

# Developing Attention and Self-Regulation in Infancy and Childhood

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## 22.1 INTRODUCTION

William James (1890) defined attention as follows:

Attention is the taking possession of the mind in clear and vivid form of one out of what seem several simultaneous objects or trains of thought.

James' definition, however, provides little perspective toward an understanding of the normal development of attention or its pathologies. The theme of this chapter is that it is now possible to view attention much more concretely as an organ system. The authors follow the Webster's Dictionary definition of an organ system:

An organ system may be defined as differentiated structures in animals and plants made up of various cells and tissues and adapted for the performance of some specific function and grouped with other structures into a system.

The authors believe that viewing attention as an organ system aids in answering many perplexing issues raised in developmental psychology, psychiatry, and neurology. Neuroimaging studies have systemically shown that a wide variety of cognitive tasks activate a distributed set of neural areas, each of which can be identified with specific mental operations (Posner and Raichle, 1994, 1998). These areas of activation may be more consistent for the study of attention than for any other cognitive system. Attention can be viewed as involving

specialized networks to carry out functions such as achieving and maintaining the alert state, orienting to sensory events, and controlling thoughts and feelings.

The goals of this chapter are first to delineate the attentional networks of the human brain (Section 22.2), mostly from adult studies. There are obvious changes in behavior between infancy and adulthood, and in the next two sections (Sections 22.3 and 22.4), the authors describe brain changes at these ages and seek to link them to developmental differences in behavior. Section 22.5 examines changes in the attention networks themselves during child development and discusses how adult control relates to these changes. The authors use the connection between attention networks and neuromodulators to discuss some of the genes that influence individual differences and network development (Section 22.6). Finally, some likely new areas for research are outlined (Section 22.7).

## 22.2 BRAIN NETWORKS

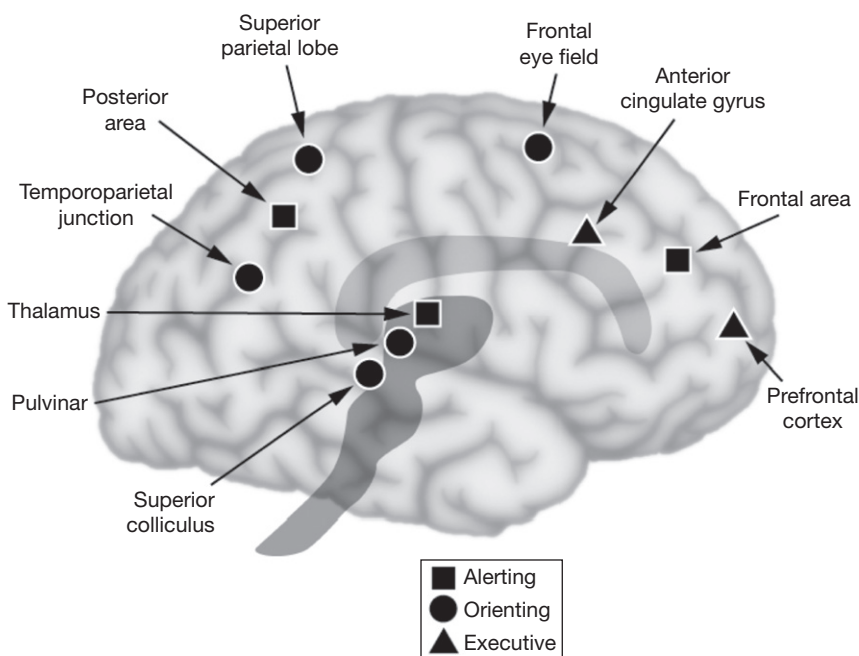
### 22.2.1 Taxonomies of Attention

Although many efforts have been made to develop taxonomies of attention, imaging studies have suggested that at least three somewhat independent networks are involved in different aspects of attention, carrying out the functions of alerting, orienting, and executive attention (Posner and Fan, 2008) (Figure 22.1). Alerting refers to achieving and maintaining a state of high sensitivity to incoming stimuli, orienting refers to the selection of information from sensory input, and executive attention

includes mechanisms for monitoring and resolving conflict between thoughts, feelings, and responses.

The brain network involved in achieving and maintaining the alert state is represented by squares in Figure 22.1. Alertness is an important prerequisite for other attentional operations. Although the alert state is often contrasted with sleep, it is probably better to consider it in relation to the default state. The default state is defined in studies using functional magnetic resonance imaging (fMRI) with an instruction not to actively process anything (Raichle, 2009). The default state is characterized by a slow oscillation between two large-scale networks. A warning signal moves the brain away from the default state toward a high level of alertness. This change involves widespread variation in autonomic signals such as heart rate (Kahneman, 1973) and cortical changes, for example, a negative shift in the scalp recorded an electroencephalogram called the contingent negative variation (CNV) (Walter, 1964).

Much of attention research involves orienting to sensory events. The ease with which the experimenter can control the presentation of visual and auditory stimuli probably accounts for the popularity of studying orienting in different organisms and ages. Precisely controlling the presentation of stimulation also allows the study of overt and covert forms of orientation. Overt orienting involves eye movements, head movements, or both toward the source of stimulation and usually occurs when sufficient time is allowed between the presentation of an orienting cue and the target. Covert orienting involves only orientation of attention and can be studied when not enough time is allowed to move the eyes, head, or both or by instructing individuals to attend to the cue



**FIGURE 22.1** The alerting, orienting, and executive attention networks. The triangles, circles, and squares indicate nodes of activation of each network.

without looking at it. The close relation of eye movements and covert shifts of attention has led to studies examining their relationship. In general, the same brain areas active before saccades also are active before covert shifts of attention (Corbetta and Shulman, 2002). However, cellular studies of alert monkeys have found that within the frontal eye fields there exist two different but overlapping populations of cells. One is active before saccades and the other before attention shifts not leading to saccades (Thompson et al., 2005). These findings suggest that eye, head, and covert attention movements become coordinated during early development so that in adults it becomes difficult, but still possible, to separate them.

Every sensory signal provides input to both sensory-specific cortical pathways and brain stem arousal systems related to alerting. Together, these signals may yield changes in a brain network of parietal and frontal areas (see circles in Figure 22.1) that orchestrate covert shifts of attention. The orienting network acts to boost the strength of input signals in sensory-specific pathways in comparison with nonattended signals.

The executive attention network is involved in the regulation of feelings (emotions), thoughts (cognitions), and actions (Posner and Rothbart, 2007a,b). The anterior cingulate gyrus, one of the main nodes of the executive attention network, has been linked to a variety of specific self-regulating functions. These include the monitoring of conflict (Botvinick et al., 2001), control of working memory (Duncan et al., 2000), regulation of emotion (Bush et al., 2000), and response to error (Holroyd and Coles, 2002). In emotional studies, the cingulate often is seen as part of a network involving the orbital frontal cortex and the amygdala that regulates our emotional response to input. Activation of the anterior cingulate is observed when people are asked to control their natural reactions to strong positive (Beauregard et al., 2001) or negative emotions (Ochsner et al., 2002). Analysis of the functional connectivity between brain areas has shown that when emotionally neutral sensory information is involved, there is strong connectivity between the dorsal anterior cingulate cortex (ACC) and the relevant sensory area (Crottaz-Herbette and Mennon, 2006); when emotional control is involved, there is functional connectivity between the ventral ACC and the amygdala (Etkin et al., 2006).

