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# School Readiness

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## *Integrating Cognition and Emotion in a Neurobiological*

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## *Conceptualization of Children's Functioning at School Entry*

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*The author examines the construct of emotionality, developmental relations between cognition and emotion, and neural plasticity and frontal cortical functioning and proposes a developmental neurobiological model of children's school readiness. Direct links are proposed among emotionality, use-dependent synaptic stabilization related to the prefrontal cortex, the development of executive function abilities, and academic and social competence in school settings. The author considers research on the efficacy of preschool compensatory education in promoting school readiness and recommends that programs expand to include curricula directly addressing social and emotional competence. Research should focus on the ontogeny of self-regulation and successful adaptation to the socially defined role of student, the development of prevention research programs to reflect this orientation, and interdisciplinary collaborations that integrate scientific methods and questions in the pursuit of comprehensive knowledge of human developmental processes.*

**T**he character of work and society in the United States is changing. The technological nature of the information-based economy is placing increased emphasis on the active role of the individual in seeking out and applying knowledge in diverse ways. The workplace and the classroom increasingly require ready access to information and analytical and creative thinking skills that allow for self-regulated learning through goal setting, strategy use, and self-monitoring. Indeed, some see the ability of our educational institutions to enhance thinking skills and produce self-regulated learners as having broad implications for the future role of the United States in the global economy and the ongoing viability of the democratic process (Bransford, Brown, & Cocking, 1999; President's Committee of Advisors on Science and Technology, 1997).

From the standpoint of research on learning, the growing emphasis on thinking skills and self-regulation signals the need for increased understanding of the ways in which young children become active seekers and appliers of knowledge (Lambert & McCombs, 1998). High levels of motivation and self-regulation are clearly associated with academic achievement independent of measured intelligence (Gottfried, 1990; Skinner, Zimmer-Gembeck, &

Connell, 1998). The developmental origins of motivation and engaged learning during early childhood, however, are less well known. Parents' involvement, peer-group influences, and school characteristics have all been shown to influence motivation and engagement (e.g., Eccles, Wigfield, & Schiefele, 1998; Grolnick & Ryan, 1989; Ryan, 2000). But children's characteristics associated with engagement in learning, particularly those related to brain development, have been less well studied.

Recent advances in developmental neuroscience indicate the rapid growth and modification in infancy and early childhood of brain areas that subserve self-regulation, including emotion, memory, and attention (Nelson & Luciana, 2001). An important next scientific step in the study of self-regulation and engaged learning is the examination of implications of this rapid change and its determinants for functional outcomes, such as the adjustment to school (Byrnes & Fox, 1998).

To this end, I propose a neurobiological model of the development of self-regulation skills and examine implications of this developmental model for the concept of school readiness. Although somewhat speculative in my approach, I look to recent research in affective neuroscience and in relations between cognition and emotion and consider how emotionality and influences on emotionality may be important for children's developing brains and attempts at effortful, self-regulated learning. Emotionality may be particularly relevant to brain development in areas of the cortex that underlie the cognitive processes involved in self-regulated learning. Researchers examining self-regulation in adolescence and adulthood have long recognized the relevance of emotional state and emotion-related processes to the functioning of component processes of cognitive regulation. Implications of emotionality for cognitive regulation in young children, in whom brain structures associated with emotionality are developmentally in advance of those as-

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sociated with higher order thinking, however, have not really been considered.

To this end, I detail a central role for emotionality and emotion-related functioning in neurological development and children's adjustment to school. I conclude by suggesting that influences on emotionality can influence the development of neurological interconnections among structures underlying emotion and higher order cognition. As such, these influences on emotionality are particularly relevant to the design and implementation of early compensatory educational programs to promote children's school readiness (see Nelson, 2000b) and can assist in the ongoing construction of an empirical foundation on which to erect social policy designed to meet America's foremost educational goal: ensuring that all children enter school ready to learn (Lewit & Baker, 1995; Zigler, 1998). However, although my focus is on the development of self-regulation abilities as an aspect of school readiness, only by keeping in mind that readiness is a multidimensional construct involving family, peer, school, and community levels of influence will the value of the neurodevelopmental perspective on self-regulation become apparent. Ecologically minded thinkers on readiness focus on transactional, systemic models of influences and seek to define processes at multiple levels (S. L. Kagan, 1990, 1992; Meisels, 1996; Pianta & Walsh, 1996). Within this developmental transactional approach, the study of emotionality provides an excellent framework for arraying multiple influences on readiness.

## **Readiness as Regulation**

Whether defined as the regulation of emotion in appropriate social responding or the regulation of attention and selective strategy use in the execution of cognitive tasks, self-

regulatory skills underlie many of the behaviors and attributes that are associated with successful school adjustment. Researchers have long considered intelligence to be a key predictor of success in school. Indicators of self-regulation ability, however, are independent and perhaps equally powerful predictors of school adjustment. Much of the literature on school readiness points to the importance of self-regulation (Grolnick & Slowiaczek, 1994; Normandeau & Guay, 1998; Wentzel, Weinberger, Ford, & Feldman, 1990). Clear relations between achievement and the percentage of time that students are engaged in academic activities have been demonstrated both in elementary and in preschool regular and special education classrooms (Carta, Greenwood, & Robinson, 1987; Greenwood, 1991).

Emotionality and regulatory aspects of measures of temperament have also been implicated in school achievement in both regular and special education classrooms. Children who are temperamentally less distractible and exhibit more positively valenced and moderate levels of emotional intensity are rated by their teachers as being more teachable and achieve at higher levels academically than do children without these characteristics (Keogh, 1992; Martin, Drew, Gaddis, & Moseley, 1988; Palinsin, 1986). As well, aspects of social and cognitive self-regulation, such as those implicated in friendship and social interaction skills (Ladd, Birch, & Buhs, 1999) and in perceived control over learning (Skinner et al., 1998), point to a key role for children's self-regulatory ability in the transition to school.

Further, data from the National Center for Education Statistics survey of kindergarten teachers' ratings of child characteristics considered to be essential or very important to being ready to start kindergarten indicate teachers' predominant concern for regulatory aspects of children's behavior (Lewit & Baker, 1995). In particular, it is noteworthy that 84% of teachers endorsed that children need to be able to communicate wants, needs, and thoughts verbally, 76% endorsed the idea that children need to be enthusiastic and curious, and 60% endorsed that children need to be able to follow directions, not be disruptive of the class, and be sensitive to other children's feelings. In contrast, only 21% of teachers endorsed the need for children to be able to use a pencil or paintbrush, and only 10% and 7%, respectively, endorsed knowing several letters of the alphabet and being able to count to 20 as being essential or very important to being ready to start kindergarten.

In addition, in a survey conducted by the National Center for Early Development and Learning, 46% of a nationally representative sample of kindergarten teachers indicated that over half the children in their class lacked the kinds of abilities and experiences that would enable them to function productively in the kindergarten classroom (Rimm-Kaufman, Pianta, & Cox, 2000). This suggests that many children are arriving at school without effective self-regulation skills. Overall, the results of these teacher surveys clearly indicate that kindergarten teachers are concerned with children's regulatory readiness for school activities rather than with more strictly cognitive and academic aspects of readiness. The surveys suggest that

teachers are concerned with being able to teach; that is, they are concerned with the capacity of each child to be attentive and responsive and to become engaged in the classroom.

