful and emotional controls of attention.

When we know the kind of tasks that activate a given brain region, we can adapt them to children as marker tasks. It is then possible to trace the development of function in the brain areas through children's performances on the tasks. At Oregon, we have used a marker task to assess executive attention (Gerardi-Caulton, 2000; Posner & Rothbart, 1998) in which the child must respond to a spatially conflicting stimulus by inhibiting the dominant response and executing a subdominant response (Spatial Conflict Task). In this task, children sit in front of two response keys, one located to the child's left and one to the right. Each key displays a picture, and on every trial a picture identical to one member of the pair appears on either the left or right side of the screen. Children are rewarded for responding to the identity of the stimulus regardless of its spatial compatibility with the matching response key (Gerardi-Caulton, 2000).

The inhibition of a prompted, but inappropriate response, is also considered basic to action monitoring, and as for conflict resolution, many cognitive tasks have been developed to measure this aspect of executive control. The most common way to measure inhibition is by using a task in which participants respond to one stimulus but are required to inhibit their response when a related stimulus is presented (go-no-go task). Under this instruction, promptness to respond can be manipulated by varying the proportion of go trials, or by presenting a no-go signal at particular time intervals immediately after the go stimulus (stop-signal paradigm). The efficiency of inhibition is measured behaviorally by the number of omissions and false alarms, but it can be also measured using physiological indices, such as muscular preparation or brain activity.

This chapter stresses recent efforts to develop a neurological basis for self-regulation based on the study of the use of neuroimaging. The tasks described and others based on them have been used with children to trace the development of executive functions. In turn, the development of neuroimaging techniques has permitted the analysis of neural systems underlying performance on executive tasks with both adults and children. Knowing the neural substrates for effortful control will provide a tool for examining which aspects of this form of self-regulation are subject to genetic influence, as well as investigating how the functioning of this system may be influenced by experience.

Development of Executive Attention

Neural systems related to executive attention make a crucial contribution to temperament. Individuals can voluntarily deploy their attention, allowing them to regulate their more reactive tendencies, and to suppress a dominant response to perform subdominant responses. How can we study the way these networks are created in early childhood?

Developmental studies have stressed the relative lack of executive control in infants (Ruff & Rothbart, 1996). However, a sign of the control of cognitive conflict is found in the first year of life. In A-not-B tasks, children are trained to reach for a hidden object at location A, and then tested on their ability to search for the hidden object at a new location B (Diamond, 1991). Children younger than 12 months tend to look in the previous location A, even though they see the object disappear behind location B. After the first year, children develop the ability to inhibit the prepotent response toward the trained location A, and successfully reach for the new location B (Diamond, 1991). Late in the first year, infants also develop the ability to resolve conflict between their line of sight and their line of reaching when retrieving an object. At 9 months, line of sight dominates completely. If the open side of a transparent box is not in line with the side in view, infants withdraw their hand and reach directly along the line of sight, striking the closed side (Diamond, 1991). In contrast, 12-month-old infants can simultaneously look at a closed side while reaching through the open end to retrieve a toy.

From 2 years of age and older, children are able to perform simple tasks in which their reaction time (RT) can be measured. In one study, toddlers were asked to perform the Spatial Conflict Task described in the previous section (Gerardi-Caulton, 2000). Between 2 and 4 years of age, children progressed from an almost complete inability to carry out the task to relatively good performance. Children 24 months of age tended to perseverate on a single response, while 36-month-old children performed at high accuracy levels. Like adults, the 36-month-olds responded more slowly and with reduced accuracy to incompatible trials. Children who performed well were also described by their parents as more skilled at attentional shifting and focusing, less impulsive, and less prone to frustration reactions. Using a very similar task with adults, research participants who performed poorly tended to be high in anxiety and low on self-reported attentional control (Derryberry & Reed, 1998). These findings are consistent with the idea that effortful attention, measured through questionnaire or laboratory methods, may help individuals constrain negative forms of emotion.

