Temperament, Attention, and the Development of Self-Regulation

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This research was funded by the National Institute of Mental Health (NIMH), grants MH43361 and MH01471 to the first author. Correspondence concerning this article should be addressed to: Mary K. Rothbart, Psychology Department, 1227 University of Oregon, Eugene, OR 97403-1227. Phone: (541) 346-4938; FAX: (541) 346-4911. E-mail: maryroth@darkwing.uoregon.edu.
Self-regulation has been defined as the modulation of thought, affect, and behavior, involving deliberate as well as automated mechanisms (Karoly, 1993). It is related to emotional control and planning as well as the control of one’s own behavior. The toddler and preschool years are basic to the development of self-control, emotion regulation, and planning. In this chapter, we present an integrated review of studies on the development of self-regulation from infancy to the early school years, focusing particularly on aspects of temperament, including individual differences in attention. We have defined temperament as constitutionally based individual differences in reactivity and self-regulation in emotion, activity, and attention (Rothbart & Bates, 1998; Rothbart & Derryberry, 1981). By constitutional, we mean biologically based, and influenced over time by genes, environment, and experience. Reactivity refers to the onset, intensity, and duration of emotional, motor, and orienting reactions. Self-regulation refers to processes that serve to modulate reactivity. Both reactive and regulative aspects of temperament are involved in the development of self-regulation.

Development of attention, including the control of orienting and the development of executive attention, provides a major basis for the development of self-regulation (Rueda, Posner, & Rothbart, 2004). In our view, executive attention provides a neural substrate for developing temperamental effortful control, with effortful control defined as the ability to inhibit a dominant response in order to perform a subdominant response, to detect errors, and to engage in planning. Our original discovery of effortful control as a broad dimension of temperament came from factor analyses of the Children’s Behavior Questionnaire (CBQ; Rothbart, Ahadi, Hershey, & Fisher, 2001) assessing temperament in children age 3 to 7. This research identified three broad factors, including a general factor of Effortful Control (with loadings from attentional shifting, attentional focusing, inhibitory control, and perceptual sensitivity), distinct
from factors of Surgency/Extraversion (with loadings from activity level, positive anticipation, high intensity pleasure/sensation seeking, impulsivity, smiling and laughter, and a negative loading from shyness) and Negative Emotionality (with loadings from shyness, discomfort, fear, anger/frustration, sadness, and a negative loading from soothability/falling reactivity) (Ahadi, Rothbart, & Ye, 1993; Rothbart et al., 2001). Similar broad factors have also been identified in the toddler period (Putnam, Ellis, & Rothbart, 2001), and we have found intercorrelations among measures of attentional focusing, attentional shifting, and inhibitory control in adults’ effortful control (Derryberry & Rothbart, 1988; Rothbart, Ahadi, & Evans, 2000).

In our review of the development of self-regulation and its links to temperament, we begin with the early months of life, when modulation of distress occurs through selective orienting. Early in development, the caregiver uses soothing techniques that include distracting the infant through orienting of attention; these may provide a basis for later self regulation in both orienting and executive attention. In development beyond infancy, children are able to make increasingly difficult adjustments in their thought and behavior through effortful control. We regard executive attention as a neural mechanism that underlies effortful control, and examine efforts to design tasks that can trace the development of executive attention. Effortful control is basic to socialization in the family and with peers, it is also important in children’s transition to the school environment.

Development of Self- and Other-Regulation

*Infant Studies*

The early life of the infant is concerned with the regulation of state, including regulation of distress (Sander, 1962). Orienting, the selection of information from sensory input, is a major mechanism for this regulation. Caregivers provide a hint as to how attention is used to regulate
the state of the infant when they attempt to distract their infants by bringing their attention to other stimuli (Halsted, 1991). As infants orient, they are often quieted, and their distress appears to diminish.

We have conducted a systematic study of orienting and soothing in three- to six-month old infants (Harman, Rothbart, & Posner 1997). Infants were first shown a sound and light display; about 50% of the infants became distressed to the stimulation, but then strongly oriented to interesting visual and auditory soothing events when these were presented. 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 exactly the levels shown prior to presentation of the soothing object. An internal system, which we termed the distress keeper, which we 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. In our later studies, infants were quieted by distraction for as long as one minute, without changing the eventual level of distress reached once orienting ended (Harman et al., 1997).