## Development of Regulation

Despite growing interest in self-regulation and evidence for its direct relevance to school readiness, individual differences in self-regulation and the relation of these individual differences to functional outcomes, such as the adjustment to school, have not been studied. The developing cognitive skills that, in part, form the basis for self-regulated learning are generally referred to as executive or metacognitive skills. Executive function is a construct that unites working memory, attention, and inhibitory control for the purposes of planning and executing goal-directed activity (Bell, 1998; Lyon & Krasnegor, 1996; Zelazo, Carter, Reznick, & Frye, 1997). That is, the construct combines basic cognitive processes within a goal-directed executive that marshals resources toward a desired end state.

Normative developmental study of executive function, usually in cross-sectional designs with a battery of neuropsychological assessments, indicates an age-related maturational developmental course for the construct and its component processes (Krikorian & Bartok, 1998; Luciana & Nelson, 1998; Welsh, Pennington, & Groisser, 1991). These findings support the idea that the emergence of behaviors indicative of cognitive processes involved in executive function are dependent to some extent on the development of the prefrontal cortex at ages approximately congruent with school entry (Gerstadt, Hong, & Diamond, 1994; Luciana & Nelson, 1998). As well, the finding that executive ability and general intelligence are only moderately correlated (Krikorian & Bartok, 1998; Welsh et al., 1991) further underscores that executive regulatory skill is an independent contributor to the school-adjustment process. Clinical examination of frontal lobe damage has indicated that frontal dysfunction, depending on the exact location of the deficit, leaves specific cognitive abilities and general intelligence largely intact but greatly impairs planning, self-monitoring, attention, and responsiveness to impending reward or punishment (Damasio, 1994; Eslinger, Biddle, Pennington, & Page, 1999; Tranel & Eslinger, 2000).

A longitudinal study of the development of one aspect of executive cognition, referred to as effortful or inhibitory control has demonstrated it to be an antecedent of the internalization of norms of conduct in young children (Kochanska, Murray, & Coy, 1997). When examined by a multimethod measure defined as the ability to inhibit a predominant response when instructed to engage in a subdominant response (i.e., to be told to wait to eat a cookie or to unwrap a present), effortful control has been shown to increase with age, to be stable, and to become increasingly coherent.

As well, several characteristics of children and parents have been associated with the construct of effortful control. Children's capacity for focused attention in infancy and maternal responsiveness to children, as well as parental

personality characteristics such as dependability, prudence, and self-control, have been associated with variation in effortful control (Kochanska, Murray, & Harlan, 2000). Similarly, maternal responsiveness in infancy, as assessed by a measure of the affective synchrony of the mother and child in face-to-face interaction, has been identified as a precursor of effortful control at age 24 months. Most notably, however, the interaction of mother-child affective synchrony with child negative emotionality appears to be a highly salient predictor of self-regulation. In particular, the impact of affective synchrony in mother-infant interaction on the development of effortful control is large for children exhibiting high negative emotionality in infancy. The effect of affective synchrony on effortful control for infants not characterized by negative emotionality is substantially smaller (Feldman, Greenbaum, & Yirmiya, 1999).

## Cognition and Emotion

Although the study of individual differences in the development of self-regulation is perhaps not well advanced, the studies outlined above highlight several important points regarding the development of this research. These studies indicate that self-regulation ability emerges gradually over time, that basic cognitive abilities in infancy, such as attention, support self-regulation behavior, and that emotionality and the interaction of emotionality with rearing experience are likely to be central to a full understanding of self-regulation and its development.

With this empirical literature in mind, I take emotionality as a starting point and consider the interface of cognition and emotion in the development of self-regulation in young children. I am particularly interested in the ways in which the construct of *emotionality* (Rothbart & Derryberry, 1981; also referred to as *affective style*, Davidson, 1992)—that is, a general disposition to relatively high or low reactivity to emotion-inducing stimuli and tendencies toward approach or withdrawal in response to these stimuli—may be related to the development of higher order effortful cognitive control of behavior. Theories of self-regulation in adults identify emotion, specifically affect (the conscious experience of emotion), as relevant to self-regulation ability.

An important distinction between self-regulation in children and adults, however, may relate to the theoretical understanding of emotion. In theories of self-regulation in adults (e.g., Carver & Scheier, 1990, 2000), emotion is understood to primarily reflect higher order cognitive processes of appraisal, rather than temperamental or subcognitive processing of emotional stimuli that occurs prior to or independently of conscious cognitive appraisal. In models of self-regulation in adults, the focus is, for the most part, on conscious cognitive appraisal of emotion. Negative emotional appraisals and expectancies lead to difficulty with the regulation and application of attention, increased disengagement, and continuing negative affect, whereas favorable emotional appraisals and expectancies lead to higher levels of engagement and persistence in a given task.



The influence of subcognitive processing of emotional information on higher order mental processes of expectancy and engagement has received far less attention in the study of self-regulation (Bargh & Ferguson, 2000; Kuhl, 2000). However, in young children, in whom higher order cognitive control and appraisal processes are nascent or developing, neurobiologically more mature subcognitive emotional structures (cf. Nelson, 1994), such as those associated with temperamental emotionality, are reaching mature levels of functioning and are likely to influence self-regulation and its developmental course.

Although there may be some room for discussion concerning the extent of nonconscious perception and processing of information, whether emotional or otherwise, the role of nonconscious perception in the automatization of higher order cognition and behavior is well established (Bargh & Chartrand, 1999; Bargh & Ferguson, 2000). Automaticity in perception and action is part of how the mind works. Whether through the establishment of preferences without conscious knowledge of a volitional choice for those preferences (Zajonc, 1980) or through the formation of procedural memories in the absence of any conscious (i.e., declarative) memory of the experiences that formed the basis for those memories (Kandel, 1998, 1999), subconscious processing of information is an aspect of mental functioning with very real implications for the self-regulation of behavior.

Surprisingly little theoretical or empirical work, however, has addressed this central fact of mental functioning in young children. Subcognitive processes relating to emotionality in young children may play a substantial role in the development of cognitive self-regulation and the formation and automatization of appraisal processes so important for fostering strategic thinking ability. Rather than examining the role of emotion in self-regulation only from the standpoint of the conscious appraisal of emotion, those studying self-regulation in young children must consider the developmental primacy of emotion and the implications this primacy may have for the automatization of behavior, particularly that related to the development and application of higher order thinking skills and conscious appraisal processes. When examined in this way, emotionality can be seen to be closely associated with the development of a propensity for self-regulated learning and engagement.