### 22.2.2 Sites and Sources of Attention

Normally, all sensory events contribute to both a state of alertness and an orienting of attention. In order to distinguish the brain areas involved in alerting and orienting (sources) from the sites at which they operate, it is useful to separate the presentation of a cue indicating

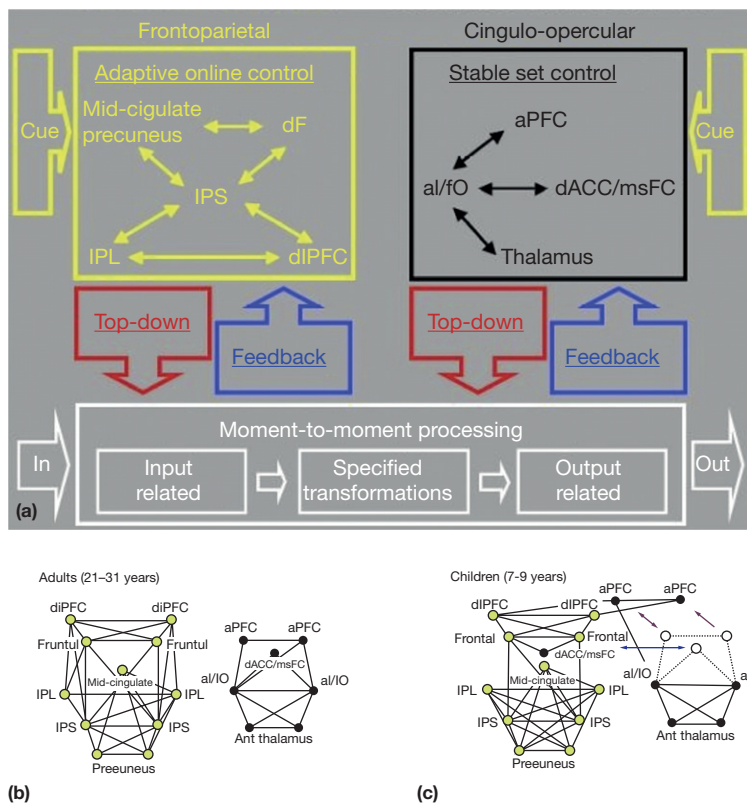
where a target will occur from the presentation of the target requiring a response (Corbetta and Shulman, 2002; Posner, 1978). This methodology has been used in behavioral studies with normal individuals (Posner, 1978), patients (Posner and Fan, 2008), and monkeys (Marrocco and Davidson, 1998), and in studies using scalp electrical recording and event-related neuroimaging (Corbetta and Shulman, 2002). Two types of cue are of interest. Some cues provide information only on when the target will occur. These warning signals lead to changes in a network of brain areas related to alerting. Other cues provide information on aspects of the target, such as where it will occur, and lead to changes in the orienting network.

Studies using event-related fMRI have shown that following the presentation of the cue and before the target is presented, a network of brain areas becomes active (Corbetta and Shulman, 2002). There is widespread agreement on the identity of these areas, but a considerable amount of work remains to be done to understand the function of each area.

When a target is presented in isolation at the cued location, the subsequent target is processed more efficiently than when no cue to its location has been presented (see Posner and Fan, 2008, for a review). The brain areas influenced by orienting will be those that would normally be used to process the target. For example, in the visual system, orienting can influence sites of processing in the primary visual cortex or in a variety of extrastriate visual areas where the computations related to the target are performed. Orienting to target motion influences area MT (V5) while orienting to target color influences area V4. This principle of activation of brain areas also extends to higher-level visual input. For example, attention to faces modifies activity in the face-sensitive area of the fusiform gyrus. The finding that attention can modify activity in primary visual areas has been of particular importance because this brain area has been more extensively studied than any other. When multiple targets are presented, they tend to suppress the normal level of activity that they would have produced if presented in isolation. One important role of orienting to a particular location is to provide a relative enhancement of the target at that location in comparison with other items presented in the visual field.

## 22.3 BRAIN CHANGES IN HUMAN DEVELOPMENT

Much of this handbook reviews the developmental brain changes that have been traced in nonhuman animals. They include material on migration of cells into cortical areas and the changes that take place in synaptic density and myelination with age. Also well



**FIGURE 22.2** The frontoparietal (orienting) and cingulo-opercular (executive) networks following the work of Dosenbach et al. (2007) (a) Greater long connections and more separation of networks in adults (b) than children (c).

documented in this volume is the role of experience in helping to sculpt gray and white matter development. This chapter deals with efforts to trace changes in development in resting connectivity and in brain activation during cognitive tasks in humans using fMRI.

An important finding was that even at rest, there is a common set of brain areas that appear to be active together (default state). While evidence for connection between brain areas related to attention is found even in infancy (Gao et al., 2009), studies suggest that the connectivity between these areas changes over the course of development. Figure 22.2 illustrates two sets of attention-related brain networks that are active at rest: they are a network of frontoparietal brain areas (related to orienting) and a cingulo-opercular (related to executive attention) network. The frontoparietal network (see top left panel of Figure 22.2) in adults is involved in short-term control operations common when orienting to sensory signals. The cingulo-parietal network (see top right panel of Figure 22.2) is involved in longer, more strategic control that fits well with an executive system (Dosenbach et al., 2007).

Connections change over the life span. The bottom panels of Figure 22.2 show that adults (left panel) have separate networks related to orienting and executive attention, while these are more integrated in children. Children at age 9 years show many shorter connections.

Adults show more segregation of the two networks and longer connections (Dosenbach et al., 2007; Fair et al., 2007, 2008). Because resting connectivity analysis requires no task, it has been studied during infancy (Gao et al., 2009). During the first year of life, the anterior cingulate shows little or no connectivity to other areas. After the first year, infants begin the slow process of developing the long-range connectivity that is typical of adults.

Some of the same brain areas found active during rest change when the person is given a task. For example, while the organization of anatomical areas in alerting and orienting is not fully known, some promising beginnings have taken place (see Posner, 2008, for a review). In alerting, the source of attention appears to be the locus coeruleus (lc). Cells in the lc have two modes of processing. One mode is sustained and is perhaps related to the tonic level of alertness over long time intervals. This function is known to involve the right cerebral hemisphere more strongly than the left. Alertness is influenced by sensory events and by the diurnal rhythm. However, its voluntary maintenance during task performance may be orchestrated from the anterior cingulate. More phasic shifts of alerting can result from presenting any environmental signal. However, if the signal is likely to warn of an impending target, this shift results in a characteristic suppression of the intrinsic brain rhythms (e.g., alpha) within a few tens of milliseconds and a



strong negative wave (CNV) recorded from surface electrodes that moves from a frontal generator toward the sensory areas of the hemisphere opposite the expected target.