For young infants, the control of orienting is at first 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, Posner, & Rothbart, 1991). Related phenomena appear to be present in preschool and older children as well as adults, and they provide an important aspect of self-regulation. Adults and adolescents who report themselves as having good ability to focus and shift attention also say they experience less negative affect (Derryberry & Rothbart, 1988),
and negative emotion and effortful control are inversely related in parent-reports of temperament in toddlers and early school age children (Putnam, Ellis, & Rothbart, 2001). Indeed, many of the ideas of both modern cognitive therapy and Eastern methods for controlling the mind are based upon using attention to reduce the intrusion of negative ideation.

**Longitudinal Studies**

We have studied the development of regulatory behaviors in a longitudinal study of 66 children seen at 3, 6, 10, and 13 months of age (Rothbart, Ziaie, & O’Boyle, 1992). The infants were presented with stimuli varying in intensity and predictability to assess their temperamental reactivity, but we were struck by the degree of active coping with distress and arousal shown by the infants. We therefore coded their self-regulatory behaviors and grouped the codes into larger functional categories. These included *active avoidance* (including the codes: arch back, arm retraction, leave chair, lean away, push back and remove hand), *orientation to the mother* (look toward mother, lean toward mother, and leave chair toward mother), *disengagement of attention* (gaze aversion, look down, look away, turn head and look toward experimenter), *approach* (lean forward, reach, reach point, and inhibited reach), *attack* (bang toy, pounding and push toy away), *body self-stimulation* (arm movement, banging, body movement, kicking, and repeated hand movement), *tactile self-soothing* (hand-mouth, mouthing, touch ear-head, and clasp hands), and *respiration* (heavy breathing, sighs and yawns).

As in our study (Rothbart et al., 1992), Murphy’s (1962) observations of self-regulation and coping in infancy included stimulus selection through orienting, physical means of selection through approach, avoidance, attack, and obtaining the assistance of another person. These strategies are present in infancy, but they persist through early childhood and into later development. Murphy described the strategies in this way:
We can see here something of the early backgrounds for devices of managing stimulation: shutting out stimuli that come at an unwanted time, by turning away so as not to see, covering up ears, protesting; rejecting stimuli that cannot be handled successfully; diminishing or terminating stimulation that is too much for pleasure, or after satiation; or in greater extremity, destroying or attacking painful stimuli. On the positive side of stimulus management we see the beginnings not only of choice and selection, approach and seeking, but of techniques for evoking response, getting more of interpersonal stimulation as well as impersonal stimuli; restructuring or merely organizing stimuli to enhance the satisfaction from exchanges with the environment. (Murphy, 1962, p. 338-339)

A number of changes in self-regulation occurred across the period of our observation (Rothbart et al., 1992). First, children increasingly looked to their mothers during the presentation of arousing stimuli such as masks and mechanical toys. Children’s disengagement of attention from arousing stimuli was also related to lower levels of negative affect by 13 months. Stability from 10 to 13 months was also found in infants’ use of disengagement, mouthing, hand to mouth (e.g., thumb sucking), approach, and withdrawing the hand, suggesting that some of the infants’ self-regulation strategies were becoming habitual. Over the period of 3 to 13 months, passive self-soothing decreased and more active approach, attack, and body self-stimulation increased. Infants who showed the greatest distress at 3 months tended to persist in a very early form of regulation, self-soothing. Once a coping mechanism develops, it may persist, because it brings relief, even though more sophisticated coping mechanisms are now available.

More recent studies have found direct links between infants’ self-regulated disengagement of attention and concurrent decreases in negative affect (Stifter & Braungart,
Correlations also have been found between infants’ use of self-regulation in anger inducing situations and their later preschool ability to delay responses (Calkins & Williford, 2003). Further support of the idea that mechanisms used early to cope with negative emotion may later be transferred to the control of cognition and behavior was reported by Mischel and his colleagues (Sethi, Mischel, Aber, Shoda, & Rodriguez, 2000). Toddlers were briefly separated from their mothers, and at age five, their behavior was observed in a situation where they could delay gratification in order to receive a more valued reward. Toddlers whose use of distraction strategies increased over the period of separation were at age five years able to delay longer.

