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School Readiness and Self-Regulation: A Developmental Psychobiological Approach

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Abstract

Research on the development of self-regulation in young children provides a unifying framework for the study of school readiness. Self-regulation abilities allow for engagement in learning activities and provide the foundation for adjustment to school. A focus on readiness as self-regulation does not supplant interest in the development of acquired ability, such as early knowledge of letters and numbers; it sets the stage for it. In this article, we review research and theory indicating that self-regulation and consequently school readiness are the product of integrated developmental processes at the biological and behavioral levels that are shaped by the contexts in which development is occurring. In doing so, we illustrate the idea that research on self-regulation powerfully highlights ways in which gaps in school readiness and later achievement are linked to poverty and social and economic inequality and points the way to effective approaches to counteract these conditions.

Keywords

school readiness; self-regulation; executive functions; education; poverty; inequality

INTRODUCTION

The advent of primary school education for large numbers of children at the turn of the twentieth century resulting from the social, demographic, and economic changes of the industrial revolution led to concerns about variation in children's ability to make progress in formal learning environments. Most notably, this concern led to the publication of the Binet-Simon scale (Binet & Simon 1916) and to the establishment of research traditions in intelligence testing, psychometrics, and learning disabilities that remain with us to this day. Notably much of the initial effort in the identification of school difficulty focused on typical age-related (nomothetic) change in cognitive abilities and acquired knowledge and skills that could be used to identify atypical ability. With the growing recognition of the importance of a developmental systems approach and a paradigm shift in the second half of the twentieth century to research on processes of development at multiple levels of analysis (Cairns &

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Cairns 2006) came increased attention to individual variation in child characteristics and in children's environments associated with progress in school. This profound shift in thinking about children's development led to foundational research on mental retardation and learning disabilities as developmental disorders (Zigler & Hodapp 1986) and to a developmental understanding of disability. Among many other things, this paradigm shift also led to current developmental approaches to the education of exceptional children (the modern special education movement) and to the advent of experimental evaluations of early care and education interventions designed to remediate the effects of adverse early environmental and psychosocial influences on children's development (Ramey & Campbell 1984).

Building on traditions in developmental science and psychobiological models of development (Cairns et al. 1996, Gottlieb 1997), advances in developmental systems thinking have reframed understanding of school readiness (Blair 2002, Mashburn & Pianta 2006). School readiness research now encompasses multiple interrelated influences on children's development that for the most part are best united under the construct of self-regulation. Self-regulation, including but not limited to attributes such as focusing and maintaining attention, regulating emotion and stress response physiology, reflecting on information and experience, and engaging in sustained positive social interactions with teachers and peers, is manifestly important for success in school. A growing empirical base clearly documents the relevance of multiple indicators of self-regulation to short- and long-term academic and behavioral outcomes in school (Hamre & Pianta 2001, McClelland et al. 2007, Riggs et al. 2004, Rimm-Kaufman et al. 2009). As such, a focus on self-regulation development provides a common framework for psychological research on what it means to be ready to start school and for the best ways in which to support school readiness.

The emphasis on self-regulation in school readiness research is heightened by advances in neurobiology and neuroendocrinology indicating that environmental conditions and interpersonal interactions, both positive and negative, are embedded biologically, shaping or canalizing the development of brain and behavior (Blair & Raver 2012, McEwen & Gianaros 2011). These advances indicate that activity early in life in the central and peripheral nervous systems and the expressed genome are responsive to experience and adaptive for the context in which development is occurring (Zhang & Meaney 2010). This experiential shaping of physiological and psychological development suggests the potential for match or mismatch between the expectations of the school environment and the expectations of the environment experienced prior to school entry. It also, however, suggests the interrelatedness and malleability of development across levels of analysis from the genetic to the behavioral.

Formal compulsory elementary schooling has historically been understood as a means of preparing children from widely different cultural backgrounds for common educational and labor market experiences within the United States (Tyack 1974). This goal is currently framed within a sociodemographic context where immigrant youth comprise one quarter of our nation's 75 million children and where socioeconomic status greatly segregates disparities in young children's access to high-quality educational opportunity (Magnuson et al. 2004, Passel 2011, Reardon 2011). As reflected by the recent adoption of early learning standards at both national and state levels, educational policy increasingly recognizes that young children's skills and abilities extend beyond the acquisition of early academic skills. As such, appropriately defining and supporting school readiness is vital to the assurance of educational equity in the face of massive and intractable income inequality in the United States. The neurocognitive and social-emotional skills integral to self-regulation undergird early learning and are likely to be compromised for children growing up in poverty and other adverse conditions. Promising findings, however, suggest that the consequences of adversity can be effectively reversed by appropriately structured prekindergarten and kindergarten experiences.