Another aspect of attention, especially prominent in the transition between infancy and early childhood, is self-regulation. Effortful and voluntary control is central to a broad range of abilities in executive functioning, such as error detection, planning, memory, and problem solving. There is evidence that effortful control (EC) is linked to the executive attention network (see triangles in Figure 22.1).

It has been possible to show that infants carry out at least one of the important functions related to the anterior cingulate, the recognition of error. In one study, 7-month-old infants were found to look longer at erroneous rather than correct events (Wynn, 1992). Error events appear to cause a scalp negative electrical potential over a set of electrodes that have been localized in the anterior cingulate (Berger et al., 2006; Dehaene et al., 1994). However, the typical regulation of behavior found in adults, that is, to slow down following an error, does not seem to emerge until about the age of 3 years (Jones et al., 2003). Together, the connectivity and task data fit well with the idea that infants can process information and use executive attention to a limited degree, but they are unable to show regulation of their behavior by this network.

## 22.4 BEHAVIORAL DEVELOPMENT IN INFANCY

Attention in infancy is less developed than it is later in life, and the functions of alerting, orienting, and, particularly, executive control are less independent during infancy. Alerting and orienting are examined first, and then, executive attention in relation to self-regulation is considered. The measurement of these variables must be different in infancy than later when voluntary responses can be directed by the experimenter. Efforts have been made to design tasks that can be performed by infants that tap the same networks of brain areas shown in Figure 22.1.

### 22.4.1 Alerting and Orienting

The early life of the infant is concerned with changes in state. Sleep dominates at birth, and the waking state is relatively rare at first. The newborn infant spends nearly three-quarters of the time sleeping at birth (Colombo and Horowitz, 1987). Many of the changes in the alert state depend on external input. Arousal of the central nervous system involves input from brain stem systems that modulate activation of the cortex. As in adults, primary

among these is the lc, which is the source of the brain's norepinephrine. It has been demonstrated that the influence of warning signals operates via this brain system, since drugs that block it also prevent the changes in the alert state that lead to improved performance after a warning signal has been provided (Marrocco and Davidson, 1998). It is likely that the endogenous changes during waking that take place without external input also involve this system.

There is a dramatic change in the percentage of time in the waking state over the first 3 months of life. By the 12th postnatal week, the infant has become capable of maintaining the alert state during much of the daytime. This ability still depends heavily on external stimulation, much of it provided by the caregiver.

Much of the response to external stimuli involves orienting toward a stimulus. Newborns show head and eye movements toward novel stimuli. Eye movements are preferentially directed toward moving stimuli and have been shown to involve properties of the stimulus, for example, how much they resemble human faces (Johnson and Morton, 1991). It has also been demonstrated that newborns can make imitative responses. When shown, for example, a face with a protruding tongue, they respond with a similar movement (Meltzoff and Moore, 1977). However, the reliability and complexity of these responses to sensory input change dramatically over the first months of life.

The most frequent method of studying orienting in infancy involves tracking of saccadic eye movements. As in adults, there is a close relation, but not identity, between the direction of gaze and the infants' attention. The attention system can be driven by external input from birth (Richards and Hunter, 1998); however, the system continues to improve in precision over many years. Infant eye movements often fall short of the target, and peripheral targets are often foveated by a series of head and eye movements. Although not as easy to track, the covert system likely follows a similar trajectory. Studies that have attempted to examine the covert system by the use of brief cues that do not produce an eye movement, followed by targets that do, show that the speed of the eye movement to the target is enhanced by the cue and this enhancement improves over the first year of life (Butcher, 2000). In more complex situations, for example, when there are competing targets, the improvement may continue for longer periods.

Orienting to sensory input is a major mechanism for regulating distress. Infants often have a hard time disengaging from high spatial frequency targets and may become distressed before they are able to move away from the target. Caregivers provide a hint of how attention is used to regulate the state of the infant when they attempt to distract the infants by bringing their attention to other stimuli. As infants orient, they are often quieted, and

their distress appears to diminish. In one study, 3- to 6-month-old infants were first shown a sound and light display; about 50% of the infants became distressed by the stimulation, but then they strongly oriented to interesting visual and auditory soothing events when these were presented (Harman et al., 1997). While the children oriented, facial and vocal signs of distress disappeared. However, as soon as the orienting stopped, for example, when the object was removed, the infants' distress returned to almost the same levels as before the presentation of the soothing object. An internal system, which was termed the *distress keeper*, and which the authors believe involves the amygdala, appears to hold a computation of the initial level of distress so that it returns if the infant's orientation to the novel event is lost. Interestingly, infants were quieted by distraction for as long as 1 min, without changing the eventual level of distress reached once the orienting ended (Harman et al., 1997).

For newborn infants, the control of orienting is initially largely in the hands of caregiver presentations. By 4 months, however, infants have gained considerable control over disengaging their gaze from one visual location and moving it to another, and greater orienting skill in the laboratory is associated with lower temperamental negative emotion and greater soothability as reported by parents (Johnson et al., 1991). Late infancy is the time when self-regulation develops. Increasingly, infants are able to gain control of their emotions and other behaviors. This transition marks the development of the executive attention system.

### 22.4.2 Executive Attention in Infancy

It is difficult to assess executive attention in infants because, as outlined earlier, caregivers provide most of the regulation of infant behavior. Effortful control (EC) is a high-level factor from parental reports on children's temperament (Rothbart and Rueda, 2005). This factor is defined as the ability to withhold a dominant response to carry out a nondominant one. Parents observing their children's behavior in particular daily-life situations (e.g., putting away toys on command) can readily respond to questions that relate to this factor. This can be done for children about 2 years of age and older. Below this age, temperament questionnaires (Rothbart et al., 1994) are confined to factors such as orienting and positive and negative affect. Older children receive scores on EC. Moreover, children older than 2 years can be scored on tasks that involve voluntary responding, such as pressing keys to visual input.

As mentioned earlier, there is evidence of the presence of the executive attention network at about 7 months for the detection of error. Later in the first year of life, there is evidence of further development of

executive attention. One example is Diamond's work using the 'A not B' task and the reaching task. These two marker tasks involve inhibition of an action that is strongly elicited by the situation. In the 'A not B' task, the experimenter shifts the location of a hidden object from location A to location B after the infant's retrieving from location A had been reinforced as correct in the previous trials (Diamond, 1991). In the reaching task, visual information about the correct route to a toy is put in conflict with the cues that normally guide reaching. A toy is placed under a transparent box. The opening of the box is on the side (it can be the front side, the back side, etc.), and the infant can reach it only if the tendency to reach directly along the line of sight through the transparent top of the box is inhibited. Important changes in performance on these tasks are observed from 6 to 12 months. Comparison of performance between monkeys with brain lesions and human infants on the same marker tasks suggests that the tasks are sensitive to the development of the prefrontal cortex, and maturation of this brain area seems to be critical for the development of this form of inhibition.