**Temperament and Early Self-Regulation**

Some children will be more subject to overstimulation and negative emotion than others, and will therefore need to decrease stimulation; other more sentient and extraverted children seek excitement (Murphy, 1962; Rothbart & Bates, 1998). Children also differ in effortful control, and we expect that the efficiency of effortful control depends in part on the strength of the dominant response (the one most likely to be made in the absence of instructions). Our only predictor of childhood effortful control from laboratory measures in infancy (we could not as yet measure this system early in life), was the speed with which children grasped high-intensity toys in the laboratory (Rothbart et al., 2000). Those who grasped the toys quickly showed higher impulsivity, anger/frustration, and aggression at 7 years, and tended to be lower in attentional and inhibitory control. Thus, strong approach tendencies may constrain the application of effortful control (Rothbart et al., 2000). If we use an analogy of approach tendencies as the “accelerator,” and inhibition tendencies as the “brakes” on behavior and emotional expression, stronger acceleration would be expected to weaken the braking influence of fear and effortful inhibitory control.
Fear as a control system. Late in the first year, some infants also begin to demonstrate fear in their inhibited approach to unfamiliar and intense stimuli (Rothbart, 1988; Schaffer, 1974), and fearful behavioral inhibition shows considerable longitudinal stability across childhood and into adolescence (Kagan, 1998). Fearful inhibition developing late in the first year of life allows inhibitory control of behavior. In our longitudinal work, infant fear assessed in the laboratory predicted childhood fear, sadness, and shyness at seven years (Rothbart et al., 2001). Fear did not predict later frustration/anger, but was inversely related to later approach, impulsivity, and aggression. These findings suggest that fear is also involved in the self-regulation of approach-related and aggressive tendencies (Gray & McNaughton, 1996).

More fearful infants also later showed greater empathy, guilt, and shame in childhood (Rothbart, Ahadi, & Hershey, 1994). These findings suggest that fear might be involved in the early development of moral motivation, and Kochanska (1995, 1997) has indeed found that temperamental fearfulness predicts conscience development in preschool age children. On the other hand, extreme fear may lead to problems in children’s rigid overcontrol of behavior, as reflected in the Blocks’ description of inflexible patterns of response that can limit children’s positive experiences (Block & Block, 1980; Kremen & Block, 1998). Thus, the temperamental dimension of fearfulness within the first year of life allows the first major control system of behavior, but it is a reactive one that can lack flexibility. During the toddler and preschool years, development of executive attention underlying effortful control allows the child greater control of stimulation and response, including the ability to select responses in a conflict situation, and we now discuss this development.

In recent exciting work by Aksan and Kochanska (2004), children who were more fearful and inhibited at 33 months showed more volitional inhibitory control at 45 months. They
suggest that more fearful and inhibited children have a greater opportunity to foster their own self-control during periods of slow approach to novel situations.

Self-Regulation in the Toddler and Preschool Years

Approach motivation related to surgency/extraversion and inhibition related to fear are both temperamental dispositions, yet we know that we can also approach the things we fear and avoid the things that promise reward. How does this come about? Effortful control provides a mechanism for this important flexibility. During the second year, language and increasing impulse control become available to the child, bringing with them the possibility of improved communication and improved self-regulation (Kopp, 1992). There is also increasing understanding of the self as an independent being in potential control of events, and increased attempts to influence objects and others (Harter, 1999). Two-year-olds do not have many self regulatory skills and little patience, however, and when their expectations are not met, they often respond with anger, sometimes crying or showing temper tantrums (Kopp, 1992).

Temperamental differences in anger are also reliably positively related to individual differences in approach or surgency/extraversion (Rothbart & Derryberry, 2002). Bronson (2000) notes the toddlers’ increasing awareness of the possibility of control; the actual skills of consciously controlling one’s own behavior will be developing during the preschool and school years, and one mechanism for this accomplishment is the development of temperamental effortful control.

Kochanska, Murray, & Harlan (2000) have characterized the construct of effortful control as being “situated at the intersection of the temperament and behavioral regulation literatures” (p. 220). 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 their positive and negative emotions or level of arousal, we are not always at the mercy of affect. Using
effortful control, we can more flexibly approach situations we fear and inhibit actions we desire. The efficiency of control, however, will depend on the strength of the emotional processes against which effort is exerted (Rothbart, Derryberry, & Hershey, 2000). For example, when the child must delay an approach response to an appealing toy, the child with a stronger disposition to approach will require greater effortful control to succeed.