At 30 months, when toddlers were first able to successfully perform the spatial conflict task, we found that performance on this task was significantly related to the toddlers' ability to learn ambiguous associations in a visual sequence learning task (Rothbart et al., 2003). In the visual sequence task, a series of cartoons is presented on three different computer monitors in a predictable sequence. In an unambiguous series, each location is followed by one and only one subsequent location. An ambiguous association refers to a sequence where a location is followed by one of two or more different locations, the particular location depending on its place within the sequence. Any context that helps specify "place" aids in acquiring the sequence representation. Any context that obscures place, such as randomly occurring events of a secondary task, make the learning of an ambiguous sequence difficult. In essence, monitoring context is a control mechanism that reduces ambiguity, and such context specification appears dependent on lateral prefrontal cortex (see, for example, Keele, Ivry, Mayr, Hazeltime, & Heuer, 2003). We would then expect that young children would have great difficulty in learning ambiguous sequences until powerful systems of contextual aid become available. In accordance with this prediction, in our studies ambiguous associations within sequences of events were not acquired at above chance levels until about 2 years of age (Clohessy, Posner, & Rothbart, 2001; Rothbart et al., 2003).

Another form of action monitoring is the detection and correction of errors. In the spatial conflict task, RTs following an error were 200 ms longer than those following a correct trial for 30-month-old children, and more than 500 ms longer at 36 months, indicating that children were noticing their errors and correcting them (Rothbart et al.,2003). No evidence of slowing following an error was found at 24 months. A somewhat more difficult conflict is introduced when participants must apply information from one verbal command while simultaneously ignoring information from another. One version of the Simple Simon game asks children to execute a response when a command is given by one stuffed animal, while inhibiting responses commanded by a second animal (Jones, Rothbart, & Posner, 2003). Children of 36 to 38 months showed no ability to inhibit their response and no slowing following an error, but at 39 to 41 months, children showed both an ability to inhibit and a slowing of RT following an error. These results suggest that between 30 and 39 months, performance changes in relation to detecting an error response.

Young children have more difficulty than older children and adults in resolving conflict from competing stimulation. We have recently developed a flanker task appropriate for use with children as young as 4 years of age (Rueda et al., 2004; see Figure 9.2). In this task, a row of five fish appear in the center of the screen and the child's job is to help in "feeding" the middle fish by pressing the key corresponding to the direction in which the middle fish is pointing. On half the trials, the flanker fish are pointing in the same direction as the middle fish (congruent trials); on the other half, the flanker fish are pointing in the opposite direction (incongruent trials).

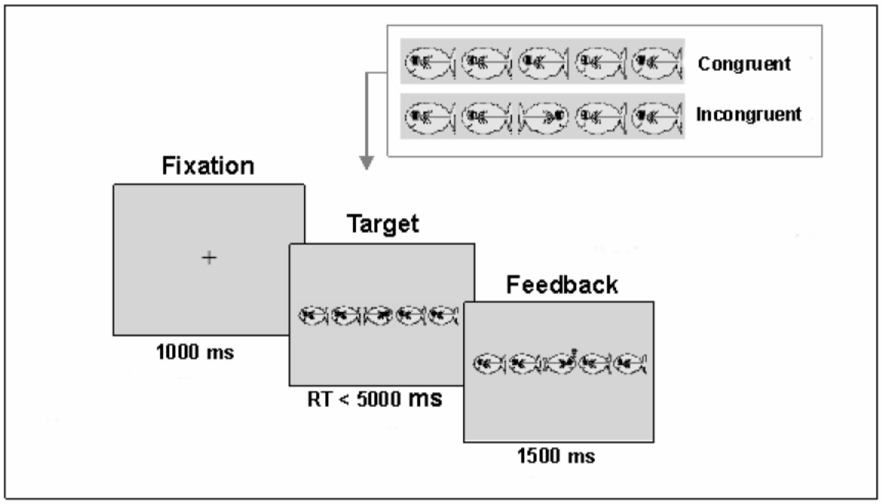

Figure 9.2
Flanker task for children.