Another task that reflects the executive system involves anticipatory looking in a visual sequence task (Clohessy et al., 2001; Haith et al., 1988). In the visual sequence task, stimuli are presented to the infant in a fixed and predictable sequence of locations. The infant's eyes are drawn reflexively to the stimuli because they are designed to be attractive and interesting. After a few trials, some infants will begin to anticipate the location of the next target by correctly moving their eyes in anticipation of the target. It has been shown that anticipatory looking occurs with infants as young as 3.5–4 months (Clohessy et al., 2001; Haith et al., 1988). Learning more complex sequences of stimuli, such as sequences in which a location is followed by one or two or more different locations, the particular location depending on the location of the previous stimulus within the sequence (e.g., 121312...), requires the monitoring of context and, in adult studies, has been shown to depend on the lateral prefrontal cortex (Keele et al., 2003). It was found that infants of 4 months do not learn to go to locations where there is conflict as to which location is the correct one. The ability to respond when such conflict occurs is not present until about 18–24 months of age (Clohessy et al., 2001). At 3 years, the ability to respond correctly when there is conflict in the sequential looking task correlates with the ability to resolve conflict in a spatial conflict task (SCT) (Rothbart et al., 2003). These findings support the slow development of the executive attention network during the first and second years of life.

The visual sequence task is related to other features that reflect control. One of these is the cautious reach toward novel toys. Rothbart and colleagues found that

the slow cautious reach of infants at 10 months predicted higher levels of EC as measured by parent report at 7 years of age (Rothbart et al., 2001). Infants of 7 months who show higher levels of correct anticipatory looking in the visual sequence task also show longer inspection times before reaching toward novel objects and slower reaching toward the objects (Sheese et al., 2008). This suggests that successful anticipatory looking at 7 months is one feature of self-regulation. In addition, infants with higher levels of correct anticipatory looking also showed evidence of higher levels of emotionality in a distressing task and more evidence of efforts to self-regulate their emotional reactions. Even at 7 months, the executive attention system is showing some properties of self-regulation, even though it is not yet sufficiently developed to resolve conflict in the visual sequence task (Clohessy et al., 2001) or the task of reaching away from the line of sight in the transparent box task (Diamond, 1991).

An important question about early development of executive attention is its relationship to the orienting network (Figure 22.1). Recall that the orienting network develops very early and has a critical role in regulation of emotion by the caregiver as early as 4 months. It was also found that orienting as measured from the Infant Behavior Questionnaire at 7 months was not correlated with EC as measured in the same infants aged 2 years (Sheese et al., 2009). However, orienting did show some early regulation of emotional responding in the infants. Orienting was positively related to positive affect and negatively related to negative affect. It was expected that orienting would be positively related to positive affect because previous work had shown that the duration of orienting as reported by caregivers was longer for children who smiled and laughed more. It was also expected that orienting would be negatively related to negative affect during infancy, given its use as a tool for soothing infants (Harman et al., 1997). It was also found that when the same infants were run in a conflict task (child Attention Network Test (ANT), see Section 22.5.1) at age 4 years, the regulatory functions found at 7 months were correlated more with the orienting network than with the executive network (Posner et al., 2012). As it was also found in parent reports that at the age of 2 years, the orienting network was related to control of emotion as mentioned earlier, it was concluded that in infancy and very early childhood, control is exercised by the orienting network, and only later as it becomes more connected does the executive network exert the major control.

By 2 years of age, parents can give reports that lead to a measure of EC. Two-year-old children, however, did not show the usual pattern of negative relationships between EC and negative affect that has been repeatedly found at other ages (Rothbart and Rueda, 2005). This

was unexpected, and it is possible that toddlers may be at a transition stage between emotional control by orienting and control by executive attention.

Colombo (2001) presented a summary of attentional functions in infancy, which included alertness, spatial orienting, object-oriented attention, and endogenous attention. This division is similar to the network approach but divides orienting into space and features and includes the functions of interstimulus shifts and sustained attention as part of endogenous attention. The researcher argues that alerting reaches the mature state at about 4 months, orienting by 6–7 months, and endogenous attention by 4–5 years. This schedule is similar to the order of development described earlier, but as discussed in the next major section, all these functions continue to develop during childhood. The genetic findings discussed below are new since the Colombo summary and add additional substance to the distinctions between functions and their integration in the achievement of self-regulation.

### 22.4.3 Summary

The findings to date suggest that orienting plays some of the regulatory roles in early infancy that are later exercised by the executive network. This fits with the more integrated networks shown in childhood at the bottom of Figure 22.2. Parenting may play an important role in the development of the executive attention network, perhaps partly through the presentation of novel objects that have been shown to activate the executive network in adults (Shulman et al., 2009). Further evidence for the role of parenting is presented in Section 22.6.

## 22.5 ATTENTIONAL NETWORKS AND CHILD DEVELOPMENT

### 22.5.1 Alerting Network

As discussed earlier, the state of alertness can be elicited by external stimulation, but it also varies in a regular rhythm over the course of the day and can be attained in a voluntary endogenously generated way. Young infants are able to attain the alert state when elicited by external stimulation, and they show a progressive increase in the frequency and duration of alert periods during the first year of life, whereas the ability to voluntarily deploy attention seems to emerge later and shows a steadier developmental course during childhood (Colombo, 2001).

Preparation from warning cues (phasic alertness) can be measured by comparing the speed and accuracy of response to stimulation with and without warning signals (Posner, 2008). Presentation of warning cues prior to

targets allows the individual to get ready to respond by increasing the state of alertness. This commonly results in increased response speed, although it may also cause declines in the accuracy of the response, particularly at short intervals between the warning cue and target (Posner, 1978).

The difficulty of using reaction time (RT) tasks with very young children makes studying developmental differences in preparation from alerting cues more challenging; yet several studies have examined developmental changes in phasic alertness between preschoolers, older children, and adults. In the authors' work, the ANT has been used to examine the efficiency of the three brain networks underlying attention: alerting, orienting, and executive attention (Fan et al., 2002). The task requires the person to press one key if the central arrow points to the left and another if it points to the right. Conflict is introduced by having flankers surrounding the target point in either the same (congruent) or the opposite (incongruent) direction as the target. Cues presented prior to the target provide information on where or when the target will occur. RTs for the separate conditions are subtracted, providing three measures that represent the efficiency of the individual in alerting, orienting, and executive networks. The child ANT is the same as described previously, but instead of arrows, fish are used and the child presses the key to feed or catch the central fish. Using the child ANT, Mezzacappa (2004) observed a trend to larger alerting scores (difference between RT in trials with and without warning cues) with age in a sample of 5- to 7-year-old children. Increasing age was associated with larger reductions in RT in response to warning cues. Older children also showed lower rates of omissions overall, indicating greater ability to remain vigilant during the task period. Young children (aged 5 years) also appear to need more time than older children (aged 8 years) and adults to get full benefit from a warning cue, and they also seem to be less able to sustain the optimal level of alertness over time (Morrison, 1982). The difficulty of maintaining the alert state without a cue is also observed in older children (aged 10 years) when compared to adults (Rueda et al., 2004a), suggesting that tonic or sustained attention continues to develop through late childhood.