Effortful control can support the internalization of competence-related goals (e.g., being kind to others, school performance), and their achievement, and is also involved in the inhibition of immediate approach with the goal of a larger reward later, in Block’s (2002) “hedonism of the future.” Effortful control allows the activation of behavior that would otherwise not be performed due to threatened punishment. In general, it allows the person to act “on principle.” Effortful control is not itself a basic motivation, but rather the means to effectively satisfying desired ends. It is similar to the attentional capacities underlying Block’s (2002) construct of ego resiliency, allowing for the flexible ability to shift levels of control depending on the situation.

Evidence for stability of effortful control has been found in research by Mischel and his colleagues (Mischel, Shoda, & Peake, 1988; Shoda, Mischel, & Peake, 1990). Preschoolers were tested on their ability to wait for a delayed treat that was preferable to a readily accessible, but less preferred treat. Preschoolers better able to delay gratification were found to have better self-control and an increased ability to deal with stress, frustration, and temptation. Their delay of gratification in seconds also predicted later parent-reported attentiveness, concentration, competence, planfullness, and intelligence during adolescence. In addition, seconds of preschool delay predicted academic competence in SAT scores, even when controlling for intelligence. In follow-up studies when the participants were in their thirties, preschool delay predicted goal
setting and self-regulatory abilities (Ayduk et al., 2000), suggesting remarkable continuity in these dimensions of self-regulatory skills.

Effortful control plays an important role in the development of conscience, with internalized conscience greater in children high in effortful control (Kochanska, Murray, Jacques, Koenig, & Vanderveest, 1996; Kochanska, Murray, & Coy, 1997; Kochanska et al., 2000). Thus, both the reactive temperamental control system of fear and the attentionally based system of effortful control appear to regulate the development of moral thought and behavior, with the influence of fear found earlier in development. At Oregon, we found that children 6-7 years old who were high in effortful control were also high in empathy and guilt/shame, and low in aggressiveness (Rothbart, Derryberry, & Posner, 1994). Effortful control may support empathy by allowing children to attend to the other child’s condition instead of focusing only on their own sympathetic distress. Eisenberg, Fabes, Nyman, Bernzweig, and Pinulas (1994) found that 4-6 year old boys with good attentional control tended to deal with anger by using nonhostile verbal methods rather than overt aggression.

Inhibitory aspects of effortful control have been related to observations of committed compliance (ready and positive acceptance of the maternal agenda) in the toddler and preschool years (Kochanska, Coy, & Murray, 2001; Kochanska et al., 1997). In this research, links were stronger in tasks where the children were asked to inhibit an enjoyable action, such as playing with attractive but prohibited toys, than in those where the child was required to initiate and sustain an activity, such as cleaning up the toys after a free play situation. Effortful control has also been related to preschool peer and teacher reported agreeableness (including helpfulness, sharing, and niceness) (Cumberland-Li, Eisenberg, & Reiser, 2004). In addition to social competence, effortful control has also been found to be related to children’s adjustment (see
Finally, individual differences in effortful control are related to aspects of metacognitive knowledge, such as theory of mind, i.e., 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. Because of the centrality of effortful control to the broad range of abilities in executive functioning, such as planning, memory, and problem solving, we focus on the development of executive attention in the next section.

**Executive Attention**

Functional neuroimaging has allowed many cognitive tasks to be analyzed in terms of the brain areas they activate, and attention has been examined in this way (Corbetta & Shulman, 2002; Driver, Eimer, Macaluso, & van Velzen, 2004; Posner & Fan, in press). Imaging data support the presence of three networks related to different aspects of attention, carrying out the functions of alerting, orienting, and executive attention (Posner & Fan, in press). 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 among thoughts, feelings, and responses. Executive attention is seen to provide the neural basis for effortful control.

The anterior cingulate gyrus, one of the main nodes of the executive attention network, has been linked to a variety of specific functions related to self-regulation. These include the
monitoring of conflict (Botvinick, Braver, Barch, Carter, & Cohen, 2001), control of working memory (Duncan et al., 2000), regulation of emotion (Bush, Luu, & Posner, 2000), and response to error (Holroyd & Coles, 2002). In emotion studies, the cingulate is often seen as part of a network involving 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, Levesque, & Bourgouin, 2001) or negative emotions (Ochsner, Bunge, Gross, & Gabrieli, 2002).