### ***Integrating Cognition and Emotion***

Work on the goal-directed activity that characterizes executive function strongly indicates that it is dependent not only on strictly effortful cognitive aspects of information processing (i.e., attention, working memory) but also on emotional systems within the brain (Derryberry & Reed, 1994, 1996; Tucker & Derryberry, 1992). Recent theoretical and empirical work on emotion strongly suggests the need for integrated and reciprocal models of influence between emotional and cognitive centers of cortical functioning (LeDoux, 1995, 1996). In particular, the study of emotion–cognition relations suggests the functional role of emotion in organizing and directing cognition (Fischer,

Shaver, & Carnochan, 1990) and, in adults, has provided clear evidence suggesting the disruptive role that negative, particularly anxious, emotional experience can have on the higher order processes of attention, memory, and problem solving (Matthews & Wells, 1999; Mogg & Bradley, 1999).

Educational researchers and practitioners have become increasingly interested in metacognitive thinking skills, such as self-monitoring and selective strategy use (Kuhn, 1999). Metacognitive skills have been shown to differentiate skilled from unskilled learners and to be relevant to understanding the learning problems of children with learning disabilities (Borkowski, Estrada, Milstead, & Hale, 1989). In accord with theoretical models of self-regulation, strategic-thinking deficits have been associated with poor attributions of the self as learner that recursively affect the perceived utility of strategic thinking (Borkowski, Carr, Rellinger, & Pressley, 1990; Paris & Oka, 1989). Studies of the attempt to teach strategic skills to children in the early elementary grades have demonstrated the necessity of including specific training on self-attributions about effortfulness and about success being controllable by effort (Borkowski, Wehying, & Carr, 1988). In accord with adult models of self-regulation, these training studies have indicated the key role that emotional–attributional processes play in engaged and self-regulated learning in elementary school age children. The ways in which social interaction and classroom structure and process can impact attributions and promote thinking skills have been at the forefront of educational research (Borkowski & Muthukrishna, 1998; Brown & Campione, 1990; Kuhn, 1990). To date, however, the developmental antecedents of strategic-thinking skills and the role of emotionality in the automatization of attributional processes that support these skills have not been the focus of concerted research effort.

From a functionalist standpoint on emotion, individual differences in emotional reactivity have descriptively informed the study of self-regulation and self-regulated learning (Rothbart & Derryberry, 1981; Rothbart & Jones, 1998). Theory and research on relations between cognition and emotion and on cortical plasticity and the development of the prefrontal cortex suggest that emotional reactivity plays some role in the development and integrity of executive cognitive functioning. An important next step is to examine how individual-difference characteristics and influences on these characteristics are related to the developmental interaction of component processes of emotionality and higher order cognition.

As noted earlier, the relation of emotional processes to cognition may be particularly relevant to young children. Given the developmental maturational primacy of limbic structures associated with emotion (Chugani, Phelps, & Mazziota, 1987; Nelson, 1994), a central question in the development of self-regulation, and in the study of children in general, is how emotional information—whether or not it is consciously experienced as affect—influences cognition and cognitive development. As noted by LeDoux (2000), “the true nature of the relation between cognition and emotion will not be understood until the interaction

rules that relate component processes on both sides of the cognitive–emotional equation are specified” (p. 129). A more complete understanding of both cognition and emotion can be gained through examinations of developmental interactions among their component parts.

### **Physiology of Regulation**

When viewed from the perspective of component processes, one salient emotion-related influence on the development of executive function in young children is physiological. The study of emotional reactivity and regulation in infants and young children has related individual variation in emotionality to physiological reactivity. For example, for children selected for characteristic behavioral inhibition, novel stimuli have been associated with a high level of arousal in limbic structures associated with emotion, in particular, the amygdala. Behaviorally inhibited children are thought to have a low threshold for limbic arousal, and this arousal results in negative emotional expression, activation of the sympathetic nervous system, and ultimately behavioral inhibition, or withdrawal from stimulation in an attempt to regulate state through reactive rather than effortful forms of regulation (Garcia-Coll, Kagan, & Reznick, 1984; J. Kagan, Reznick, & Snidman, 1987; J. Kagan & Snidman, 1991).

Although sympathetic arousal appears to play a primary role among children selected for characteristic behavioral inhibition (Marshall & Stevenson-Hinde, 1998), investigators concerned primarily with emotionality and arousal among unselected samples have suggested a particularly important role for individual differences in parasympathetic rather than sympathetic reactivity, particularly the reactivity related to cardiac physiology (Porges, 1995, 1998). Autonomic parasympathetic influence on the heart, as indexed by vagal tone, an indicator of the efferent connection to the sinoatrial valve of the heart originating in the nucleus ambiguus of the medulla, is particularly relevant to children’s ability to regulate emotional arousal, respond to stress, and focus attention (Bornstein & Suess, 2000; Porges, Doussard-Roosevelt, Portales, & Greenspan, 1996; Stifter & Fox, 1990).

Although psychophysiological work has indicated the importance of taking into account the combined activation of parasympathetic and sympathetic influence (Berntson, Cacioppo, & Quigley, 1993), the developmental relevance of parasympathetic regulation has been shown in relation to the expression and regulation of emotion in infants and young children. Infants with higher resting cardiac vagal tone are better regulators of emotional reactions, and high levels of emotional reactivity in combination with high vagal tone have been associated with positive social developmental outcomes (Fox & Stifter, 1989; Porges, Doussard-Roosevelt, Portales, & Suess, 1994; Stifter, Fox, & Porges, 1989).

Vagal regulation of the heart in young children, referred to as vagal suppression (i.e., a decrease in vagal tone occurring in response to emotionally or cognitively demanding situations), is associated with appropriate re-

sponding in a variety of situations, including approach to the unfamiliar and response to surprising or unexpected events (DiPietro, Porges, & Uhly, 1992; Porges, Doussard-Roosevelt, & Maiti, 1994). Numerous studies examining relations among emotional reactivity, vagal tone, and social development in infants and young children have indicated that both resting level of vagal tone and vagal suppression are related to increased sociability and low levels of problem behavior (Calkins, 1997; Fox & Field, 1989; Porges et al., 1996).

### **Neural Connectionist Models of Cognition and Emotion**

That infants and young children characterized by difficulty in the physiological regulation of emotion might be likely to experience difficulty in the development of higher order cognitive self-regulation skills, such as those characterizing executive function, has been supported by neuroscientific study of the relations between emotion and cognition. A neural cortical basis for cognition–emotion relations is suggested both by connectionist models of cognitive function that focus on patterns of connectivity as the basis for cognitive representations, as well as by clinical observations of cognitive impairment and emotional disorders (Fischer & Bidell, 1998; Tucker & Derryberry, 1992).

Rather than indicating a predominant influence of cortical, higher order cognitive processes on subcortical emotional processes, however, neuroanatomical and clinical studies have suggested that emotional processes play a substantial role in cortical activation (Derryberry & Tucker, 1994). Neuroanatomical examination of neural pathways interconnecting dorsolateral, anterior cingulate, and orbital areas of the prefrontal cortex (areas associated with working memory, attention, and sensitivity to reward) with subcortical limbic structures associated with emotion, most notably the amygdala, has provided anatomical evidence for functional links between prefrontal executive processes and limbic emotional–motivational aspects of functioning (Derryberry & Tucker, 1994; LeDoux, 1996). Within this connectionist framework, efferent connections from the amygdala to the vagus might suggest that high levels of negative emotional reactivity would inhibit parasympathetic influence, leading to difficulty with emotion regulation and thereby to difficulty in the development and use of executive cognitive processes.