Sustained attention is frequently measured by examining variations in performance on a task over a relatively extended period, as in the so-called Continuous Performance Tasks (CPT). Variations in the level of alertness can be observed by examining the percentage of correct and/or omitted responses to targets or through indexes of perceptual sensitivity ( $d'$ ) over time. With young children, the percentage of individuals able to complete the task can also indicate maturational differences in the ability to sustain attention. In a study

conducted with preschoolers, only 30–50% of those aged 3–4 years were able to complete the task, whereas the percentages rose to 70% for those aged 4–4½ years and close to 100% for those older than 4½ years (Levy, 1980). Even though the largest development of vigilance seems to occur during the preschool period, children continue to show larger declines in performance in CPT over time than adults through middle and late childhood, especially under more difficult task conditions, reaching the adult level by approximately 13 years of age (Curtindale et al., 2007; Lin et al., 1999).

Developmental changes in alertness during childhood and early adolescence appear to relate to continuous maturation of frontal systems during this period. One way to examine brain mechanisms underlying changes in alertness is by registering patterns of brain-generated electrical activation through electrodes placed on the scalp while warning cues are processed. Typically, several hundred milliseconds after a cue predicting the upcoming occurrence of a target stimulus is presented, a negative variation of brain activity is generated up until the target appears (Walter, 1964). This electrophysiological index is called the CNV, and it appears to be related to a source of activation in the right ventral and medial frontal (ACC) brain areas (Segalowitz and Davies, 2004). The CNV is related to performance on various measures of intelligence and executive functions as well as to the functional capacity of the frontal cortex (Segalowitz et al., 1992). The CNV and other slow waves have been related to changes in activation as studied by fMRI (Raichle, 2009). Various studies have shown that the amplitude of the CNV increases with age, especially during middle childhood. For instance, Jonkman found that the CNV amplitude is significantly smaller in 6- to 7-year-old children than in adults, but no differences were observed between 9- and 10-year-old children and adults (Jonkman, 2006). The difference in CNV amplitude between children and adults seems to also be restricted to early components of the CNV observed over the right frontocentral channels (Jonkman et al., 2003), suggesting a role of maturation of the frontal alerting network.

### 22.5.2 Orienting Network

Infants are able to orient attention to external stimulation from early in their life. Nonetheless, aspects of the attention system that increase precision and voluntary control of orienting continue developing throughout childhood and adolescence. Most infant studies examine overt forms of orienting. By the time children are able to follow instructions and respond to stimulation by pressing keys, both overt and covert orienting can be measured with this method. The cuing task has been



widely used to study the development of visual orienting over the life span. In this task, a cue is displayed prior to the presentation of a target to which a response, usually a key press, is required. The cue is aimed to induce orientation of attention to a particular location. Then, the target may appear at the cued location or at an uncued one. When the target appears at the cued location, benefits of orienting attention to that location in the RT and the accuracy of response to the target can be measured. When the cue is presented at a location different from that of the target, a decrease in RT is observed that is thought to be due to operations of disengagement of attention from the cued location and reorientation to the location occupied by the target. Imaging research and studies on patients have provided information on the brain anatomy related to each of these orienting operations (Posner and Fan, 2008). For example, endogenous (voluntary) orientation of attention is associated with structures of the superior parietal lobe and the frontal eye fields, whereas exogenous (automatic) orienting seems to be the function of a network comprised by the temporoparietal junction and ventral frontal cortex, largely lateralized to the right hemisphere (Corbetta and Shulman, 2002). Activation of these cortical areas is required for disengaging from the current focus of attention. Moving attention from one location to another involves the superior colliculus, whereas engaging attention requires thalamic areas such as the pulvinar nucleus.

Mostly using a cuing paradigm, several studies have examined the development of orienting during childhood. Despite a progressive increase in orienting speed to valid cues during childhood (Schul et al., 2003), data generally show no age differences in the orienting benefit effect among young children (5–6 years of age), older children (aged 8–10 years), and adults (Enns and Brodeur, 1989), regardless of whether the effect is measured in covert or overt orienting conditions (Wainwright and Bryson, 2002). However, there seems to be an age-related decrease in the orienting cost (Enns and Brodeur, 1989; Schul et al., 2003; Wainwright and Bryson, 2002). In addition, the effect of age when disengaging and reorienting to an uncued location appears to be larger under endogenous orienting conditions (e.g., longer intervals between cue and target) (Schul et al., 2003; Wainwright and Bryson, 2005). This suggests that mostly aspects of orienting related to the control of disengagement and voluntary orientation, which depend on cortical regions of the parietal and temporal lobes, improve with age during childhood. In a study in which endogenous orienting was examined in children aged 6–14 years and in adults, all groups but the youngest children showed larger orienting effects, calculated as the difference in RT to targets appearing at cued and uncued locations, with longer cue–target

intervals (Wainwright and Bryson, 2005). This indicates that young children seem to have problems endogenously adjusting the scope of their attentional focus. This idea was also suggested by Enns and Girgus (1985), who found that attentional focusing as well as the ability to effectively divide or switch attention between stimuli improves with age, between ages 5, 8, and 10 years and adulthood.

### 22.5.3 Executive Attention Network

Self-regulation of cognition and action can be measured in the laboratory by registering responses to tasks that involve conflict. Common conflict tasks such as the classic Stroop task require the participant to avoid paying attention to aspects of the stimulation (e.g., the word *WHITE*) that may be dominant (i.e., semantic information contained in the word) while responding to nondominant features (i.e., the color in which the word is written). From 2 years of age and older, children are able to perform simple conflict tasks in which their RT can be measured. The SCT (Gerardi-Caulton, 2000) induces conflict between the identity and the location of an object. In this task, pictures of the houses of two animals (e.g., a duck and a cat) are presented at the bottom left and bottom right sides of the screen; then one of the two animals appears either on the left or right side of the screen in each trial and the child is required to show the animal what its house is by touching it. Location is the dominant aspect of the stimulus, although instructions require responding according to its identity. Thus, conflict trials in which the animal appears on the side of the screen opposite to its house usually result in slower responses and larger error rates than nonconflict (when the animal appears on the same side as its house) trials. Between 2 and 4 years of age, children progressed from an almost complete inability to carry out the task to a relatively good performance. Although 2-year-old children tended to perseverate on a single response, 3-year-old children performed at high accuracy levels, although, like adults, they responded more slowly and with reduced accuracy to conflict trials (Gerardi-Caulton, 2000; Rothbart et al., 2003).

The detection and correction of errors is another form of action monitoring. While performing the SCT, 30- and 36-month-old children showed longer RTs following erroneous trials than those following correct ones, indicating that children were noticing their errors and using them to guide their performance on the next trial. However, no evidence of slowing following an error was found at 24 months of age (Rothbart et al., 2003). A similar result with a different time frame was found when using a version of the Simple Simon game. In this task, children are asked to execute a response when a

command is given by a stuffed animal, while inhibiting responses that are commanded by a second animal (Jones et al., 2003). Children of age 36–38 months were unable to inhibit their response and showed no slowing following an error, but at 39–41 months of age, children showed both an ability to inhibit action and a slowing of RT following an error. These results suggest that between 30 and 39 months, children greatly develop their ability to detect and correct erroneous responses and that this ability may be related to the development of inhibitory control.