Using this task, we have observed considerable development of conflict resolution up to 7 years of age, but a striking consistency in performance after this age up to adulthood (Rueda et al., 2004). In a pilot study conducted in our lab, we have also attempted to adapt the flanker task to age 3 years, using a touch-screen version. We ran this pilot task with a group of children of 3.5 years of age and found that approximately half of them were unable to understand and perform the task. At age 4, however, children did not seem to have trouble understanding the instructions and were able to carry out the task using response keys, although their RT and conflict effects were considerably longer than those for older children and adults (see Table 9.1).

	Age	**Overall (RT)**	**Overall (% of errors)**	**Conflict (RT)**	**Conflict (% of errors)**
Study 1	4	1598	12.8	207	5.8
	adults	443	1.4	31	2.3
Study 2	6	931	15.8	115	15.6
	7	833	5.7	63	0.7
	8	806	4.9	71	-0.3
	9	734	2.7	67	1.6
	10	640	2.2	69	2.1
	adults	483	1.2	61	1.6

Table 9.1

Development of Conflict Resolution as Measured by the Child Version of the Flanker Task

Conflict is measured by subtracting the data (RT or % of errors) for the congruent flanker condition from the data for the incongruent flanker condition. Although the experimental procedures used in Study 1 and 2 were the same, the stimuli in Study 1 were larger than stimuli in Study 2, resulting in slightly smaller conflict scores.

The greater susceptibility to interference from irrelevant stimulation for young children has been reported using many different tasks, including flanker tasks (Enns, Brodeur, & Trick, 1998; Ridderinkhof & van der Molen, 1995; Ridderinkhof, van der Molen, Band, & Bashore, 1997), go-no-go (Casey et al., 1997a) and stop-signal tasks (Bedard et al., 2002; Ridderinkhof, Band, & Logan, 1999), S-R compatibility tasks (Casey, Thomas, Davidson, Kunz, & Franzen, 2002), Stroop tasks (Gerstadt, Hong, & Diamond, 1994), visual discrimination tasks (Casey et al., 1997b), and negative priming (Tipper, Bourque, Anderson, & Brehaut, 1989). Depending on the difficulty of the task, developmental differences in the ability to resolve conflict between children and adults can be observed up to middle childhood and early adolescence, suggesting that full maturation of the executive control network does not take place until early adulthood.

Imaging the Executive Attention Network

In the past decade, the development of noninvasive brain imaging methods has permitted the analysis of the anatomy and time course of activations of cognitive functions. A network of brain areas have consistently shown to be active when executive attention is required. This network consists of the anterior cingulate cortex (ACC) and lateral prefrontal areas (Posner & Fan, in press).

Recent studies have been able to dissociate different operations involved in the resolution of conflict and the brain areas within the executive network responsible for these operations. In a functional magnetic resonance imaging (fMRI) study, Botvinick, Nystrom, Fissell, Carter, and Cohen (1999) showed the ACC to be involved in the detection and monitoring of conflict, whereas lateral prefrontal areas have been shown to be mainly related to conflict resolution (Casey, Durston, & Fossella, 2001). Moreover, the detection and resolution of conflict has been anatomically dissociated from selective attention. The selection of relevant information has been associated with a different system that involves areas of the superior parietal cortex and the right sides of the superior frontal gyrus and the cerebellum (Casey et al., 2000). In addition, Fan, Flombaum, McCandliss, Thomas, and Posner (2003) carried out a study in which a group of adults performed three types of conflict tasks (Stroop, Spatial Conflict, and Flanker) while their brain activation was being scanned with fMRI. Although all tasks activated parts of the cingulate gyrus, suggesting an integrated network for conflict processing, some distinct activations were also found for each particular task (see Figure 9.3). This suggests a role for ACC in conflict detection and monitoring but relates conflict resolution to different subregions of the lateral prefrontal cortex, depending on the particular type of information used to induce conflict.