From a connectionist standpoint, work in affective neuroscience has indicated the interrelatedness and interdependence of cognition and emotion in the brain and the ways in which emotional experience is associated with attentional processes (Davidson, 1999; Davidson, Chapman, Chapman, & Henriques, 1990; Lane & Nadel, 2000; Panksepp, 1998). The link between an affective style characterized by withdrawal and greater relative activation of the right prefrontal cortex, as measured by electroencephalograph (EEG) recording, is well established (Davidson, Jackson, & Kalin, 2000). In this case, behavioral and physiological manifestations of negative emotionality associated with high limbic arousal, social withdrawal, and sympathetic

activation are associated with a particular pattern of electrophysiological activity in the prefrontal cortex. Manifestations of positive emotionality and approach behavior, however, are associated with a different, distinct pattern of prefrontal activation. Investigation of the short- and long-term developmental implications of the relation between these specific types of behavior and specific patterns of brain activity is ongoing. Findings will most likely continue to indicate disruptive and facilitative relations between emotional reactivity and higher order cognitive functioning.

Work at the interface of cognitive and affective neuroscience has increasingly been able to document a phenomenon by which neurological processes associated with emotional reactivity interfere with or support processes that are considered to underlie higher order cognition (Panksepp, 1998). A notable example of interference is Jacobs and Nadel's (1985) parallel between infantile amnesia and fear learning in adults. Jacobs and Nadel suggested that infantile amnesia results from the slower maturational timetable of the hippocampus relative to other learning systems in the brain during infancy. Noting that characteristics of learned fears and phobias in adults are similar to those of infantile memories, they proposed that fearful reactivity works to inhibit hippocampal function. Accordingly, fear and phobic memory formation is thought to take place largely outside of conscious awareness (Nadel & Jacobs, 1998). Evidence of such implicit procedural memory formation associated with fear reactivity is supported by a variety of evidence, in particular work indicating the inhibitory function that hormones released during stress have on the hippocampus (Kandel, 1998; LeDoux, 1996).

Although it is well established that high fear reactivity is related to a particular pattern of prefrontal activation (Davidson et al., 2000), many questions remain unanswered regarding the relation of emotionality to higher order cognition and functional outcomes, such as the adjustment to school. One in particular concerns excessive approach behavior or impulsive aggression in early childhood and implications of this aspect of emotionality for developing cognitive self-regulation. Unlike the reasonably well-established neurobiological model relating fear reactivity to the amygdala and to the prefrontal cortex, no similar model of the neural circuitry of impulsive aggression exists to guide empirical efforts. However, the neuropsychological study of children with early-onset conduct problems has clearly noted deficits in executive function skills (Cole, Usher, & Cargo, 1993; Speltz, DeKlyen, Calderon, Greenberg, & Fisher, 1999).

One might expect that cognition–emotion relations in early-onset conduct problems would be similar in some ways to those for high fear reactivity. Sensitivity to arousal and difficulty with the physiological regulation of emotion could work similarly for both fear reactivity and impulsive aggression (Emery & Amaral, 2000). Examination of the physiology of high fear reactivity and aggressive impulsiveness in humans and in rhesus monkeys, however, suggests some differences in the neurobiology of these two

aspects of emotion-related functioning. Although high fear reactivity has been associated with the high level of autonomic reactivity outlined above, impulsive aggression has been associated primarily with abnormally low levels of the primary metabolite of the neurotransmitter serotonin (Suomi, 1999), perhaps implicating disturbances in the functioning of the mesolimbic pathway interconnecting the basal ganglia with the prefrontal cortex. Additionally, population prevalence estimates of high fear reactivity in children and rhesus monkeys is quite high at 15% to 20%, whereas estimates for impulsive aggressiveness are much lower at around 5%. From a public health standpoint, whether or not cognition–emotion relations in both behavior types are similar, fearful reactivity would have the greater impact on school readiness because of its higher prevalence among preschool children.

### ***Selectionist and Constructivist Approaches to Brain Development***

From a perspective on brain–behavior relations that emphasizes connections between different areas of the brain, evidence for a neural substrate linking limbic structures associated with emotion with areas of the prefrontal cortex associated with higher order cognition has strong implications for a conceptualization of school readiness that focuses on the development of self-regulation. Such a connectionist approach, however, has little specifically to say about the neurological and functional development of cognition–emotion relations in early childhood. In particular, it has little to say about the role of experience in influencing the brain's developing connectivity (see Quartz & Sejnowski, 1997, and associated commentary).

In this regard, proponents of a selectionist approach to developing connectivity in the brain favor the now standard idea that maturational processes lead to an exuberance or overproduction of possible synaptic connections that develop early in life but are pruned in response to experience as certain connections are preserved and strengthened while others are eliminated (Greenough & Black, 1992; Huttenlocher, 1979). Referred to as activity-dependent or use-dependent selection, synaptic connections that are active are maintained and strengthened as they consume available resources (glucose, oxygen) and incorporate existing neuronal groups. This process of selective innervation and strengthening of neuronal groups, described by Edelman (1987) as a process of neuronal group selection, plays a key role in establishing neural connectivity in the brain early in life.

More recently, a constructivist approach to the development of mind has been forwarded to suggest a potentially somewhat larger and more determining role for experience in cortical connectivity (Quartz & Sejnowski, 1997). Within the constructivist perspective, much of the cerebral cortex early in development is characterized by equipotentiality and is essentially undedicated. The interaction of experience-dependent neural activity and neural growth mechanisms shapes the representational properties of the cortex and imposes structure. Experience brings about

structural as well as functional change in the ability of the brain to represent the world, coordinate information, and produce responses. Far from a radically empiricist approach to brain development, however, the constructivist approach recognizes phylogenetically determined aspects of structure and growth, particularly in subcortical brain structures, but accords a more flexible path to the neocortex.

The implications of the approach are wide ranging. The constructivist perspective suggests that the neocortex is chiefly characterized by plasticity and that the role of experience is to impose order by organizing neuronal groups in the active construction of the cortex. Within this framework, functional relations between interconnected areas of the brain follow no genetically determined pattern but emerge epigenetically in response to experience. The approach suggests a broad and determining role for experience in the ontogeny of the cortex. Considering that the brain's limbic structures develop early, a constructivist approach to brain development might highlight individual differences in emotional reactivity in the study of the development of prefrontal executive thinking skills.

### **Development of the Frontal Cortex**

Regardless of whether a selectionist or constructivist approach is adopted, neural connectivity between cortical and subcortical brain structures can be considered to reflect, to some extent, experience-dependent connectivity. The question is no longer whether experience plays a role but rather how much experience influences brain development and what are the implications for later functioning. For executive cognition, the emergence and development of the cognitive processes associated with frontal function appear to be related to increased neuronal maturation and selective innervation between the parietal, temporal, and limbic areas of the brain and the cerebral frontal cortex (Shore, 1996, 1997; Thatcher, 1994a, 1994b).