The development of executive attention has also been traced into the primary school period (Rueda et al., 2004a) using the child version of the Attention Networks Test (ANT). Overall, children's RTs were much longer than those of adults, but considerable development in the speed of resolving conflict from age 4 to about 7 years was observed. However, the ability to resolve conflict on the flanker task, as measured by increases in RT and percentage of errors produced by the presence of incompatible compared to compatible flankers, remained about the same from age 7 years to adulthood. Nonetheless, studies in which the difficulty of the conflict task is increased by other demands, such as switching rules or holding more information in working memory, have shown further development of conflict resolution between late childhood and adulthood (Davidson et al., 2006).

To study the brain mechanisms that underlie the development of executive attention, some developmental studies have been carried out using event-related potentials (ERPs) and conflict tasks. In one of these studies, a flanker task was used to compare conflict resolution in three groups of children aged 5–6, 7–9, and 10–12 years, and a group of adults (Ridderinkhof and van der Molen, 1995). In this study, developmental differences were examined in two ERP components, one related to response preparation (lateralized readiness potential (LRP)) and the other related to stimulus evaluation (P3). The authors found differences between children and adults in the latency of the LRP peak, but not in that of the P3 peak, suggesting that developmental differences in the ability to resist interference are mainly related to response competition and inhibition, but not to stimulus evaluation.

Brain responses to errors are also informative of the function of the executive attention system. The error-related negativity (ERN) is a potential with a frontocentral scalp distribution that appears some time (usually between 60 and 120 ms) after an error response (Gehring et al., 1993) and is thought to be generated by the ACC (van Veen and Carter, 2002). The amplitude of the ERN seems to reflect detection of an error as well as salience of the error for a particular individual in the context of the task, and it is therefore subject to individual differences in affective style or motivation. Generally, larger ERN amplitudes are associated with

greater engagement in the task and/or greater efficiency of the error detection system (Santesso et al., 2005; Tucker et al., 1999). Developmentally, the amplitude of the ERN shows a progressive increase during childhood into late adolescence (Segalowitz and Davies, 2004), with younger children (aged 7–8 years) less likely to show the ERN to errors than older children and adults. This is likely to reflect the progressive maturation of the brain system for action monitoring and regulation.

Another evoked potential, the N2, has been related to situations that require executive control (Koop et al., 1996) and has been directly associated with activation coming from the ACC (van Veen and Carter, 2002). An ERP study was conducted in which the fish flanker task of the child ANT was used on 4-year-old children and on adults (Rueda et al., 2004b). Adults showed larger N2 for incongruent trials than for congruent trials over the midfrontal leads. Four-year-old children also showed a larger negative deflection for the incongruent condition at the midfrontal electrodes that, compared to adults, had greater amplitude and was extended over a longer period. While the frontal effect was evident in adults at around 300 ms post target, children did not show any effect 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. Another important difference between 4-year-old children and adults was the distribution of effects over the scalp. In adults, the frontal effects appear to be focalized on the midline, whereas in children, the effects were observed mostly at prefrontal sites and in a broader number of channels, including the midline and lateral areas.

The focalization of signals in adults as compared to children is consistent with neuroimaging studies conducted with older children in which children appeared to activate the same network of areas as adults when performing similar tasks, but the average volume of activation appeared to be remarkably greater in children than in adults (Casey et al., 2002; Durston et al., 2002). Altogether, these data suggest that the brain circuitry underlying executive functions becomes more focal and refined as it gains in efficiency. This maturational process not only involves greater anatomical specialization but also reduces the time these systems need to resolve each of the processes implicated in the task. This is consistent with the recent findings that the network of brain areas involved in attentional control shows increased segregation of short-range connections but increased integration of long-range connections with maturation (Fair et al., 2007). Segregation of short-range connectivity may be responsible for greater local specialization, whereas integration of long-range connectivity likely increases efficiency by improving coordinated responses between different processing modules.

### 22.5.4 Summary

The attention network shows substantial development during childhood. Rates of development appear to differ among the three networks, with alerting showing a very slow developmental time course. While the ANT shows most of the development in the executive network to occur before the age of 7 years, the connectivity data (Figure 22.2) indicate increased segregation between orienting and executive networks beyond the age of 9 years.

## 22.6 GENES AND EXPERIENCE BUILD NETWORKS

The finding that common brain networks are involved in self-regulation provides an important approach to evolution by looking at commonalities and differences in nonhuman organisms. Another approach of equal importance involves an examination of individual differences in the efficiency of this network. Such differences could rest in part on the genetic variation known to exist among individuals and in part on differences in cultural or individual experiences. The study of temperament examines individual differences in reactivity and self-regulation that are biologically based (Rothbart and Bates, 2006). One of the most important individual differences has been called 'effortful control.' It is a higher order factor consisting of a number of subscales measuring attentional and behavioral control.

### 22.6.1 Effortful Control

EC is derived from parents and self-reports of behavior in dimensions such as inhibitory control, attentional control, and low-intensity pleasure.

### 22.6.2 Attention Network Test

The ANT was used in a sample of 40 normal adults (Fan et al., 2002) where each of these measures was found to be reliable over repeated presentations. In addition, no correlation was found among the measures. An analysis of RTs in this task showed large main effects for cue type and target type. There were only two small interactions indicating some lack of independence among the cue conditions. One of these interactions was found when a cue directed orienting to the correct target location and the influence of the surrounding flankers was reduced. In addition, omitting a cue, which produces relatively long RTs, also reduced the size of the flanker interference. Presumably, this is because some of conflict is resolved in parallel with alerting.

Subsequent work has confirmed the relative independence among networks, while showing that they can interact when conditions are made more difficult or otherwise changed (Fan et al., 2009). A study using fMRI showed that the anatomy of these three networks was for the most part independent (Fan et al., 2005). In addition, each of the networks has a dominant neuromodulator arising from the subcortical brain areas. The alerting network is modulated by norepinephrine produced in the lc; the orienting network, by acetylcholine from the basal forebrain; and the executive network, by dopamine from the ventral tegmental area (Posner and Fan, 2008).

Scores on the conflict network of the ANT have been shown to correlate with the temperament factor of EC at several ages during childhood. Gerardi-Caulton (2000) carried out some of the first research linking EC to underlying brain networks of executive attention using spatial conflict as a laboratory marker task. Similar findings linking parent-reported EC to performance on laboratory attention tasks have been shown for 24-, 30-, and 36-month-old children (Rothbart et al., 2003); 3- and 5-year-old children (Chang and Burns, 2005); and 7-year-old children (Gonzalez et al., 2001). Some adult studies have also found a correlation between conflict resolution ability and EC (Kanske, 2008), and some disorders involve both executive attention (Fernandez-Duque and Black, 2006) and EC.

### 22.6.3 Daily Life

The correlation between conflict scores in this simple and easily administered cognitive task and parental reports of EC forms the basis for the association between self-regulation and executive attention.