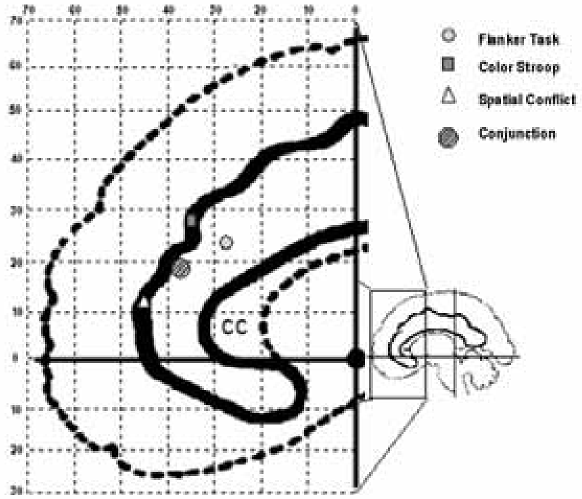

Figure 9.3
Anterior cingulate activations associated with performance in three different conflict tasks (from Fan et al., 2003).

Despite the fact that the special setting for fMRI studies is not easily adapted to children, a number of neuroimaging studies have been conducted with children as young as 6 years of age. In general, children activate the same network of areas as adults when performing similar tasks, although the average volume of activation appears to be remarkably greater in children compared to adults (Casey et al., 1997a; Casey et al., 2002; Durston et al., 2002). This suggests that the brain circuitry underlying executive functions becomes more focal and refined as it gains in efficiency. In addition to the role of the ACC in the regulation of cognitive processing, this area appears to be also implicated in the regulation of emotions (Bush, Luu, & Posner, 2000). For instance, in a study by Whalen et al. (1998), a group of research participants showed activation in the dorsal part of the ACC when performing a Stroop-like task, but in ventral areas when the task involved emotional stimuli.

A number of studies have used the temporal resolution of event related potentials (ERPs) to measure the timing of these action-monitoring processes. The N2 and ERN are the two main ERP indexes associated with executive control. The N2 is a preresponse negative deflection in the ERP around 300 ms poststimulus, which appears to be greater (more negative) on trials involving conflict. The N2 is observed over parietal and frontal leads and has been obtained in both flanker (Kopp, Rist, & Mattler, 1996; van Veen & Carter, 2002) and go-no-go tasks (Jackson, Jackson, & Roberts, 1999). In both situations, the N2 has been associated with the withholding of a prepotent but inappropriate response.

The ERN develops around 100 ms following the commission of an error or the display of feedback that an error has been committed, and has a midfrontal topographic distribution. The ERN appears to represent a postresponse index of error detection and monitoring (Dehaene, Posner, & Tucker, 1994; Gehring, Goss, Coles, Meyer, & Donchin, 1993). Recently, van Veen and Carter (2002), using a flanker task, found a common source of activation in the caudal ACC for both N2 and ERN, suggesting that the same conflict detection process underlies both potentials. The N2 may reflect a preresponse monitoring of the conflict produced by incongruent trials that is resolved in a correct response, while the ERN may relate to a mechanism of adjustment and correction of upcoming responses.

Characteristics of the ERP make this technique amenable to children of all ages. In a recent study conducted in our lab at the University of Oregon, we have used a high-density system of electroencephalography (Tucker, 1993; see Figure 9.4) to register brain activity while 4-years-olds and adults were performing the fish flanker task presented above. This procedure allows for the evaluation of differences between children and adults on the time course for monitoring and resolving conflict. Stimulus-locked ERPs are presented for children and adults in Figure 9.5. Despite dramatically different RTs (1244 ms versus 443 ms) and conflict resolution times (82 ms versus 31 ms), the ERP differences between incongruent and congruent trials were strikingly similar. Consistent with other studies (Kopp et al., 1994; van Veen & Carter, 2002), we found the N2 effect for the adults over the midfrontal leads. The children's data also show a larger negative deflection for the incongruent condition at the midfrontal electrodes. Compared to adults, this effect has a larger size, greater amplitude, and is extended over a longer period of time.