*Development of Executive Attention*

Assessments of executive attention have focused on situations of conflict and delay tasks in which it is easy to identify the dominant (inhibited) and subdominant (activated) responses. For example, in the standard Stroop task, where different color words are printed in conflicting ink colors, naming the color of ink is a subdominant response (requiring longer reaction times) for a skilled reader than in naming the word, which is a dominant response. Since reading is learned rather late, a number of conflict tasks have been developed for younger children, such as the Day/Night Stroop task (Gerstadt, Hong, & Diamond, 1994), where children are asked to say “day” when they see a picture associated with night (e.g., moon and stars) and “night” when they see a picture associated with day (e.g., sunshine).

Another example is the spatial conflict task in which object identity and spatial location of a stimulus are placed in conflict. In this task the child has two response keys, labeled with pictures of stimuli. The stimuli are presented on a computer screen and the child is instructed to press the key that corresponds to the picture that is presented. Conflict trials are those in which the stimulus appears on the side opposite the corresponding key (Gerardi-Caulton, 2000; Simon, 1969). Another example is the flanker task, in which the response to a target is in conflict with
surrounding stimuli, such as pressing a key corresponding to a fish that is facing one direction, while several fish on either side of it are facing the opposite direction (Ericksen & Ericksen, 1974; Rueda, Fan, et al., 2004). Both the spatial conflict task and the flanker task have been linked to functioning of the brain’s executive attention network (Fan, Flombaum, McCandliss, Thomas, & Posner, 2003), and can be used as model tasks for its development.

Figure 1 provides a timeline illustrating changes in children’s performance on tasks that assess executive attention or executive functioning during early childhood. Different tasks have been used at different ages. The ranges above the time line represent periods where there has been significant improvement in children's performance on the tasks. The arrows below the timeline indicate the age at which children typically can perform each task successfully. Performance was considered typical for children of a given age when either: 1) the authors of the referenced paper stated that most children of this age could perform the task successfully or that successful performance was typical at that age, or 2) data indicated that the majority of children could perform the task successfully. A bold box indicates that the arrow points to the earliest age at which most children can do the task: here, the referenced paper reported that children of the previous age on the time line could not perform the task successfully.

The tasks discussed involve two different types of responses: those that are reflexive and non-arbitrary (such as reaching along the line of sight), and those that are based on an arbitrary rule (such as sorting red cards on the left and blue cards on the right). The difficulty of delay and conflict tasks and the developmental course of their successful completion depend in part on the strength and automaticity of the response to be inhibited, and the arbitrariness of the non-dominant response.
Non-conflicting responses can be learned as early as 3 to 4 months. At 3 to 4 months, infants can move their eyes in anticipation of a visual event that has repeatedly occurred at a particular location (Haith, Hazen, & Goodman, 1988). They can also execute a series of eye movements in anticipation of locations when the next location is unambiguous (e.g., positions 1, 2, 3, 1, 2, 3). However, if conflict is induced (e.g., in the sequence 1, 2, 1, 3, where a 1 is followed by a 2 early in the sequence, but by a conflicting 3 later in the sequence), children are unable to successfully resolve the ambiguity until about 2 years of age (Clohessy, Posner, & Rothbart, 2001).

During the first year of life, children learn to resolve conflict between reaching along the line of sight and detour reaching in a 3-sided, transparent plexiglas box (e.g., Diamond, Cruttenden, & Neiderman, 1994). Late in the first year, children can also pass the A ~ B task, showing that they are able to override an automatic (non-arbitrary) dominant response (repeating a previously rewarded motor movement toward an object) and replace it with another relatively automatic but initially subdominant response (reaching and looking toward the location where the object was just hidden) (Diamond, 1991).

Between 30-36 months, children learn to perform the spatial conflict key press task described above. This task requires inhibiting the dominant response toward a spatial location, in order to make a response based on matching identity (Gerardi-Caulton, 2000; Rothbart, Ellis, Rueda, & Posner, 2003). At 24 months, children are only able to carry out the task when the stimulus is on the same side of the computer screen as the matching response key (congruent condition), but by 30 months, most children can handle the incongruent trials where the matching target is on the opposite side of the stimulus (adults are also slowed by this condition). Children
performing better on spatial conflict have also been rated by their parents as having relatively higher levels of temperamental effortful control and lower levels of negative affect (Rothbart et al., 2003), and children at 30 months who performed well on the spatial conflict task also performed well on the eye movement conflict task. Two-year-old children who were unable to complete the spatial conflict task were described by their parents as having lower effortful control and higher negative affectivity on the CBQ measure of temperament (Rothbart et al., 2003). These findings are consistent with the idea that the capacity to engage in rule based action supports responding to social rules and regulating emotion.