As discussed, ANT executive attention scores and EC have been related to many aspects of child development. EC is related to the empathy that children show toward others, their ability to delay an action, and their ability to avoid behaviors such as lying or cheating when given the opportunity (Posner and Rothbart, 2007b; Rothbart and Rueda, 2005). High levels of EC and the ability to resolve conflict are related to fewer antisocial behaviors such as truancy in adolescents (Ellis et al., 2004). These findings have convinced the authors that self-regulation, a psychological function crucial for child socialization, can also be studied in terms of specific anatomical areas and their connections.

The common nature of brain networks such as those in Figure 22.1 argues strongly for the role of genes in their construction. This has led cognitive neuroscience to incorporate data into the growing field of human genetics (Green et al., 2008; Posner et al., 2007). One method for doing this relates individual variations in genes (genetic alleles) to aspects of human behavior. Brain activity

can serve as an intermediate level for relating genes to behavior. As one example, the ANT has been used to examine individual differences in the efficiency of executive attention. Strong heritability of the executive network (Fan et al., 2002) supported the search for genes related to individual differences in network efficiency.

#### 22.6.4 Neuromodulators

The association of the executive network with the neuromodulator dopamine provides a way of searching for candidate genes that might relate to the efficiency of the network (Fossella et al., 2002; Posner and Fan, 2008). For example, several studies using conflict-related tasks have found that alleles of the *catechol-O-methyl transferase* (COMT) gene were related to the ability to resolve conflict (Blasi et al., 2005; Diamond et al., 2004). A number of other dopamine genes have also been found to be related to this form of attention, and research has suggested that genes related to serotonin transmission also influence executive attention (see Posner et al., 2007, for a summary). It has also been possible to show in brain imaging studies that some of these genetic differences are related to the degree to which the anterior cingulate is activated during task performance (Fan et al., 2003). In the future, it may be possible to relate genes to specific nodes within neural networks, allowing a much more detailed understanding of the origins of brain networks underlying attention.

#### 22.6.5 Longitudinal Study

One goal of our longitudinal study was to see if the genes that were shown to influence attention in adults (Posner et al., 2007) would have specific roles in the development of self-regulation during infancy and childhood. The study began when the infants were 7 months old. The children were retested and genotyped at age 2 years and were tested a final time at age 4 years when they are able perform the ANT as a measure of executive attention.

Rothbart and Derryberry (1981) proposed a distinction between reactive and self-regulatory aspects of child temperament. They argued that early in life, negative affect, particularly fear and orienting of attention, served as regulatory mechanisms that were supplemented by parental regulation. Rothbart and Bates (2006) argued for developmental changes in which EC arose at about 3–4 years when parents could first report on their children's self-regulatory ability.

The longitudinal study has not only confirmed but also revised and extended this analysis. A negative correlation was found at 7 months between parental reports of infant orienting of attention and negative affect.

Orienting also correlates positively with reports of positive affect. By 2 years, orienting is no longer related to affect, but EC shows modest nonsignificant negative correlations with both positive and negative affect. There is substantial evidence that for children, adolescents, and adults, EC shows a negative correlation with negative affect in Western countries, although Ahadi et al. (1993) found that in China, EC was negatively correlated with positive affect in children. They argued that culture shaped the direction of the interaction between EC and emotion.

As discussed previously, the results of the longitudinal study suggest that early in life, orienting serves as a regulatory system, and it both reduces negative affect (Harman et al., 1997) and increases positive affect. In this view, both orienting and executive networks serve parallel regulatory functions during infancy. Later on, executive attention appears to dominate in regulating emotions and thoughts, but orienting still serves as a control system. This parallel use of the two networks fits with the findings of Dosenbach et al. (2007) showing that in adults their frontoparietal network controls behavior at short time intervals while their cinguloopercular network exercises strategic control over long intervals. These changes in regulation during early childhood served as a framework to examine continuities and discontinuities in the influence of genetic variations.

##### 22.6.5.1 CHRNA4

The nicotinic cholinergic receptor modulates the release of dopamine in the mesolimbic system. Polymorphisms in the CHRNA4 gene have been associated with nicotine dependence in humans and with cognitive performance (Rigbi et al., 2008). The CHRNA4 C1545T polymorphism (rs1044396) has been associated with variation in performance of shifts of attention during visual search (Parasuraman et al., 2005) and in brain activity when performing visual attention tasks (Winterer et al., 2007).

During infancy, the T/T allele of CHRNA4 is related to a better performance in anticipatory looking, but at 18 months, the C/C homozygotes have the higher scores on EC (Voelker et al., 2009). The finding that alleles associated with higher attention during infancy (as measured by anticipation) have lower parent-reported EC at age 2 years may indicate that infants who exercise control through orienting are slower to transition to control via the executive network. As the measurement at 18–20 months occurs well before regulation by executive attention is complete, infants with strong orienting may not yet have made the transition.

As visuospatial attention requires orienting, the CHRNA4 polymorphism was expected to influence orienting in the subjects, and it was thought that it might also influence higher-order attention. The authors'



genetic findings provided support for the parallel model of regulation discussed earlier. At 7 months, CHRNA4 is related to aspects of anticipatory looking (Sheese et al., 2008). At about 2 years, the main influence of this gene appears to be on EC, which depends on executive attention. In adults, CHRNA4 seems to be related to tasks that clearly involve the orienting network (Parasuraman et al., 2005), but these tasks may involve executive attention as well. These findings support the idea that gene expression during development may vary as different brain networks change in importance.

### 22.6.5.2 *Catechol-O-methyl Transferase*

COMT plays an important role in dopamine metabolism by modulating extracellular levels of dopamine. The functional Val/Met polymorphism of COMT has a measurable effect on COMT enzyme activity, with the Val allele degrading extracellular dopamine more quickly than the less enzymatically active Met allele. The Met allele has been associated with anxiety and negative mood states (Drabant et al., 2006), affective disorders (Karayiorgou et al., 1997), and decreased novelty seeking (Reuter and Hennig, 2005).

A finding from the authors' current longitudinal study is that the COMT gene, which has consistently been shown to be related to executive attention in adults and older children (Blasi et al., 2005; Diamond et al., 2004), is also related to aspects of attention in toddlers (Voelker et al., 2009). It was found that haplotypes of the COMT gene (Diatchenko et al., 2005) influenced both anticipatory looking and nesting cup activity at 18–20 months, both tasks thought to be at least partly related to executive attention. At 7 months, COMT was also related to positive affect as reported by parents. The finding of a relation of COMT to positive affect together with the influence of this gene on executive attention at 18–20 months could provide a genetic link between reactive emotion and emotional regulation during early development. However, it is also possible that COMT's relation to positive affect in infancy is mediated by regulatory aspects of executive attention. Evidence for this is mixed in the authors' current study in that positive affect in infancy was unrelated to later EC, but other studies have shown such a connection (Rothbart and Rueda, 2005).

