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The executive attention network is involved in regulating emotions and cognitions, forming a neural basis for temperamental self-regulation. New brain imaging and molecular genetics methods can enhance our understanding of common mechanisms of self-regulation and individual differences in their expression.

Genes and Experience in the Development of Executive Attention and Effortful Control

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Findings from neuroimaging research suggest that the physical basis of thoughts and emotions can be understood in terms of activation of anatomical areas organized into networks. These findings hold out the promise of integrating psychology—as proposed by Hebb (1949, 1966) decades ago—on the basis of the behavioral consequences of how network activation influences the behavior and mental processes of the person (for a recent and more detailed argument for the integration of psychology along these lines, see Posner & Rothbart, 2004). As we come to understand how brain mechanisms allow a child to control his or her own behavior, we have increased means to help the child overcome the many difficulties involved in self-regulation.

In this chapter, we describe new research strategies in the study of temperamental differences involved in effortful control and self-regulation as inspired by this integrated approach. We first describe our current understanding of the broad structure of temperament. Then we examine the functioning of the executive attention network, which has been shown to be related to the ability to regulate thoughts and feelings. This network involves a specific anatomy, including the anterior cingulate and prefrontal areas, modulated by dopaminergic input. Individual differences in the efficiency of the network are systematically related to particular genes. Finally, we examine how the training of attention in childhood might modify the network, and we consider how the interaction of genes and environment can influence the development of self-regulation.

Temperament

Temperament has been defined as constitutionally based individual differences in emotional, motor, and attentional reactivity and self-regulation, differences that demonstrate consistency across situations and relative stability over time (Rothbart & Derryberry, 1981). The term *reactivity* refers to the latency, rise time, intensity, and duration of responsivity to stimulation. The term *self-regulation* refers to processes that serve to modulate reactivity. In this chapter, we discuss executive attention networks in the human brain related to individual differences in temperamental self-regulation, which is termed "effortful control."

The concept of temperament stresses the links between biological mechanisms and their behavioral consequences. Over its long history of study, temperament has consistently been conceptualized in terms of the biology of the organism as understood at the time. In recent research, factor analyses of parent-report questionnaires have reliably extracted three or four broad temperament factors in childhood (Rothbart & Bates, 1998, in press). The first is *surgency,* or *extraversion,* with loadings from activity level, sociability, impulsivity, and enjoyment of high-intensity pleasure. The second is *negative affectivity,* with loadings from fear, anger or frustration, discomfort, and sadness; the third is *effortful control,* with loadings from attentional focusing and shifting, inhibitory control, perceptual sensitivity, and low intensity pleasure. Imaging studies have examined the neural systems underlying each of these systems (Canli et al., 2001; Ochsner, Bunge, Gross, & Gabrieli, 2002), but in this chapter we concentrate on effortful control in relation to development of the neural networks that support self-regulation.

Effortful control is the ability to inhibit a dominant response in order to perform a subdominant response, detect errors, and engage in planning. It develops in the second or third year of life and beyond (Rothbart, Posner, & Kieras, in press; Rothbart & Rueda, 2005). The development of executive attention skills underlies effortful control; as these skills develop individuals are more able to voluntarily deploy their attention, regulating their emotional and behavioral reactivity, including tendencies such as approach, fear, and anger (Posner & Rothbart, 2000; Rothbart & Bates, in press; Ruff & Rothbart, 1996). In situations where immediate approach is not allowed, for example, children can use their attention to resist temptation and delay gratification. When faced with a threatening stimulus, children can constrain their fear by attending to environmental sources of safety. Individual differences in effortful control allow children to suppress their more reactive tendencies, take in additional sources of information, and plan more efficient strategies for coping.

Findings indicate that individual levels of effortful control stay stable across childhood and adolescence (Rothbart & Bates, in press). For example, the number of seconds that a preschool child is able to delay while waiting to obtain a reward predicts parent-reported attentiveness and ability to concentrate in adolescence (Mischel, Shoda, & Peake, 1988). Low effortful control has been linked to development of children's externalizing problems and to depression (Rothbart & Bates, in press). Effortful control is also positively associated with empathy and development of conscience (Kochanska, 1995; Rothbart, Ahadi, & Hershey, 1994). As an aspect of temperament, effortful control allows flexible regulation of thought, emotion, and behavior.