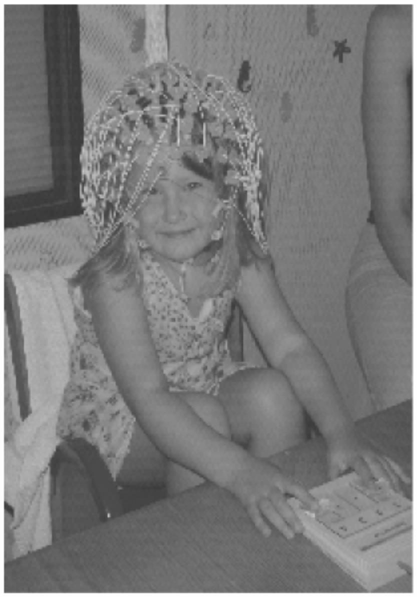

Figure 9.4
Four-year-old girl wearing the
128-channelGeodesic Sensor Net

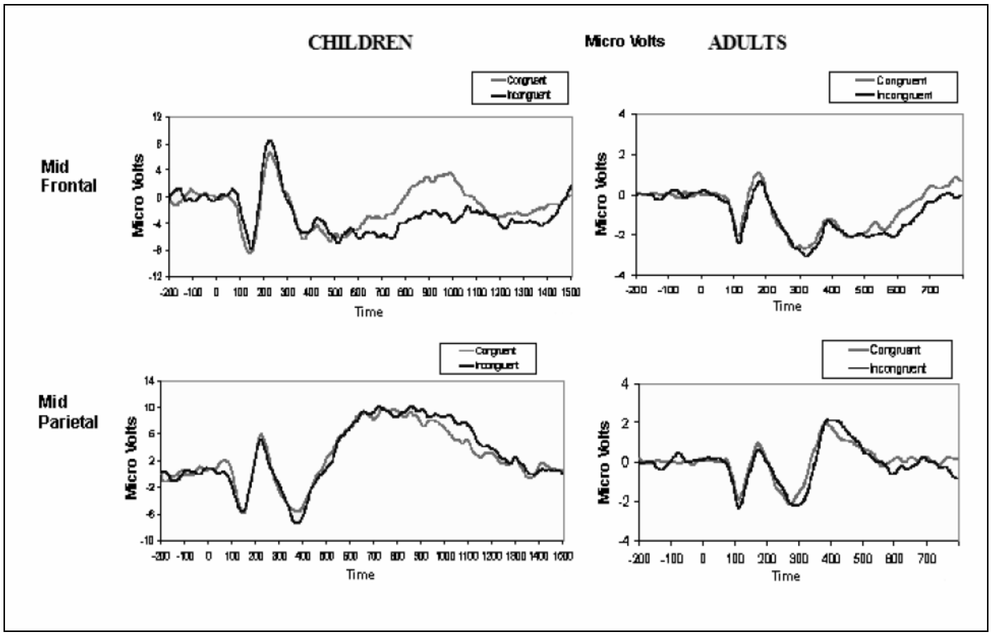

Figure 9.5

ERPs from 4-year-olds and adults on the child version of the flanker task.

Differences between children and adults in ERP amplitude have been related to brain size and skull thickening. Differences in the latency of components, however, may be more related to observed differences in conflict resolution between children and adults as measured in the flanker task. Although the frontal effect was evident for adults at around 300 ms posttarget, children did not show any difference until approximately 550 ms after the target. In addition, the effect was sustained over a period of 500 ms before the children's responses, in contrast with only 50 ms in the case of adults. This difference observed between children and adults over the frontal channels differed from other components observed at mid parietal channels. For both children and adults, we found a greater positivity for incongruent trials over midparietal leads. For adults, this effect was observed at the time window of the P300, whereas it was more delayed in the case of children (between 800 and 1200 ms posttarget). The P300 is thought to be an index of stimulus evaluation (Coles, Gratton, Bashore, Ericksen, & Donchin, 1985). This parietal effect could reflect developmental differences in the difficulty of orienting to the central target depending on the congruence of surrounding flankers, while the frontal effect could reveal differences in the time course of conflict resolution.

Genetics

Links between the neural network of executive attention and the chemical modulators involved in its functioning have provided a tool for studying the genetic basis of normal and pathological forms of attention. Convergent studies from different fields have helped define the attentional functions in neurochemical and physiological terms (Posner & Fan, in press). The anterior cingulate is only one synapse away from the ventral tegmental area, a source of dopamine neurons. Moreover, the five types of dopamine receptors are all expressed within the cingulate.