Games of young children like “Simon Says” or “Mother May I?” give children practice under conflict in inhibitory control (Reed, Pien, & Rothbart, 1984), and a somewhat more difficult conflict task involves asking the child to follow the well learned instruction of one puppet, while inhibiting the instruction when given by another puppet (Simple Simon game) (Jones, Rothbart, & Posner, 2003), an arbitrary instruction. At 36-38 months children were unable to avoid responding to both puppets, and showed no slowing following making an error. However, at 39-41 months most children were correct on both kinds of trials and also slowed their responses after a mistaken compliance, indicating they had detected an error. Physical responses often provide the means of self-regulation in these inhibition tasks. In the Simple Simon game, for example, rather than using verbal means of self-regulation, preschool children frequently physically prevented their actions by sitting on their hands or holding down one hand with the other (Jones et al., 2003).

Thirty-six-month-old children can sort cards based on an arbitrary one-dimensional rule (e.g., blue cards go on the right, red cards on the left). Frye, Zelazo, and Palfai (1995) found that 30-month-old children could demonstrate they knew a card sort rule, but they were not able to
sort cards based on that rule until about three years of age (Frye et al., 1995). For example, children might be told that red cards are to be placed in a pile on the left and blue cards in a pile on the right. When asked “which pile do the red (or blue) cards go in?” most children of 30 months can indicate the location correctly. However, when asked to put each card in its place, most of them are unable to do so. Children who correctly answer the knowledge questions continue to make errors on the actual sorting task until about 36 months. Most of the errors involve putting a card in the pile where a card was placed on the previous trial. This is similar to the A ~ B error, in that the children have a tendency to repeat a motor movement in spite of a change in the stimulus context. However, in this case, the task involved arbitrary sorting rules, rather than more reflective or automatic response tendencies. In summary, from infancy to age three, children learn first to regulate conflict in relation to reflexive actions, and later begin to develop the ability to behave in ways that are consistent with arbitrary cognitively represented rules.

Years Three to Six

Between three and five years of age, children develop the ability to succeed in tasks where the subdominant responses directly conflict with the dominant responses. These include saying “day” for a picture of night and vice versa (Carlson & Moses, 2001; Gerstadt et al., 1994). Diamond, Kirkham, and Amso (2002) tested children on the day/night task and a modified version, where children were told to say “pig” or “dog” for the day and night picture stimuli. Children performed more poorly on the day/night version than on the pig/dog version, indicating that conflict of the response contributed to the difficulty of the task. They also include making a conflicting motor response in the Hand Game (Hughes, 1998). In the hand game, children first repeat the hand movements of the experimenter, either making a fist or placing the hand flat on
the table. Later, children are asked to make the fist when the experimenter puts the hand down flat, and vice versa.

Correct performance on two-dimensional card sorts is not seen until 4 to 5 years (Zelazo, Muller, Frye, & Marcovitch, 2003). In this case, the dominant response is arbitrary (e.g., color) and has been learned during the pre-switch phase, which can be as short as only one trial. The subdominant response follows a new arbitrary set of rules (e.g., shape). Children tend to perseverate on the pre-switch rules when they are in conflict with the post-switch rules. Improvement during these years may be due in part to children’s ability to organize rules into a hierarchical system, where the child switches from one set of rules to another, depending on a specific condition, reducing conflict between the pre- and post-switch rules (Zelazo et al., 2003).