### 22.6.5.3 *DRD4*

The 7-repeat allele of the DRD4 gene has been linked to attention deficit hyperactivity disorder (ADHD) and to the temperamental dimension of risk taking. Adults and children with the 7-repeat allele have been shown to be higher in the temperamental quality of risk-taking and at greater risk for attention deficit disorder than those with fewer repeats (Auerbach et al., 1999). In one series of studies (Auerbach et al., 1999), it was found that the orienting of 2-month-old infants as rated by parents and as observed

during inspection of toys was related to the presence of the 7-repeat allele of the dopamine 4 receptor gene. This allele appears to interact with a gene related to serotonin transmission (5-HTT) to influence orienting.

Evidence that the environment can have a strong influence in the presence of the 7-repeat alleles has been reported by other investigators (Bakermans-Kranenburg and van Ijzendoorn, 2006; van Ijzendoorn and Bakermans-Kranenburg, 2006). The same group (Bakermans-Kranenburg et al., 2008) carried out a parenting training intervention and found that the training decreased externalizing behavior, but only for those children with the DRD4 7-repeat allele. This finding is important because assignment to the training group was random, ensuring that the result was not due to something about the parents other than the training.

In the longitudinal study, the authors added an observation of caregiver–child interaction in which the children played with toys in the presence of one of their parents. Raters observed the caregiver–child interaction and rated the parents on five dimensions of parental quality according to a schedule developed by NICHD (1993): the ratings included support, autonomy, stimulation, lack of hostility, and confidence in the child. Although all the parents were likely concerned and caring, they did differ in their scores, and the combined scores were divided at the median into two groups. One of the groups was considered to show a higher quality of parenting and the other a lower quality.

A strong interaction was found between genes and parenting. For children without the 7-repeat polymorphism, variations in parenting within the range examined were unrelated to the children's scores on impulsivity and risk taking. For children carrying the 7-repeat gene variant, however, variations in parenting quality mattered. Children with this allele and high-quality parenting showed normal levels of risk taking, but those with lower-quality parenting showed very high values for risk taking. It seems paradoxical that the 7-repeat allele associated with developmental psychopathology (ADHD) is also under positive selective pressure in recent human evolution (Ding et al., 2002). Why should an allele related to ADHD be positively selected? It is the authors' view that positive selection of the 7-repeat allele could well arise from its sensitivity to environmental influences.

Parenting provides training for children in the values favored by the culture in which they live. For example, Rothbart and colleagues (Ahadi et al., 1993) found that in Western culture, EC appears to regulate negative affect (sadness and anger), while in China (at least in the 1980s), it was found to regulate positive affect (outgoingness and enthusiasm). In recent years, the genetic part of the nature by nurture interaction has been given a lot of emphasis, but if genetic variations are selected according

to the sensitivity they give children to cultural influences, this could support a greater balance between genes and environment. Theories of positive selection in the DRD4 gene have stressed the role of sensation seeking in human evolution (Wang et al., 2006). The authors' findings do not contradict this emphasis but suggest an interpretation that could have even wider significance. It remains to be seen whether the other 300 genes estimated to show positive selection would also increase an individual's sensitivity to variations in rearing environments.

How could variation in genetic alleles lead to enhanced influence of cultural factors such as parenting? The anterior cingulate receives input on both reward value and pain or punishment, and this information is clearly important in regulating thoughts and feelings. Dopamine is the most important neuromodulator in these 'reward' and 'punishment' pathways. Thus, changes in the availability of dopamine could enhance the influence of signals from parents related to reward and punishment. Another interaction has been reported between the serotonin transporter gene and parental social support on the temperamental dimension of behavioral inhibition or social fear (Fox et al., 2005). To explain this interaction, Fox et al. (2007) argue that children with a short form of the serotonin transporter gene who also have lower social support from parents show enhanced attention to threat and greater social fear. In the authors' study of the DRD4, however, attention did not appear to be the mechanism by which the genetic variation influenced the child's behavior. In the authors' study, there was no influence of the 7-repeat allele on executive attention; instead, gene and environment interacted to influence the child's behavior as observed by the caregiver. However, an interaction between the DRD4 7-repeat allele and EC as rated by parents did appear at age 4 years and older (Sheese et al., 2012). This finding lends support to the idea that control shifts to the executive network during childhood. The authors also found that the COMT genotype showed an interaction between attention and parenting quality, and unlike the DRD4, it did operate through attention even at age 2 years. However, in the case of COMT, attention involved anticipatory looking, which is at least partly influenced by orienting at this age.

Overall, the authors found both continuity and discontinuity in the influence of genetic variation in early childhood. The DRD4 influence on executive attention emerged only at age 4 years and continued into adulthood, while the COMT influence on tasks involving attention shifting was exhibited as early as 2 years. The CHRNA4 genetic variation was most variable for attention changes between infancy and adulthood. These variations appear related to the changes in dominant control networks described in this chapter.

### 22.6.6 Summary

While a few candidate genes have been related to individual differences between infants and young children, these account for only a small portion of the differences in temperament and behavior. One reason for these small effects is that parenting and other forms of cultural variation interact with genes in determining behavior. However, it is likely that the genes whose variation is related to individual differences in attention are also those important in building the common attentional networks. Combined human and animal studies may be helpful in further explicating connections between genes and control networks. See also Chapter 38 and Rubenstein and Rakic, 2013.

## 22.7 FUTURE RESEARCH

In this chapter, the authors have examined some of the tools used in studies of the human brain and mind during development. These tools may allow for a deeper understanding of how the developing brain makes possible the changes in attention and self-regulation that occur in behavior early in life. Future research should enable the use of these tools to understand how developmental changes in functional activation and connectivity relate to the specific behavioral markers at the same age. Research can help one understand how changes in activation relate to differences found in functional connectivity and in white and gray matter. Is there a fixed order of these changes, or does their rate and order of occurrence depend on whether they take place as the result of development or from practice on a task? Better coordination of human and nonhuman animal work may allow one to determine the relationship of changes found with noninvasive imaging to those seen in studies of the microanatomy and circuitry of brain areas in animal research.

It is also difficult to know how brain changes relate to behavioral changes found at the same time. Longitudinal studies will allow one to better define this relationship. Doing so may require the use of tasks and methods that remain relatively stable across ages. The use of resting fMRI may be the most important of these since it allows testing of different ages without the need to develop comparable tasks (Fair et al., 2007). The discovery that the electroencephalogram signal for error detection involves similar brain areas at 7 months as it does for adults provides another means of examining an event that may be comparable across wide differences in age. The use of more analytic behavioral observations (e.g., anticipatory eye movement, the ANT, and parent reports of temperament) may allow for the mapping of changes in mental operations to brain changes in development.

The growing knowledge of genetic and epigenetic methods has only just begun to influence research in human development. Mainly genetic variation has been related to individual differences in behavior (Posner et al., 2007). However, it seems likely that the same genes related to individual differences are involved in building the common networks underlying attention. Thus, studies designed to relate the expression of genes at particular nodes in neural networks to key aspects of behavior will be of great importance in realizing the goal of understanding how neural networks become organized in development.

Although it is known that some genetic variants interact with environmental experience, the actual mechanisms involved are not yet known, as genetic variations are expressed at numerous places in the brain and the rest of the body. As the mechanisms by which genes can be altered by the environment are enlarged in the field of epigenetics, it is possible to learn more about how training influences development.

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