To determine if there was sufficient evidence of genetic influence in the efficiency of this network to support the hunt for candidate genes, it was necessary to determine its heritability. Heritability is usually studied by comparing monozygotic twins who have identical genes with dizygotic twins who, like siblings, share about half of their genes. The heritability measure assumes that the mono- and dizygotic twins do not differ systematically in environmental influences on their development. Because this assumption is somewhat doubtful, heritability remains only an estimate. One of the problems for studying the genetic underpinnings of cognitive functions is to find an adequate phenotype for the particular function to be studied. Recently, Fan in collaboration with Posner and others (Fan, McCandliss, Sommer, Raz, & Posner, 2002) developed the Attention Network Test (ANT). This task provides a measure for each of the three anatomically defined attention networks: alerting, orienting, and executive attention. The ANT was used as a phenotype of the efficiency of these three attentional functions in a small scale twin study. In this study, the executive network showed high enough heritability (.89) to justify the search for specific genes (Fan, Wu, Fossella, & Posner, 2001).

DNA from cheek swabs of research participants who performed the ANT could then be used to examine candidate differences in gene polymorphisms related to dopamine. This process demonstrated at least two candidate genes that were related to the executive network to a greater degree than to overall performance as measured by RT and accuracy (Fossella, Posner, Fan, Swanson, & Pfaff, 2002). One of these genes was the dopamine D4 receptor (DRD4) gene, widely reported to be associated with attention deficit hyperactivity disorder (ADHD) and with the personality trait of sensation seeking (Swanson et al., 2000). The other was the MAOA gene, which is related both to dopamine and to norepinepherine.

The DRD4 gene has one area in which a sequence of 48 bases are repeated either two, four, seven, or more times. The presence of the more common 4 repeat allele appeared to be associated with more difficulty in resolving conflict (Fossella et al., 2002). Children with the less common 7 repeat allele showed behavioral aspects of ADHD but did not have deficits in overall RT or in conflict as measured by the color-word Stroop task (Swanson et al., 2000).

Evidence from detailed evolutionary studies suggest that the 7 repeat allele is under positive selective pressure (Ding et al., 2002), indicating that it might convey some advantages. This might relate to the association of the 7 repeat with sensation seeking, a temperament trait that might have conveyed an advantage during human evolution (Ding et al., 2002). This trait might well be a prominent characteristic in individuals with ADHD. These findings are all rather new, and require additional confirmation and extension. However, they do indicate the possible utility in relating genetic differences to specific brain networks and temperamental characteristics.

Neuroimaging can serve as a tool to examine the role of genetic variation in influencing brain networks. The two genes that were associated with differences in conflict RT (DRD4 and MAOA) also produced differences in brain activation within the anterior cingulate gyrus (Fan, Fossella et al., 2003). The number of participants required to find a significant difference in brain activity were far fewer than those needed to do so when looking at amount of brain activation. A similar result was reported for the BDNF gene (Egan et al., 2003), thought to be related to long-term memory storage. It required several hundred participants with each allele to show a behavioral difference in a memory test, but fewer than 10 participants per group to establish a difference in degree of activation within the hippocampus. These findings indicate that brain imaging may play an important role in examining the influence of genetics on neural networks.

Training of Attention

Rhesus monkeys and chimpanzees have been trained to carry out some of the high-level skills known to produce activation of the anterior cingulate in human adults in a numerical version of the Stroop task (Rumbaugh & Washburn, 1995). After many months of training, rhesus monkeys were able to indicate which of two displays had the larger number of items, even when the larger number of items was in a display made up of the smaller digits (incongruent condition). Although their RTs were similar to humans in showing a difference between incongruent and congruent trials (Washburn, 1998) the trained monkeys made about 25% errors, while humans made only 3% errors in this condition. Additional research showed that cues helping to direct the participant's attention to the target location were more effective with monkeys than with humans. On the other hand, rewards that operated by executive attention are more effective in humans than in monkeys. In general, the monkeys' performance seem more like those of young children whose executive attention is still immature than like human adults.