Tasks measuring children's abilities to suppress a dominant response (inhibitory control) are often included in effortful control batteries (e.g., Kochanska et al., 1997; Kochanska, Murray, Jacques, Koenig, & Vandegeest, 1996). The subdominant conflicting response is always to inhibit an action, so the difficulty of the task depends on how strong the dominant response is. A number of inhibitory control tasks require the child to wait for a signal before responding. For example, in the Pinball task, children are asked to hold onto the plunger that releases a ball until the experiment says "go" (Reed et al., 1984). The goal here is to inhibit the dominant response, which is releasing the plunger and shooting the ball into the game. Another set of tasks used to assess inhibitory control involves slowing down motor activity (Kochanska et al., 1996). Different variants of these tasks have been used to study children between ages two and six. Generally, children are asked to perform a motor task, such as walking down a strip of tape on the floor or drawing a line on a piece of paper and are then asked to perform the same task again, only as slowly as possible. Children’s times on the two sets of trials are compared to get a
measure of their abilities to slow down their motor activity. As shown in Figure 1, children show improvement in waiting for a signal and slowing down motor activity and other inhibitory tasks between 2 and 6 years of age (Kochanska et al., 1997; Kochanska et al., 1996; Reed et al., 1984).

Summary

In summary, as executive attention develops, there are changes in the conflicts that children are able to resolve. Children by a year of age can override a strong, natural or non-arbitrary tendency, provided that the subdominant response is also somewhat natural; children at age 2 can resolve conflicts related to spatial locations; children older than 2.5 can apply a matching rule and override a tendency to reach in the direction of the original stimulus when pressing a key; and between 3 and 5 years, children learn to resolve conflicts in which the subdominant and dominant responses are in conflict with one another. Children’s skills at conflict resolution as measured on flanker tasks continue to improve at least until age 7 (Rueda, Fan, et al., 2004). When tasks involve other executive functions, such as the ability to retain multiple dimensions in working memory, or planning several steps ahead as in the Tower of Hanoi problem (Klahr & Robinson, 1981), development occurs later and may be more protracted. Improved performance on more complex conflict-related tasks can be observed up to middle childhood, and full development of these skills may not take place until early adulthood (Rothbart & Rueda, in press).

Environmental and Genetic Influences on Effortful Control

Social Environment

What social experiences might facilitate the development of effortful control? Although it is difficult to separate the direction of influence in these studies, 18-month-olds’ use of
distraction and constructive coping during frustration is related to their mothers’ guidance by positive rather than negative, directive, or controlling behavior (Calkins & Johnson, 1998). This correlation was found concurrently at 18 months, and mothers’ behavior at 18 months predicted their children’s self-regulation at 24 months (Calkins, Smith, Gill, & Johnson, 1998). Similar findings have linked warm and supportive parenting to later inhibitory and attentional control (Gilliom, Shaw, Beck, Schonberg, & Lukon, 2002; Kyrios & Prior, 1990). Kochanska et al. (2000) found that mother’s responsiveness at 22 months predicted effortful control at 22 and 33 months, whereas mothers’ use of power assertive discipline was linked to low levels of effortful control. The relation between parental power assertion and children’s later conscience development has also been found to be mediated by children’s level of effortful control, with mothers’ power assertion negatively predicting child effortful control, which continued to predict conscience even though the effect of power assertion dropped to non-significance (Kochanska & Knaack, 2003).

Although the direction of influence could be from mother to child in these studies, it is important to remember that the direction of influence may also be reversed, so that children who are difficult to regulate may require more controlling efforts from parents at the earlier ages, and children who are more self-regulated may elicit more warmth and approval. This raises the question of possible genetic influences on the development of executive attention and effortful control.

Genes

Goldsmith, Buss, and Lemery (1997) have found evidence for both genetic and shared family influences on CBQ effortful control scales in childhood, and Fan, Wu, Fossella, & Posner (2001) have found evidence for heritability of executive attention in adulthood. Links have also
been reported between specific genes related to dopamine and norepinephrine function and individual differences in the efficiency of executive attention (Diamond, Briand, Fossella, & Gehlbach, 2004; Fossella, Posner, Fan, Swanson, & Pfaff, 2002). In infants, specific genes have also been linked to lower orientation and higher distress scores (Auerbach et al., 1999; Ebstein et al., 1998). Suomi and his colleagues have recently reported interactions between genes and environment in rhesus monkey studies. In these studies, the effect of specific genes depended on peer versus mother rearing, with a short allele of the 5-HTTLR gene linked to lower orientation scores, but only for monkeys who had been nursing monkeys reared with peers, not for mother reared monkeys (Barr et al., in press; Bennett et al., 2002). One interpretation of these findings is that mothers may buffer their infants’ experience so as to moderate the expression of the genetic characteristic. This work may serve as a model for future research in understanding the development of self-regulation.