SELF-REGULATION AND SCHOOL READINESS: THEORY AND NEUROBIOLOGY

What Kindergarten Teachers Say

An early indication of the importance of self-regulation as a focus for the study of school readiness emerged from the eminently practical step of asking a nationally representative sample of kindergarten teachers what they thought school readiness to be (Heaviside & Farris 1993). When asked to rank the skills and abilities most relevant to children's readiness for school, teachers responded by endorsing a conception of readiness as being physically well nourished and rested, able to communicate wants and needs verbally, to be enthusiastic and curious in approaching new activities, to pay attention and follow directions, to not be disruptive, and to be sensitive to other children's feelings. Very few teachers endorsed a strictly academic conception of readiness characterized by such skills and abilities as being able to count to 20, to know the letters of the alphabet, to know colors and shapes, or to be able to use a pencil or paintbrush. In short, teachers clearly endorsed a model of readiness as self-regulation, in which children arrive with the social skills and ability to regulate attention and emotion that facilitate teaching and learning activities in the classroom.

Implicit in kindergarten teachers' views on school readiness is a multidimensional theory of learning and of the process by which children engage with and make sense of interrelated and increasingly complex types of information. Included in this process are children's social and emotional skills that foster a positive relationship with the teacher and with classmates and that help to create an organized and emotionally supportive classroom environment. Also included are aspects of cognitive ability, attention, language, and executive functions that provide the direct proximal mechanisms through which children acquire increasingly complex knowledge through social interactions with teachers and classmates.

Indications of the relevance of self-regulation to school readiness and school achievement are well represented in the literature. A number of early studies focusing on temperament found not unsurprisingly that high levels of positive emotionality and low levels of distractibility are associated with better adjustment to kindergarten, as seen in measures of academic ability and teachers' perceptions of readiness for learning, or teachability (Keogh 1992, Martin et al. 1988, Palinsin 1986). It is not, however, that temperament or social and emotional aspects of children's development are more (or less) important for school readiness than are cognitive abilities. As meta-analyses of six longitudinal datasets indicated, early academic ability is the best predictor of later academic ability (Duncan et al. 2007). The key idea here is that temperamental and social-emotional aspects of the child are not simply separate influences on school readiness, distinct from cognitive abilities. They are, in fact, interrelated with and integral to aspects of child cognitive ability, primarily executive functions and the regulation of attention that are centrally important for learning in school.

The Neurobiology of Self-Regulation and School Readiness

The approach to school readiness as self-regulation is based in the neurobiology of executive functions and emotional development as seen in the psychobiological model of temperament developed by Rothbart, Posner, and colleagues (Derryberry & Rothbart 1988, Posner & Rothbart 1998, Rothbart 2004, Rothbart et al. 2004). In that model, individual differences in temperament are understood as the give and take between biologically based tendencies toward emotional and motor reactivity and the regulation of this reactivity through approach and withdrawal behavioral strategies and through attention (Posner & Rothbart 2000). Behavioral and emotional reactivity are determined by variation in sensitivity to stimulation in the brain's emotional and motivational systems. The regulation of this reactivity through attention is associated with three functionally, anatomically, and neurochemically distinct networks of attention in the brain: the alerting, orienting, and executive systems (Petersen & Posner 2012). These attention systems serve to both amplify and modulate reactivity in emotional and motivational systems (Posner & Rothbart 2007). Executive attention, or the volitional control of attention, is particularly relevant because it is activated by conflict or disparity between an expected and current state of events. The executive attention system calls on executive functions to organize top-down control of thinking and behavior by holding information in mind in working memory, flexibly shifting the focus of attention, and inhibiting automatic, unthinking responses to stimulation.