Informal observations made by Rumbaugh and Washburn indicate that the animals tended to become less aggressive and more sociable after the training. These observations might fit with the central midline control systems and the reciprocal inhibition observed in positron emission tomography (PET) studies between cognitive and emotional tasks. The observations on animals raised the question of whether it might be possible to influence both the cognitive and emotional controls on behavior by systematic training of preschool children in tasks similar to those used with the monkeys. It would clearly not be possible to match the number of trials used with monkeys, but it may be possible to perform some training with young children designed to make subtle improvements in their executive attention during the time that it is undergoing development.

We have created a set of training exercises designed to help preschool children develop their executive attention skills that have been adapted from Rumbaugh & Washburn's (1995) work with primates. Each exercise is presented in the form of a game the child can enjoy. The exercises are designed to teach a set of cumulative skills training the elements of executive attention (Posner & Fan, in press). There are a total of nine exercises structured in three sets depending on the aspect of attention they are targeting: (a) navigating and object-tracking exercises; (b) visual discrimination exercises; and (c) conflict resolution exercises. Using these training programs, a study was run with a group of 4-year-old children. The games were completed in a total of five training sessions, and there was also a pre- and posttraining assessment session. For the pre- and postassessment sessions, the children completed the child version of the Attentional Network Test (ANT; Rueda et al., 2004) and the Kaufman-Brief Intelligence Test (K-BIT; Kaufman & Kaufman, 1990). Parents of the children also completed the Children's Behavior Questionnaire (CBQ) before and 2 weeks after the training program.

We chose 4-year-olds for the initial test because executive attention as measured by conflict tasks has shown substantial development between 2.5 and 7 years (see previous section on development of executive attention). Thus, we felt that 4-year-olds would be in the process of developing this network and would show a good chance for improvement. For the initial test we ran a small group of 24 4-year-old children (52 months old on average). Half of them were assigned to the experimental group and were run in a total of seven sessions, five training sessions, and pre- and postassessment sessions. The children in the control group participated only in the pre- and postassays.

All but two children completed most of the trials within the 5-day period. The average number of trials performed by the children on the training exercises was 247, 8% of which were incorrect and 4.2% missed. Results on the pre- and postassays for overall RT and the conflict scores are shown in Table 9.2a. A minus sign before the difference score means there was a pre- to posttest improvement. The control group showed as large or larger improvement as the experimental group in overall RT. In conflict scores, the experimental group showed considerable improvement, while the control group showed a small decline, although in none of these cases was the pre-post difference statistically significant, because of high variability across children. In addition, we found that the training produced significant increases in overall IQ and for the visual matrices scale measured by the K-BIT (Table 9.2b).

Tables 9.2a and 9.2b
Changes in overall RT and conflict (a) and IQ (b) scores with training.

The conflict effect is measured by subtracting the data (RT or % of errors) for the congruent flanker condition from the data for the incongruent flanker condition.

		Overall		**Conflict**	
		RT	**% errors**	**RT**	**% errors**
EXPERIMENTAL GROUP	PRE	1702	26.3	80.5	14.1
	POST	1453	23.8	51.5	17.4
	DIF	-249	-2.4	-29	+3.4
CONTROL GROUP	PRE	1906	25.0	192.2	12.1
	POST	1456	19.3	210.4	11.3
	DIF	-550	-5.7	+18.2	-0.8

		IQ Composite	**Vocabulary Subtest**	**Matrices Subtest**
EXPERIMENTAL GROUP	PRE	111.3	115.3	104.8
	POST	117.4	117.0	113.8
	DIF	+6.1	+1.7	+9.1
CONTROL GROUP	PRE	115.4	116.3	111.4
	POST	115.8	123.1	104.9
	DIF	+0.4	+6.8	-6.4

We also found significant correlations between performance on the training exercises and the degree of improvement experienced by the experimental group on some of the assessment scores. For example, children who needed more trials to advance from one level to the next, and therefore completed more training trials, were the ones improving more in the matrices score (*r* = .67).