Thatcher (1994a) has provided evidence to support experience-dependant connectivity specific to the frontal cortex early in life by examining patterns of coherence in EEG readings from a number of brain regions. By examining patterns of electrical activity in anterior and posterior brain regions, he has identified peak times of coherence that are considered to represent increases in the number and/or strength of connections between two or more cortical areas. By examining the location of the points of coherence at different ages, Thatcher has demonstrated a pattern of EEG activity in which "a dominant feature of human postnatal cerebral development appears to be the sequential unfolding and elaboration of (neural) connections between and within specific zones of the frontal lobes and the posterior, central, and temporal cortical regions" (Thatcher, 1994a, p. 253). Specifically, the pattern of activity is one in which the neural connection of the frontal lobes with posterior sensory regions of the brain occurs over time in response to sensory input. Relations between experience-dependent activity in the brain and executive function in young children have been suggested by Bell and

Fox (1992, 1994; Bell, 1998; Fox, Calkins, & Bell, 1994), who demonstrated relations between EEG coherence representing anterior-posterior activity in the brain and the ability to tolerate delay in the *A-not-B* task, a task that is dependent on executive cognitive abilities.

In line with the findings of EEG coherence studies, the establishment of neural connectivity between the prefrontal cortex and the limbic structures, most notably the amygdala, is particularly important for cognition-emotion relations, at least for high fear reactivity. Increasing evidence indicates that the amygdala is the limbic structure most clearly implicated in fear reactivity (Aggleton, 1992, 2000; LeDoux, 1996). The role of the central nucleus (CN) of the amygdala in fear reactivity, however, appears to be primarily related to conditioned (i.e., learned) fear, rather than temperamental fearfulness. An area adjacent to the CN, a part of the extended amygdala or amygdala complex called the bed nucleus of the stria terminalis (BNST), appears to be more closely related to traitlike anxiety and temperamental fearfulness (Davis, Walker, & Lee, 1997).

Sensitivity to fear- and anxiety-evoking stimuli in both regions of the amygdala complex are similar, and most important for present purposes, the neural characteristics and circuitry of the CN and BNST are highly similar and interrelated (Rosen & Schulkin, 1998). In particular, connections within the amygdala complex and between the amygdala complex and the cortex are extensive, yet little or no work has specifically addressed the contribution of the amygdala to higher cortical function. It is now clear, however, that the functional neuroanatomy of the prefrontal cortex involves extensive interconnections with structures associated with autonomic arousal (Amaral, Price, Pitkanen, & Carmichael, 1992; Van Eden & Buijs, 2000). It may be that this interconnectivity represents an evolutionary development that promotes the survival of the species through increased vigilance to potential threat. This increased vigilance, however, may unfortunately work to the detriment of children experiencing chronic stress, as stressful experiences act to stimulate the amygdala and the release of corticotrophin. Increased cortisol in the bloodstream then further stimulates activation of the amygdala, in particular the BNST (Davis et al., 1997), and, as noted above, inhibits hippocampal function (LeDoux, 1996). As a result, young children repeatedly exposed to stress early in life may be at high risk for activation in the amygdala that promotes patterns of use-dependent connectivity that are detrimental to attention and executive cognitive processes. Specifically, patterns of connectivity may be promoted that foster the influence of anxiety and fear on attentional and executive processes rather than fostering attentional and executive influence on amygdala activation and fear.

The important role of prefrontal influence on the control of fear and anxiety has been demonstrated in studies of conditioned fear in rats. Among rats with lesions of prefrontal neural projections to the amygdala, the maintenance of conditioned fear is greatly prolonged (Morgan & LeDoux, 1995). Work on the fear system, however, has shown that the operation of this system and its attendant



consequences for cognition need not require the conscious experience of fear but likely reflect vigilance to possible threat and the directing of cognitive resources to the maintenance of the vigilant state (LeDoux, 1996; Whalen, 1998).

### ***Psychobiology and Temperament***

The study of relations between cognition and emotion suggests that an important goal for school readiness research is to make explicit the developmental neurobiology of self-regulated learning. An important issue, however, is the extent to which the construct of emotionality being considered refers to constitutionally based temperamental differences, to aspects of functioning acquired through early exposure to stress, or to both. The role of the amygdala in the neurobiological model of readiness presented here and the evidence implicating primarily the CN in conditioned fear and the BNST in stress responses perhaps highlight the importance of the early environment rather than an individual biological predisposition to high negative emotional reactivity.

Be that as it may, whether constitutionally determined or environmentally induced, the degree to which individuals differ in the propensity to experience positive or negative affect, in the rapidity of onset, magnitude, and duration of this response, and in the ability to regulate affective arousal (e.g., Derryberry & Rothbart, 1984, 1988; Rothbart & Derryberry, 1981) is highly relevant to the development of higher order cognitive self-regulation skills and the occurrence of self-regulated learning. My goal in relating emotionality to school readiness through executive cognition is not to define distinct temperament types or to equate school readiness with a particular temperamental style per se. It is to identify individual differences in certain aspects of behavior that are labeled as temperamental in order to outline how they may be related to the development of the skills and abilities that underlie adaptation to the socially defined role of student.

Individual differences in children's temperaments can serve as indicators of increased or decreased risk for poor developmental outcome in the face of chronic stress. Temperamental fearfulness or overly approachful behavior may place children at risk for poor developmental outcomes when combined with environmental stressors. Certainly, such a layering on of risk is consistent with notions of causality prominent in the social and public health sciences (Rothman, 1976; Sameroff, Seifer, Barocas, Zax, & Greenspan, 1987), just as the absence of risk associated with temperamental emotionality would be consistent with conceptions of resilience in the face of environmental adversity (Luthar, Cicchetti, & Becker, 2000; Werner, 2000). Rather than pointing toward temperamental nature or environmental nurture, however, it is more accurate to think in terms of how the combined actions of nature and nurture influence propensities toward particular developmental trajectories.

When viewed from a genuinely epigenetic psychobiological approach to development (e.g., Gottlieb, 1992,

1998), the distinction between a constitutionally based versus an environmentally induced emotional reactivity proves illusory. An important tenet of the psychobiological approach and of developmental cortical plasticity and the organization of behavior over time concerns the active role of the individual in directing development (Cicchetti & Tucker, 1994). Children on a developmental trajectory toward a regulatory system characterized predominantly by reactive regulation, withdrawal and avoidance, or approach and reward may be likely to establish and maintain patterns of responding that are maladaptive (i.e., that serve to maintain high levels of reactivity and reactive regulation; Derryberry & Reed, 1994).

Within the psychobiological scientific framework in which behavior is understood to be the leading edge of development (Cairns, 1991), school readiness can be seen as influencing and being influenced by developmental processes occurring at the neurobiological, physiological, behavioral, family, classroom, school, and community levels. That is, the behavior of children characterized by high negativity can set into motion a series of reactions in the child's immediate environment that can reciprocally affect and essentially maintain or increase the level of negativity with cascading difficulties for higher order thinking and regulation. Therefore, under the psychobiological approach, children's levels of emotionality and regulatory ability are expected to vary among settings and perhaps change over time (e.g., Huffman et al., 1998; Kochanska, Coy, Tjebkes, & Husarek, 1998). An observed lack of correlation among various reporters on temperament is expected. Reports by parents, teachers, or researchers are each made with reference to distinct settings and may represent children's functioning in contexts providing differing opportunities for child emotional reactivity and levels of support for regulation. Though some temperament researchers might seek to identify underlying biological substrates for ideal temperament types and may accordingly question the validity of certain reporters on child temperament, namely parents (J. Kagan, 1998), under a psychobiological model, it is reasonable to expect that differing reports of temperament are valid but not representative of all contexts.