The neurobiology of the self-regulation system as the give and take between emotion and attention provides the basis for its application to school readiness and school achievement. Attention serves to amplify or regulate levels of emotional and physiological arousal, and does so in the form of an inverted U-shaped curve (Arnsten 2009, D. Diamond et al. 2007). At moderate increases in emotional and physiological reactivity, attention is increased and effortful regulation is maximized. At very low or very high levels of reactivity, however, control of attention is decreased and effortful regulation is less likely to occur. That is, as arousal is registered in the emotional-motivational and alerting and orienting systems of the brain, the stress response is activated, stimulating the production of corticotrophin-releasing hormone from the hypothalamus. Corticotrophin-releasing hormone initiates the rapid sympathetic adrenal response and the production of catecholamines, namely norepinephrine and dopamine, and also initiates activity in the slower-acting hypothalamic-pituitary-adrenal (HPA) axis, leading to the production of the steroid hormone cortisol (Gunnar & Quevedo 2007). As these neurochemicals rise to moderate levels, they stimulate neural activity in areas of prefrontal cortex (PFC) that underlie executive attention and executive function abilities. At moderate levels of increase, neural activity in PFC is high and executive function abilities are maximized. As these neurochemicals continue to rise beyond a moderate level, however, activity in PFC is reduced and activity is increased in brain areas associated with reactive motoric and emotional-motivational responses to stimulation (Ramos & Arnsten 2007). In this way, the neurobiology of executive functions maps onto the well-known inverted U-shaped Yerkes-Dodson curve relating anxiety to performance; at moderate levels of stress, performance is increased, whereas at very low or very high levels, performance is frequently compromised.

From this neurobiological perspective, the association between self-regulation and school readiness is clear. Children are ready to start school when they have reached a point in development at which they are sufficiently able to manage stimulation and attention in ways that begin to allow for the regulation of emotion and attention that enables sustained engagement with learning activities. Given what is known about the timetable for brain maturation, particularly maturation of PFC, it is logical that children would begin formal schooling at about the age of 6 years. This would, on average, be the point at which PFC, for many children, would be sufficiently developed to begin to exert the top-down control of reactive systems in ways that begin to allow for sustained engagement in learning activities: In the language of the kindergarten teachers who were asked to describe the characteristics important for readiness, this would be when children are able to be enthusiastic and curious in approaching new activities, to pay attention and follow directions, to not be disruptive, and to be sensitive to other children's feelings.

Of course, such a simple maturational perspective on readiness fails to take into account the process of development itself. Self-regulation is developing from infancy onward and shaped by the context in which development is occurring. Variation in self-regulation is present in individual characteristics and in contextual factors as well as in in the interaction between them (Blair 2014). At the genetic level (see Figure 1) are individual differences in genes that code for the sensitivity of neural receptors to catecholamines and glucocorticoids. Variation at this level will influence physiological, emotional, attentional, and executive control responses to stimulation; individual differences at each of these levels feed forward to influence activity at higher levels. Increased emotional reactivity influences the demand on the control of attention, and the control of attention influences the demand on executive functions. Activity at each level, however, also feeds back on the level below. Executive functions can help to focus attention, and through attention enable the regulation of emotion and stress physiology. Through stress physiology, the feedback system extends to the genetic level to influence gene expression (Meaney 2010, van IJzendoorn et al. 2011).

Through these recursive feed-forward and feedback processes, the self-regulation system is understood to come, developmentally, to a particular set point or level. That is, self-regulation in the individual is understood developmentally as a cybernetic, self-regulating system that adjusts in response to experience (Luu & Tucker 2004). This process of adjustment is referred to as allostasis, as opposed to homeostasis, and occurs primarily through alteration of levels of stress hormones in response to experience, with consequent effects on emotion, attention, and executive functions. Allostasis, or biased homeostasis, refers to the idea that the activity of a given system, such as the stress response system or the self-regulation system more generally, is adjusted adaptively to a given set point or resting level in order to meet the demands of a given context or set of contingencies. Unlike homeostatic systems such as body temperature, which must remain within a narrow band or variation around an established set point (98.6°F) in order to maintain the integrity of the organism, allostatic systems can take on a wide range of possible values in which the organism can function adaptively.

Such an allostatic understanding of self-regulation development informs understanding of how children may arrive at school with very different profiles of self-regulation capabilities and also the best ways to structure learning opportunities for children to support self-regulation. The development of effective self-regulation is promoted in early childhood by fostering the regulation of emotion, attention, and stress reactivity, primarily within the context of the family but also within the context of child care prior to school entry. Ongoing research on school readiness emphasizes the respective roles of maturation and of family investments such as parents' provision of sensitive, nurturant, and language-rich care as key influences on young children's early social-emotional and cognitive skills (Smith et al. 1997). Increasingly, studies have also demonstrated that young children's exposure to supportive versus negative interactions with parents, teachers, and peers shapes individual differences in emotional reactivity and regulation, in the control of attention, and in higher-order cognitive functions, in part through the mechanism of stress physiology (Blair et al. 2011b, Evans & Schamberg 2009, Ursache et al. 2013).