*Training*

We have tested whether a specific educational intervention during development of executive attention in 4- and 6-year-olds can influence the efficiency of children’s attention (Rueda, et al., 2005). Since a central aspect of the executive attention network is the ability to deal with conflict, we used this feature to design a set of training exercises adapted from efforts to train rhesus monkeys for space travel (Rumbaugh & Washburn, 1995), which had resulted in monkeys’ ability to resolve conflict in a Stroop-like task (Washburn, 1994). Our exercises began with training the child to control the movement of an animated cat on a computer screen by using a joystick. Other exercises involved prediction of where an animated figure would move, given its initial trajectory, retention of information for a matching to sample task, and the resolution of conflict.
We tested the efficacy of a very brief five days of attention training with children brought to the laboratory over seven days for sessions lasting about 40 minutes and conducted over a two- to three-week period. The first and last days were used to assess the effects of the training on the attention network test (Rueda, Fan, et al., 2004), which assess the efficiency of the alerting, orienting, and executive network, and was performed while recording 128 channels of EEG recorded from scalp electrodes. In addition we used a general test of intelligence (the K-BIT, Kaufman & Kaufman, 1990) to determine how well the learning might generalize, and a temperament scale (CBQ; Rothbart et al., 2001).

We randomly assigned 4- and 6-year-old children to experimental groups that underwent the five days of training or to one control group that had only pre and post tests or to one that came in for five days to work with interactive videos. The trained children showed better overall scores in the executive network than either control group, but this difference was not significant owing to extreme variability. However, the training generalized to overall IQ and to the matrix sections of the K-BIT test, tests were quite different than the training. EEG evidence suggested that the children after training had more adult like event-related potentials in comparison to what was found prior to training or in either of the control groups. There were no main effects of training on temperament scores, but we are examining the role of temperament and of genes in the pre-post differences and in the rate of learning during training. These results provide evidence of some ability to train the executive attentional network. How replicable and general these effects are and how long they would last is still unknown.

Somewhat similar forms of training involving working memory for older children with ADHD have also improved performance on the same aspects of the K-BIT as we found (Klingberg, Forssberg, & Westerberg, 2002). An additional fMRI paper (Olesen, Westerberg, &
Klingberg, 2004) reported increased prefrontal and parietal activity after training of working memory in these children.

Future Prospects in Self-Regulation Research

While our understanding of the biology of socialization is still very incomplete, we know that the neural networks underlying the control of thoughts and emotions develop strongly during early childhood. We also have evidence of the influence of genes in laying down the common structure of these networks and influencing individual differences in their efficiency, as well as influences provided by specific early experiences. The task remains to understand these developments more fully, to expand the range of attention training and socialization, and to link them in detail to the improvement in task performance during early childhood, as documented in Figure 1.

It will also be important to further link children’s attentional skills to the kind of emotional self-regulation and coping mechanisms they develop early and later in life. This will of necessity require longitudinal research that takes into account individual differences in temperament, and make links early coping strategies to those used later in development. A related concern will be to follow the ways in which fearful self-regulation may be unhelpful for adaptation, when reflected in rigid and self-limiting control of thought, emotion, and behavior (Block & Kremen, 1996), and in links of fearful inhibition, anxiety and depression (Rothbart & Bates, in press; Rothbart & Posner, in press).
References


Figure Caption

Figure 1. The Development of Executive Functioning. Ranges above the time line represent significant improvements in children's performance on the tasks. Arrows below the timeline indicate the age at which children can typically perform each task successfully. A bold box indicates that the arrow points to the earliest age at which most children can do the task. In these cases, the referenced paper found that children of the previous age on the time line could not perform the task successfully. For example, children were able to perform the action version of the 1-dimensional card sort task at age 3, but not at age 2.5. A non-bolded box indicates that the previous age was not tested.

The numbers next to the tasks correspond to the following references: 1) Rothbart et al. (2003); 2) Sharon & DeLoache (2003); DeLoache (1995); 3) Kochanska et al. (1996); 4) Diamond (1991); 5) Diamond et al. (1994); 6) Zelazo & Reznick (1991); 7) Thompson, Barresi, & Moore (1997); 8) Carlson & Moses (2001); 9) Jones et al. (2003); 10) Johnson et al. (1991); 11) Hughes (1998); 12) Zelazo et al. (2003); 13) Klahr & Robinson (1981); and 14) Kochanska et al. (1997).