### ***Reactivity and Readiness***

From a neuroscientific and functionalist standpoint, emotional reactivity plays a key role in focusing selective attention and applying mental processes necessary for learning. Examination of school readiness in light of emotional reactivity and regulation suggests that an organized emotional response to stimulation in the classroom facilitates the entraining of arousal and the focusing of attention necessary for learning to occur. Essentially, within models of self-regulation, emotional processes, when experienced as affect, are seen as facilitating goal-directed behavior and establishing motivation (Pintrich, 2000). When affect can assist and support processes of attention, memory, inhibitory control, and problem solving, it promotes self-regulation and optimal functioning (Campos & Barrett, 1984;



Carver & Scheier, 1990, 2000), and the individual can be understood to be in a state of regulatory organization. That is, affective experience does not compete with or interfere with the cognitive demands of a particular setting.

When the goals of the affective response compete with higher order cognitive processing demands, however, the individual attempts to regulate emotion in reactive ways, through withdrawal or approach, rather than through effortful processes involving memory, attention, planning, and problem solving. As with empathic responding in social situations, in which the individual uses higher order cognitive processes to take the perspective of another, the motivated affective response within the classroom can be thought of as a prerequisite for the use of the cognitive-processing resources necessary for learning. The regulation of emotion through reactive means, through withdrawal or vigilance in response to anxiety or through acting out in response to frustration or underarousal, will interfere with or inhibit the application of higher order cognitive processes.

In one sense, young children characterized by negative emotionality are likely to experience difficulty in the application of higher order cognitive processes simply because their emotional responses do not call for reflective planning and problem solving, and these skills are underused and consequently underdeveloped. As suggested by Lazarus's (1991) cognitive-motivational-relational theory of emotion and by Lewis, Sullivan, and Michalson's (1984) conception of the cognitive-emotional fugue, a negative emotional experience may elicit a reactive response to reduce or in some way alter the state of arousal. Reflection, planning, and problem solving are less likely to serve as adequate responses and as a consequence are not used.

Similarly, from a Vygotskian conception in which thinking skills are socially constructed through interactions with a supportive other (Vygotsky, 1978), individual differences in emotionality might impact the meaningfulness of social interactions through which metacognitive skills would be socialized. Much of the pedagogy of the teaching of thinking skills, such as the reciprocal teaching model of Brown and Campione (1990), stems from the Vygotskian approach. Individual differences in emotionality may be important to assessments of the efficacy of educational efforts based on relational or Vygotskian approaches. If so, both high fear reactivity and impulsive aggressiveness might have similar functional consequences for the development of higher order thinking skills, even though their underlying neurobiology may be distinct. Of course, the neurobiological approach suggests that experience-dependent neural connectivity is highly relevant to developing self-regulation skills but that there may be multiple pathways to poor regulatory outcome.

## Summary and Conclusions

If the use and automatization of executive function abilities are dependent to some extent on reciprocal interactions of higher order thinking and the emotional centers of brain function, at least two important implications for school

readiness are immediately apparent. The first is that infants and toddlers characterized by high levels of negative emotionality may be at high risk for poor school readiness. The second, which is related to the first, is that a home environment and preschool education specifically designed to reduce stress and foster emotional competence should promote the attention and cognitive self-regulation needed for both social and cognitive adaptation to the classroom.

The argument has been made that the occurrence of cognitive self-regulation is in part related to neurological developmental relations between limbic and frontal brain structures. This should in no way, however, be taken to support the concept of a critical period during which development of executive function abilities may or may not occur, nor should it be taken to support a belief in the long-term stability of temperamental differences. On the contrary, it indicates a position suggesting that higher order cognitive abilities may be less likely to be used when needed and that children may fall into patterns of responding that engender a propensity for reactive rather than effortful regulation.

In the model of neural plasticity relating emotionality to school readiness that I have presented here, the emotionally reactive and poorly regulated but otherwise typically developing child in an environment that cannot optimize and support the child's regulatory capability is likely at risk for an atypical trajectory toward the development of executive-function skills and school readiness. However, the same child in a supportive environment will be less likely to develop reactive forms of regulation and will exhibit a greater propensity toward effortful regulatory skills.

Researchers studying prefrontal EEG asymmetry associated with approach versus withdrawal behavior have noted considerable plasticity in early childhood (Davidson et al., 2000). A certain proportion of infants and young children who begin life exhibiting greater relative right prefrontal activation and high fear reactivity have been shown to change in both frontal asymmetry and in behavior, exhibiting greater left prefrontal power and increased approach behavior and positive emotionality over time, presumably in response to rearing experience (Davidson & Rickman, 1999; Fox, Henderson, Rubin, Calkins, & Schmidt, 2001). Similarly, although neural development related to vision, speech perception, and aspects of emotion appears to exhibit some critical-period characteristics, neurological structures associated with higher order cognitive functioning maintain plasticity in response to experience well into maturity (Benes, 2001; Nelson, 2000a).

A number of studies have demonstrated the crucial role of the environment in the unfolding of developmental pathways toward either reactive or effortful regulation in young children. These findings indicate large effects of caregiving competence on later behavior among young children characterized by high levels of negative, particularly fearful, emotionality. For example, researchers studying the stability of negative emotionality in infancy and early childhood have found evidence for what has been termed *lawful discontinuity*. Specifically, appropriate and

sensitive parenting has been associated with discontinuity in negativity among children exhibiting high negative emotionality at age three months but not at age nine months (Belsky, Fish, & Isabella, 1991). Similarly, a longitudinal investigation of relations between negative emotionality in infancy and later internalizing and externalizing types of behavior problems at age three years has suggested that the rearing environment plays a crucial role in the continuity of negative emotionality and problems with self-regulation. Among children characterized by negativity in sensitive caregiving environments, rates of internalizing and externalizing problems are low. Among children characterized by negative emotionality in insensitive caregiving environments, however, rates of both externalizing and internalizing problems are high (Belsky, Hsieh, & Crnic, 1998).

As noted earlier, Feldman et al. (1999) showed that caregiving sensitivity had the greatest effect for infants characterized by negativity. Specifically, the relation of parenting sensitivity, measured when children were 12 months old, to children's effortful control, measured when the children were 24 months old, was greatest among infants characterized by negative emotionality. Similarly, although Suomi (1995, 1999) has observed considerable stability in fearful reactivity and impulsive aggressiveness in rhesus monkeys, the effect of rearing competence on social outcomes in these primates is particularly noticeable among highly reactive young monkeys. Further, Kochanska (1993, 1995) has demonstrated that children characterized by fearful emotionality are more receptive to gentle maternal discipline in situations requiring child compliance and effortful control. As noted by Belsky et al. (1998), such findings suggest that children characterized by negative emotionality may be more susceptible to rearing influence (see Belsky, 1997) and that in the absence of environmental support, negative emotionality is likely to lead to long-term problems with self-regulation.