Over the past 10 years, studies of young children's neuroendocrine function have demonstrated that low-quality care from primary caregivers at home (Blair et al. 2008a, 2011a; Evans et al. 2007) and caregivers in child-care facilities (Dettling et al. 1999, Watamura et al. 2003) are associated with patterns of HPA activity that are not conducive to the flexible regulation of cortisol and catecholamines important for executive function and social-emotional well-being. Notably, altered activity in the HPA axis in child-care facilities has been shown to be specific to weekdays if children attend lower-quality settings and is not manifested on days when children remain at home receiving higher-quality care from parents. Conversely, more time in out-of-home care when the quality of the home environment is very low is associated with a lower resting level of cortisol (Berry et al. 2014). Further evidence of the role of lower- versus higher-quality out-of-home care in "getting under the skin" extends to children's compromised immune function, with child-care-linked increases in cortisol accompanied by lower immune function and higher rates of parent-reported illness (Watamura et al. 2010). These findings are well aligned with the neurobiology of self-regulation and higher-order cognitive function: Key aspects of school readiness at both neurobiological and behavioral levels are shaped by family and classroom settings and social contexts. These findings have important implications not only for understanding children as ready for those settings but also for ways that settings and caregivers are ready to meet and support the self-regulatory needs of young children (e.g., Rimm-Kaufman & Pianta 2000).

SELF-REGULATION AND SCHOOL READINESS: EMPIRICAL EVIDENCE

Executive Functions

Evidence demonstrating the role of self-regulation, including executive functions as well as social and emotional regulation abilities in school readiness and early school achievement, has been steadily accruing over the past decade or more. One primary finding of this research has been that executive function abilities are as important (if not more so) for early success in school than is general intelligence. An early demonstration of this relation was seen in a correlational study in which measures of working memory and the flexible shifting of attention were shown to independently predict early mathematics achievement over and above measures of reading ability and IQ (Bull & Scerif 2001). A number of additional studies have shown distinct relations of executive functions to mathematics and reading, again controlling for general mental ability (Clark et al. 2010, Espy et al. 2004), baseline measures of academic ability (McClelland et al. 2007), and aspects of social and emotional competence and temperamental effortful control (Blair & Razza 2007).

Executive function abilities are central to performance on many of the types of learning activities in which children are engaged in kindergarten and the early elementary grades. This is clearly seen in both mathematics and reading. The inherent demand of mathematics activities on executive functions is highlighted by conceptual and content-based analyses of early mathematics learning activities for young children (Blair et al. 2008b, Bull & Lee 2014) as well as by analyses of mathematics achievement (Espy et al. 2004). The executive cognitive demand of early mathematics is also seen in research on the neurobiology of mathematical thinking (Nieder 2005, Rosenberg-Lee et al. 2011) and in the types of activities that children encounter in early mathematics as represented by exercises in textbooks (Blair et al. 2007). Exercises in ordinality, cardinality, transivity, and pattern completion require young children to flexibly shift attention among problem elements and to inhibit one representation of a given symbol or object in favor of another in response to context-dependent cues. As such early mathematics learning represents a classic executive function challenge.

Similar executive cognitive challenge or demand is seen in aspects of early literacy development such as phonemic awareness. Children demonstrating phonemic awareness are able to recognize smaller units of meaning and sound, i.e., smaller words embedded within larger words, such as the word tooth in toothbrush. This ability requires the flexible shifting of attention, of seeing the word toothbrush in two ways, both as a complete word and also as composed of two smaller words. Similarly, learning to spell in English requires holding multiple representations of letter-sound correspondence in mind and inhibiting one over the other, such as when learning the letters C and K and letter combinations such as “kn” and “ph.” These are only two of multiple examples of the executive demand of early literacy.

In addition to the growth of academic knowledge, the role of executive functions in school readiness and early school success is also seen in their relation to motivation and engagement. Executive functions are important for making sense of complex information, but skills such as working memory and inhibitory control are overwhelmed when the complexity of information is too great. Executive functions are also overwhelmed, as noted above, when stress is too great and hormones rise beyond optimal levels. That is, executive function abilities at all ages, but particularly in young children in whom they are just developing, are dependent on an appropriate level of complexity and support for the regulation of moderate stress. When information is too complex and environments are too stressful, executive functions shut down; when information is too simple and environments are uninteresting, executive functions are not called on. This relation of executive cognitive ability to the complexity of information is the basis for the Vygotskian notion of the zone of proximal development. If information is presented in ways that are consistent with prior information and in the range of the individual's prior knowledge, then executive functions are more likely to be utilized. As the complexity of information rises, however, and the task is no longer within the individual's reach, executive function abilities are less likely to be utilized, and confusion and depressed motivation are likely to ensue.