Networks Underlying Executive Attention and Effortful Control

In our work with preschool children, we have shown that the ability to regulate conflict as measured by cognitive tasks is related to effortful control as measured by parent report (Gerardi-Caulton, 2000; Rothbart, Ellis, Rueda, & Posner, 2003). The Stroop conflict task and others appropriate for children have been shown in adult imaging studies to activate a specific network of brain areas, including the anterior cingulate and lateral prefrontal areas (Fan, Flombaum, McCandliss, Thomas, & Posner, 2003). For example, when conflict is induced between the direction of a central target arrow and the direction of surrounding flanker arrows in the Attention Network Task (ANT), children and adults show elevated reaction times, and adult studies indicate activation of the anterior cingulate. These and other findings (Botvinick, Braver, Barch, Carter, & Cohen, 2001) suggest that the cingulate monitors conflict between any two systems that are simultaneously activated and as such is part of a network underlying self-regulation (Botvinick et al., 2001; Rueda, Posner, & Rothbart, 2004). In support of this view, imaging studies of adults have shown that adjacent areas of the anterior cingulate are involved in regulation of cognition and emotion (Bush, Luu, & Posner, 2000). The anterior cingulate is also activated when adult subjects are asked directly to control their emotional reactions to positive and negative stimuli (Beauregard, Levesque, & Bourgouin, 2001; Ochsner, Bunge, Gross, & Gabrieli, 2002). These results suggest that a common brain network underlies the ability to resolve conflict and that important individual differences can be measured by self-report and by the efficiency of conflict regulation in cognitive tasks.

Genes

To understand both the common characteristics of this network and how the network differs among individuals, it is important to know which genes might be involved in network function. Animal studies have shown that dopamine is the principle modulator of the frontal areas important for self-regulation, and alleles of three dopamine genes have been reported to influence performance in conflict-related tasks such as the Stroop task and versions of the flanker task appropriate for young children (Diamond, Briand, Fossella, & Gehlbach, 2004; Fossella et al., 2002). Alleles of two of these genes have been shown in an imaging study to produce differential activation of medial and lateral frontal brain areas related to executive attention (Fan, Fossella, et al., 2003).

These studies demonstrate that at least part of the variability in the efficiency of executive attention is due to genetic differences, although the differences observed so far account for only a small part of the variance found in behavioral and imaging studies of attention. The genetic differences related to individual performance may nevertheless serve as clues to the genes involved in building the networks common to all individuals. Animal studies will allow further examination of the physical details involved in constructing such networks (Grandy & Kruzich, 2004).

Attention Training

There is evidence that educational experience can influence the functional anatomy of children following training. For example, studies of reading (Shaywitz et al., 2004; Temple et al., 2003) have demonstrated greater activation in phonological and visual word form areas following training in reading. It remains to be seen if these training effects involve changes in networks or reflect learning of a skill that can now better activate the networks. Even without knowing what lies behind these functional changes, it is already clear that imaging studies can result in a significant gain in design of interventions.

For children who suffer from attention deficit hyperactivity disorder (ADHD), training of attention and working memory have been found to produce improvements in concentration and in performance on general intelligence tests (Kerns, Esso, & Thompson, 1999; Klingberg, Forssberg, & Westerberg, 2002; Shalev, Tsal, & Mevorach, 2003). These studies all involved children age eight or older, with known difficulties in attention. In our recent studies, we have worked with normal four-year-olds to determine if attention training might serve as a potential contributor to preschool education (Posner, Rothbart, & Rueda, in press; Rueda, Posner, Rothbart, & Davis-Stober, 2004). Our studies were designed mainly to support the general concept of training attention and used small samples of children for limited periods of training.