However, although researchers have demonstrated the extent to which change is possible for young children characterized by negative emotionality, it is perhaps more likely for many children that factors will conspire to maintain rather than deflect developmental trajectories toward poor self-regulation in early childhood. As development proceeds through transactions that are in part determined by reciprocal relations among child physiology, neurobiology, and the environment in which the child resides (Gottlieb, 1998; Gottlieb, Wahlsten, & Lickliter, 1998), negativity and poor regulation in the absence of early environmental support for regulation might serve to constrain the developmental trajectory at multiple levels.

### **Early Intervention**

Studies demonstrating the important joint contributions of child reactivity and caregiving competence to regulatory outcomes indicate that emotionally reactive children in unsupportive environments are likely at high risk for difficulty with higher order regulation and poor school readiness and need appropriate and timely intervention that is grounded in current understanding of brain-behavior rela-

tions. Unfortunately, relatively few compensatory education programs focusing on school readiness and academic achievement have specifically addressed social-emotional development in infancy and early childhood, and even fewer have targeted intervention efforts at infants at high-risk because of negative emotionality (van den Boom, 1994). The psychobiological approach to readiness, however, provides an excellent framework for the conduct of compensatory education. This approach suggests that the development of physiological and neurobiological processes related to emotional reactivity and to the regulation of reactivity through attention and selective strategy use will vary in relation to specific characteristics of the child and specific features of the environments within which reactivity and regulation are required (J. Kagan, 1998; Rothbart & Ahadi, 1994; Rothbart, Derryberry, & Posner, 1994).

Within such a psychobiological framework on development, the efficacy of early educational intervention for enhancing the cognitive abilities and school success of children from high-risk backgrounds is notable. Model programs, such as the Abecedarian Project and the Perry Preschool Project, have indicated that high-quality intensive educational interventions for children at risk for school failure because of socioeconomic factors is associated with higher IQ and academic achievement and a reduced likelihood of grade retention and special education placement (Bryant & Maxwell, 1997; Ramey & Campbell, 1991). Similar results from the Chicago Parent-Child Center's preschool intervention and school-age follow-through intervention—a public service program—suggest the efficacy of combining preschool compensatory education with additional supports in the early elementary grades for children at high risk for school difficulty (Reynolds & Temple, 1998).

Although early intervention programs have demonstrated effects on recipients' intelligence and school progress, the extent to which the success of early compensatory education, whether in model programs or in large-scale public service programs, influences children's emotional reactivity and self-regulation skills is less well known. Such effects may be important mediators of program effects on school readiness and academic achievement, but this possibility has not been explicitly addressed. This may be because much of the preschool compensatory education literature emphasizes strictly cognitive aspects of readiness, namely the relation of the programs' effects on intelligence to academic achievement. However, analysis of program effects on school outcomes in the study of the Chicago Parent-Child Center, indicated that preschool effects on cognitive ability accounted for only 32% of the program's overall effects on Grade 6 reading and mathematics achievement. Additional pathways of effects included those relating preschool intervention to parental involvement in school and to teachers' ratings of adjustment to school (Reynolds, Mavrogenes, Bezruczko, & Hagemann, 1996), effects that may represent the program's

impact on emotional and regulatory aspects of the children's functioning.

Similarly, in an analysis of a comprehensive educational intervention program for low-birth-weight, preterm infants, the Infant Health and Development Program (IHDP, 1990), large program effects were observed among participants characterized by negative emotionality in infancy (Blair, *in press*). Specifically, an intervention combining educational day care with home visiting and parent support over childrens' first three years was associated with a fourfold decrease by the end of the program in the incidence of clinically meaningful externalizing and internalizing types of behavior problems among children with high levels of negativity in infancy. Similarly, for children with high negativity and higher (but still low) birth weights, the intervention was associated with a fivefold decrease in the occurrence of IQ less than or equal to 75 at age three years. These findings may have particular relevance to early intervention because low-birth-weight, preterm infants are at particularly high risk for negative emotionality and poor self-regulation due to physiological immaturity at birth. High rates of cognitive and social deficits among children born at low birth weight may be mediated through nervous system deficits that limit their ability to regulate state (Porges, 1996).

Furthermore, follow-up studies of the long-term effectiveness of the IHDP indicated few if any lasting program effects by the time the children reached ages five and eight years. It may be that emotionality and self-regulation difficulties among low-birth-weight infants contributed to the lack of long-lasting IHDP program effects. As noted above, relations between emotional and cognitive aspects of children's functioning may be of particular importance to the assessment of long-term intervention effects. In the IHDP in the absence of intervention after age three years, negative emotionality may have reemerged to constrain developmental processes and outcomes even among children receiving intervention from birth to age 3.

### **Grade Retention**

Another aspect of school readiness and adjustment in which the effects of early intervention on self-regulation may be key is the prevention of grade retention. In the analysis of the effects of the Chicago program on the transition to school, Reynolds et al. (1996) reported that parents' involvement in school and teachers' ratings of adjustment, not cognitive readiness, were direct predictors of grade retention in the early elementary grades. Cognitive readiness demonstrated only an indirect relation with retention. This finding accords well with longitudinal studies of retention indicating that factors present prior to school entry, including cognitive readiness for school, are relatively weak predictors of grade retention (Dauber, Alexander, & Entwisle, 1993; Reynolds & Bezruczko, 1993). By far, variables present following school entry, such as early academic achievement and teacher perception of ability, are better predictors of retention.

Longitudinal studies of retention, however, have not attended specifically to social and emotional aspects of readiness. Indirect longitudinal evidence suggests that social and emotional factors present prior to school entry may be important for the prediction of retention above and beyond general intelligence. In a large-scale follow-up study of children from low-income homes, many of whom were at high neonatal risk, findings indicated only a conditional relation between IQ at school entry and grade retention in the first three elementary grades. Specifically, children with IQ less than or equal to 75 faced increased risk for retention only when they had experienced extended out-of-home care prior to school entry. Those children cared for at home prior to kindergarten faced no increased risk for retention relative to their higher IQ counterparts (Blair, 2001). In the absence of alternative explanations for this effect, it may be that care at home in this instance was a marker for aspects of the parent-child relationship, parent involvement in school, and child social-emotional competence, all factors that could offset risk for grade retention associated with low IQ. If so, these factors may have been indicative of children's increased social and emotional competence at school entry that could offset risk for grade retention associated with low IQ.

The role of negative emotionality in early intervention to prevent grade retention is of strong interest. Grade retention appears to be a well-intentioned educational practice that frequently has deleterious consequences for children's academic and social success in school (Shepard & Smith, 1989). In spite of evidence indicating adverse outcomes associated with its use, the practice persists, and effective programs to prevent its occurrence are needed. The continued use of grade retention as a remedial strategy seems to reflect the lack of alternative solutions when teachers have concerns about the academic progress, maturity, and general school readiness of individual children. To the extent to which grade retention is dependent on interrelations among children's social, emotional, and cognitive adaptation to school, it may be that early compensatory education interventions that specifically address social and emotional functioning can prevent its occurrence.