This relation of executive functions to task complexity is seen in neuroimaging studies with adults and children that parametrically manipulate complexity (Callicott et al. 1999). At moderate levels of complexity, neural activity in areas of PFC that support executive functions is relatively more focused and efficient in individuals with higher executive cognitive ability relative to individuals with lesser ability. At a given level of task complexity, individuals with higher ability display more focal and less diffuse brain activity than those with lower ability (Rypma et al. 2006). With increasing task complexity, however, activation increases in the inverted U-shaped pattern. Activity in PFC increases in individuals with higher ability but decreases for individuals with lower ability as task complexity exceeds the capability of the individual. That is, individuals with lower executive ability will show greater neural activity relative to high-ability individuals at lower levels of complexity, whereas individuals with higher ability will show greater activity at higher levels of complexity. This pattern is mirrored in the developmental literature, as seen primarily in cross-sectional samples. On relatively simple relational reasoning tasks, children at younger ages show increased levels of activity in PFC relative to children at older ages (Durston et al. 2006, Eslinger et al. 2009). With increasing age, activity in PFC is decreased as children are able to solve relatively simple relational problems through faster pattern recognition and knowledge retrieval processes.

Social-Emotional Competence

The relation of self-regulation to school readiness is also seen in research on the role of child social development in the context of classroom settings. This research has elucidated the ways in which attention and emotion regulation support or constrain opportunities for learning in part through the facilitation of executive functions and engagement in learning and also through relationships with teachers and peers (Mashburn & Pianta 2006). For example, a small proportion of children enter classrooms with a strong biobehavioral tendency to show high levels of reticence and anxiety when confronted with new people, places, and things (Rubin et al. 1995). In contrast, a second group of children enter the classroom with a remarkably different profile, a biobehavioral tendency to approach new peers and new situations with emotional displays that are characterized by exuberance rather than fear (Kagan et al. 1987, Rimm-Kaufman et al. 1999). Not surprisingly, children with these very different biobehavioral profiles have been found to engage in preschool classrooms in very different ways, with behaviorally uninhibited children more likely to talk more often in class, to play more readily with new peers, and to show more positive emotion in the context of the school day than their more behaviorally inhibited counterparts.

Temperamental predisposition to approach versus withdraw has been argued to play a particularly important role in structuring young children's opportunities to engage their teachers in positive ways; for example, teachers have been found to spend more time talking with and providing instruction to children whom they view as more emotionally positive and less negative, difficult to manage, or clingy (for reviews, see Raver 2003, Stuhlman & Pianta 2002). Recent evidence from a large longitudinal study of children's emotional profiles of reactivity and regulation, or temperamental effortful control, supports these links to learning: Children with more emotionally negative, less well-regulated profiles performed less well academically from fall to spring of the school year than did their more emotionally well-regulated counterparts, with more emotionally negative compromised relationships with their teachers as one likely, empirically supported mediating mechanism (Valiente et al. 2008). Additional mechanisms may include simply spending less time in formal and informal instructional contexts: More emotionally negative, less well-regulated children have also been found to be less likely to participate in class, to be absent from school more often, and to like school less than more emotionally well-regulated children (Valiente et al. 2007, 2008).

One question raised by these studies of school readiness has been whether children who are emotionally more positive have an easier time building social relationships with peers and, consequently, whether early friendships matter for long-term adjustment and early academic achievement. Most children are able to develop close friendships with peers in preschool, demonstrating patterns of behavioral homophily, with more exuberant and physically aggressive children picking similarly "wired" classmates as best friends, as do more inhibited or shy children (Eivers et al. 2012). Children who are more dispositionally positive may learn more (and may like learning more) when interacting with peers: Prosocially oriented children who are more likely to approach and play with peers have also been found to demonstrate greater attention, persistence, and more positive attitudes toward learning across the school year than do more socially reticent children (Coolahan et al. 2000). In contrast, recent meta-analyses have suggested that children's capacity to form friendships and to maintain prosocial relationships with peers has low predictive power when estimating long-run academic outcomes (Duncan et al. 2007). However, because these models rely on teachers' reports of individual children's social skills as predictors of their later achievement, they may miss out on key ways that peers are likely to affect learning. Aligned with basic research findings on the role of moderate stress and high positive mood in supporting executive functions and problem solving (Arnsten 2009, Ashby et al. 1999), a number of studies have found positive engagement with peers to extend children's attention, to support encoding and retrieval of information, and to support key outcomes such as early reading and mathematics (Bryan & Bryan 1991, Coolahan et al. 2000, Fuchs et al. 2001). Second, peers' behavioral self-control and academic and language skills have been found to be of substantial importance when considering classroom composition as a predictor of academic achievement (Whitmore 2005). That is, children's abilities to get along with peers may have a substantial impact on learning at the group level that is less easily detectible at the individual level.