For the vocabulary subtest, participants in the control group showed a larger gain than the experimental children, but this was not significant. The vocabulary subtest measures the individual level of language development and verbal conceptualization, which depends greatly on formal schooling and cultural experiences, whereas the matrices subtest measures simultaneous processing, nonverbal reasoning, and fluid thinking (Kaufman & Kaufman, 1990). Matrices scores represent a more abstract and culture-free measure of intelligence, similar to the one provided by Raven's abstract matrices (Raven, Court, & Raven, 1983). Other forms of attention training for children with ADHD have also proven to improve performance on abstract reasoning as measured by Raven's Progressive Matrices (Klingsberg, Forssberg, & Westerberg, 2002). This suggests that training of attention may produce a benefit on a general form of cognitive functioning that extends over a wide range of tasks. Finally, as expected by the short time period elapsing between the pre- and postassessment sessions, there was little hint of any change in reported temperament scores.

Although the results of this first phase of the study are greatly encouraging, additional investigation involving more extensive controls will be necessary to understand what aspect of the training is important for the fostering of reasoning and attentional skills. During our future training studies, we plan to use high-density electroencephalograms (EEGs) to examine changes in brain networks that might occur as a result of training. Previous studies have shown that we can record ERPs from 4-year-olds and that they show both similarities and differences from adults (see Figure 9.5). The use of ERPs during the pre- and postassessment sessions will allow us to study possible changes in the timing and topography of activations that could be related to the behavioral improvements produced by training.

Conclusion

Effortful control refers to a construct that consistently emerges from factorial analyses of temperament questionnaires. This construct includes the ability to inhibit dominant responses to perform subdominant responses, to detect errors, and to engage in planning. This temperamental dimension appears to be closely related to executive attention. According to cognitive models, executive attention is required in situations that require a careful and attentive control of action. These situations involve overcoming habitual responses (conflict), action planning, novelty, error detection and compensation, and dealing with difficult or dangerous conditions (Norman & Shallice, 1986). The functions associated with executive attention overlap with the more general notion of executive functions in childhood, which includes working memory, planning, switching, and inhibitory control (Welch, 2001). All these capacities, together with the regulatory functions of the attentional systems (Rueda, Posner, & Rothbart, 2004) seem likely to underlie effortful control.

The development of effortful control has been traced using not only temperament questionnaires but also laboratory tasks adopted from adult studies but adapted to children and designed to isolate specific measures of control. On the basis of this research, the system appears to experience considerable development between 2 and 7 years of age. In this chapter, we stressed the crucial role the development of this system has in the internalization of moral principles and socialization as well as the development of the theory of mind.

Making use of appropriate cognitive tasks, neuroimaging studies have provided a valuable understanding of the neural basis for executive attention. Different parts of the anterior cingulate cortex have been shown to be implicated in processing cognitive and emotional information in close connection with other prefrontal areas more related to action-monitoring processes. Developmental studies have suggested that when the system is still immature, a broader area around the same brain circuitry has to be activated during a longer period of time to resolve the same type of conflict situations. Knowing the biological basis of a function opens the door to the possibility of studying its genetic influence. Pioneering studies following this approach have shown the neural network for executive control to be in part determined by the biological background expressed in particular dopamine-related genes. However, the impact of genetic factors on the functioning of the executive control system could wrongly lead the reader to the conclusion that the system cannot be influenced by experience. We reported a cross-cultural study of China and the United States, suggesting that the functioning of this self-regulatory system may be subject to cultural demands.

Finally, we have also presented a recent effort in our laboratory to develop a set of exercises for training attention in younger children. Our training program produced improvement in 4-year-olds' abstract reasoning and conflict resolution abilities. The brain mechanisms responsible for these improvements may be also analyzed in the future using imaging techniques appropriate to young children. Considering effortful control as a central system for the successful development of cognitive and emotional regulation of children's behavior, the training of attentional abilities known to relate to the control of action may be an important complement to preschool and early elementary education.

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