We chose to focus on children age four because our previous studies had shown improvement in performance between four and seven years of age in the ANT (Rueda et al., 2004; Rueda, Posner, & Rothbart, 2004), which surveys the efficiency of performance related to attentional networks. The exercises in this research were patterned after those used to train rhesus macaque monkeys for space travel (Rumbaugh & Washburn, 1995). Exercises began with training the child to control the movement of an animated cat by using a joystick. The children were then able to control its movement to predict where an object would move, given its initial trajectory. Other exercises emphasized the use of working memory to retain information and the ability to resolve conflict. The exercises progressed from easy to difficult in seven levels, with the requirement that children perform each level correctly three times to proceed to the next level. Most of the children were able to complete the exercises within the five days allotted. For children who did not, we abbreviated some of the exercises to allow completion. Children seemed to enjoy the training, although they were clearly tired at the end of each half-hour to forty-minute session.

Children came to the laboratory on seven days for sessions conducted over a two- to three-week period. On the first and last days, effects of the training were assessed with the ANT; the K-BIT, a general test of intelligence (Kaufman & Kaufman, 1990); and a parent-report temperament scale (Children's Behavior Questionnaire, or CBQ; Rothbart, Ahadi, Hershey, & Fisher, 2001). During administration of the ANT, we recorded 128 channels of electroencephalograms (EEGs) to observe the amplitude and time course of activation of brain areas associated with executive attention in adult studies (van Veen & Carter, 2002). In our first study, we compared twelve randomly selected children who underwent this training with twelve children who took no training but came in twice for assessment. In our second experiment, we again used 12 four-year-olds, but the control group came on seven occasions and worked with interactive videos.

The findings showed significant impact from training. Five days is a minimal amount of training to influence the development of networks that change over many years. Nonetheless, we found a general improvement in intelligence in the experimental groups compared with the control groups, as measured by the K-BIT. This was primarily due to improvement of the experimental groups in performance on the nonverbal portion of the IQ test. Reaction time (RT) measures in the ANT proved to be highly unstable and of low reliability in children of this age; thus, we were not able to obtain significant improvement in the measures of the various networks, although overall RT did improve. We found that the experimental children produced smaller conflict scores after training than the control children, but this might have been due to differences in the pretest (despite random assignment).

Analysis of the brain networks using EEG recordings showed that the trained children's performance closely resembled performance by adults when they participated in the same conflict task. The N2 is a negative wave in the event-related EEG that, when recorded over frontal areas, has been shown to arise from activity in the anterior cingulate (Rueda, Posner, Rothbart, & Davis-Stober, 2004; van Veen & Carter, 2002). Both trained children and adults showed a larger N2 component of the event-related potential in trials where they were required to resolve conflict with the surrounding flankers. This was not true of the control children. We do not know if this change indicates merely that children performed the task better or that there was a change in the underlying network. However, the finding that differences in training generalized to an IQ test suggests a more general change in the network. We did no training of IQ, and the exercises in the K-BIT did not resemble any of the training tasks, yet in our studies and in related findings with older children (Klingberg et al., 2002) significant improvement in IQ was found.

The five-day training had no effect on parent reports of effortful control. As the number of children who undergo attention training increases, however, we will be able to examine aspects of children's temperament and genotype to help understand who might benefit from attention training. To this end, we are currently genotyping the children in an effort to examine candidate genes previously found to be related to the efficacy of executive attention. We are also beginning to examine the precursors of executive attention in even younger children, with the goal of determining whether there is a sensitive period during which interventions might prove most effective.

Conclusion

We hope in the future to have some preschools adopt attention training as a specific part of their curriculum. This would allow training over a more extensive time period, and it would allow evaluation of other forms of attention training, such as those that can occur in social groups (Mills & Mills, 2000). Although we do not yet know whether our specific program is effective, much less optimal, we believe that evidence for the development of specific brain networks during early childhood offers a strong rationale for sustained study to see if we can improve the attentional abilities of children.

The neural networks underlying thought and emotion are not limited to the specific skills of attention. In the future, increased understanding of how multiple networks develop and are shaped by experience may allow many aspects of socialization to benefit from training efforts. For example, through intervention research children's social adaptations and development of conscience might also be better understood.

More research will clearly be needed to tie together differences in behavior and the neural networks involved. We believe that future work in this field must rely on close coordination of methods, including parent- and child-report questionnaires, cognitive and emotional tasks that can be used to image human networks, and investigation of specific genes that may be related to the development of these networks. These approaches have made understanding of detailed mechanisms of temperament and their consequences for behavior in the real world a reasonable direction for developmental research in the coming years.

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