### **Future Directions**

Examination of emotionality within early intervention to promote school readiness and prevent grade retention provides a useful model for evaluating the role that programs to enhance social and emotional competence might play in preschool education. The study of emotionality suggests that a particularly promising direction for early intervention efforts may be the implementation in preschool and early elementary school of programs that combine interventions focusing on social and emotional competence with early compensatory education. Such programs would provide an exceptionally strong model for the promotion of school readiness and school success. As noted above, several early compensatory education interventions have demonstrated cognitive benefits to program recipients. Several school-based programs to enhance social and emotional competence have also demonstrated benefits to children's social



competence (see Eisenberg, Wentzel, & Harris, 1998, for a review).

An interesting area in which programs focusing on social competence interface with more cognitively oriented programs is problem solving related to the development of executive cognitive functioning. A particular example of the executive cognitive problem-solving approach to the promotion of prosocial behavior and social competence is the Promoting Alternative Thinking Skills (PATHS) curriculum, an intervention curriculum with demonstrated benefits to young children's social competence, emotion regulation, and problem-solving skills in the early elementary grades (Greenberg, Kusche, Cook, & Quamma, 1995).

In the PATHS program, recipients are taught a specific sequence of problem-solving steps. Namely, the program teaches children to stop and inhibit impulsive tendencies, to identify feelings, to think of alternative solutions to problems, and to plan and implement solutions. Evaluations of PATHS have indicated that among children in the first three primary grades, the program facilitates cognitive flexibility and problem solving, assists children in generating effective, as opposed to aggressive, solutions to problems, and increases understanding and recognition of emotions (Greenberg & Kusche, 1997, 1998).

A preschool version of a PATHS-like curriculum combined with a compensatory education curriculum would be likely to assist children with both the social and cognitive demands of the transition to school. Children in such preschool programs would be more amenable to educational stimulation and would, on average, have more educationally stimulating material available than children in naturally occurring environments. The theoretical and empirical knowledge base are in place to design and implement such truly comprehensive programs to support readiness.

Research and theory suggest that compensatory education programs can affect the biological and physiological developmental processes underlying age-appropriate social and cognitive competence at school entry. The challenge for prevention research is to explicitly identify and measure key physiological, neurobiological, and behavioral processes within a coherent developmental systems model of the promotion of school readiness. This would allow for the tailoring of services to meet the needs of particular children, families, and schools. To reach this goal, interdisciplinary programs of research are required. The study of preventive intervention has traditionally been viewed as an applied science endeavor. Interdisciplinary prevention research, however, can serve to test theory and advance basic science knowledge of human developmental processes while also meeting the applied science goal of fostering growth and development. As outlined in this article, knowledge of human developmental processes related to cognition and emotion over children's first five years can both inform and be informed by the study of programs to foster children's school readiness.

## **Readiness Redux: Implications of the Neurobiological Model**

The neurobiological approach to early childhood education and school readiness is premised on the idea that the school classroom represents a distinct context within which specific regulatory demands are made of children. Children are expected to adapt to a socially defined role for which they may or may not have been previously socialized. Differences among children in the capacity for regulation within this environment, as well as differences in supports for children's self-regulatory attempts both within and without this environment, are important to conceptualizations of readiness that view the transition to school within an ecological framework (Meisels, 1996; Pianta, Rimm-Kaufman, & Cox, 1999). From the foregoing, it can be seen that a focus on children's characteristics in the development of readiness does not preclude study of the influences of parents, schools, and communities. On the contrary, when viewed from the ecological contextual perspective that drives much of the research on child development, it necessitates their inclusion.

Researchers concerned with readiness over the past two decades have rightly moved from static child-focused conceptions of readiness embodied in academically oriented standardized tests of ability or aptitude. An exclusive focus on children's cognitive skills and abilities in the assessment of readiness has proved to be of limited benefit (Pianta & Walsh, 1996). This fact has rightly led researchers to seek alternative definitions for and determinants of readiness. This recognition of readiness as a socially constructed phenomenon has led to a broadening of the research base to include a focus on schools and teachers and the development of educational policies geared toward maximizing children's potential for success in school (Graue, 1993; NAEYC, 1990; Willer & Bredekamp, 1990).

Continued efforts to foster readiness with an eye toward the neurobiology and psychophysiology of children's emotionality and regulation may be particularly likely to yield long-term benefits. In this, measures of biologically based processes can serve as both predictors and outcomes in the evaluation of programs to promote readiness and success in school. Programs to foster regulation can use physiological and neurocognitive measures to identify individuals at high risk for poor school outcome because of negative emotional reactivity. Treatment  $\times$  Risk interactions can be specified that can increase the precision with which intervention effects on outcomes are estimated.

Although-brain imaging techniques are perhaps not currently usable with children younger than seven years of age because of features of the assessment, magnetic resonance imaging and perhaps, under certain conditions, positron emission tomography could be used, along with physiological and neurocognitive assessments, as outcome measures of the efficacy of preschool interventions. Programs could demonstrate efficacy through assessments of behavioral outcomes and underlying neurobiology and physiology.

As in the studies by Fox et al. (2001) and Davidson and Rickman (1999), which indicated change over time in emotional reactivity and EEG measures of frontal asymmetry, intervention studies might demonstrate change in frontal asymmetry and emotionality in response to curricula designed to reduce stress, foster emotional competence, and enhance attention, working memory, and other components of cognitive self-regulation. As noted by Nelson (1999), neuroscientific measurement techniques and knowledge of neural plasticity and human development are now sufficiently advanced to inform the conceptualization and evaluation of interventions to promote competence and foster resilience.

In conclusion, the neurobiological approach to the study of readiness can now supplant nativist or idealist conceptions of readiness that focus exclusively on maturation. The maturational view, primarily associated with Arnold Gessell (1925), posited that readiness comes about through the gradual development of abilities that facilitate learning: being able to sit quietly, to focus on work, to attend, and to follow directions. Certainly, there is some maturational component to the neurodevelopmental view of readiness; however, the traditional maturational view has been fully supplanted by an epigenetic conception of relations between nature and nurture (Elman et al., 1996). Indeed, the ideas that fostered the replacement of the traditional maturational view with an epigenetic conception of development were clearly in place in Gesell's time, most notably in the work of Myrtle McGraw (1946/1995).

Although any explicitly maturational view is and always has been unsuitable as a theoretical basis for child study, the child characteristics important for readiness that such a view purports to explain remain vital to the construct. In their modern form, however, these characteristics are now tethered to a comprehensive and ecologically sensitive framework relating neurobiological and behavioral research. Behavioral scientists, educators, and policymakers studying readiness and school adjustment should be aware of this. To this end, I have attempted to propose a conception of readiness that maintains a focus on relevant aspects of child functioning in a way that is theoretically and empirically well established and that has demonstrated or demonstrable links to family, peer, classroom, school, and community influences on readiness and school achievement.

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