The Student-Teacher Relationship

The foregoing studies clearly illustrate the importance of the quality of interpersonal interactions between young children in the classroom for learning. A second body of research on children's social skills considers the role of their relationships with teachers, with hypothesized consequences for both emotional and behavioral adjustment and also for early learning. Characterized through teachers' ratings of their closeness versus conflict with children on standardized measures (such as the Teacher-Student Rating Scale), those early relationships have been found to be moderately to strongly predictive of students' attention and engagement during classroom activities (Skinner et al. 1990, Split et al. 2012). A positive relationship with one's teacher has been argued to set the stage for important motivational processes that are hypothesized to carry forward through elementary school: Children engaging in lower levels of conflict with teachers in their kindergarten year have demonstrated higher levels of academic achievement and more productive work habits through middle school grades (Hamre & Pianta 2001, O'Connor & McCartney 2007).

Teacher-student relationships can also be viewed through an attachment-oriented set of mechanisms and through mechanisms of self-determination, emphasizing ways that positive relationships with teachers may meet children's needs for relatedness, competence, and autonomy (Roorda et al. 2011). Effect sizes of approximately one-quarter of a standard deviation have been found across 99 studies examining the relation between teacher-reported relationships with students (both positive and conflictual) and student achievement, with smaller-sized estimates (approximately $d = 0.15$) for those studies relying on standardized measures of achievement as the outcome (Roorda et al. 2011). Though modest, these estimates are robust to the inclusion of earlier, baseline measures of academic ability, lowering the concern that teachers are inadvertently influenced by implicit assessments of student cognitive talent in their ratings of closeness versus conflict; notably, these estimated effect sizes are larger for children who are academically or behaviorally at risk (Hamre & Pianta 2001, Liew et al. 2010).

Together, these studies focusing on children's social and emotional skills across areas of emotional reactivity, regulation, and relationships with teachers and peers underscore the importance of these domains for school readiness. The past 15 years of research have also underscored the ways in which children's social and emotional functioning are shaped by classroom experience as much as children may also shape it. A series of child-care studies (both in center-based and home-based care) has consistently demonstrated that children's physiological reactivity as indicated by morning-to-afternoon rising cortisol levels on days attending out-of-home programs as well as emotional reactivity is affected by the quality of sensitivity versus intrusiveness and attention provided by teachers in those settings (Badanes et al. 2012, Crockenberg & Leerkes 2005, Dettling et al. 1999, Tout et al. 1998). These child-care studies suggest that the stressful nature of low-quality care may get under the skin for some children, with cascading influences on child emotion regulation and executive functions (Ursache et al. 2013, Watamura et al. 2011). Through such models of the role of affect, attention, and learning, an emphasis on the emotional climate of the classroom is not simply a caring approach to young children's experience but represents a productive pathway through which learning can be facilitated. This newer set of studies on the ways that children's emotional regulatory development may be influenced by their classroom environments represents a major advance in our understanding of the ways that social contexts shape school readiness through biological pathways.

A FOCUS ON SELF-REGULATION DOES NOT DETRACT FROM A FOCUS ON ACADEMIC LEARNING

In framing school readiness as the development of self-regulation, two points are central. One is that a focus on self-regulation and executive functions in school readiness research does not supplant or take precedence over a focus on acquired knowledge and the development of cognitive abilities, such as language, vocabulary, and knowledge of letters and numbers. If anything, it supports and expands the focus on acquired knowledge. As noted above, it is well established that the best predictor of later academic ability is early academic ability. The analysis of Duncan and colleagues (2007) of six datasets indicated that early mathematics ability was the strongest predictor of later academic outcomes, over and above a variety of primarily teacher report measures of attention and behavior problems. It is necessary, however, to avoid characterizing the distinction between acquired ability and self-regulation as an either-or dichotomy. Both are necessary. Just as executive function abilities will facilitate the acquisition of knowledge, increases in vocabulary, language ability, and competence with numbers, letters, and words will facilitate executive function abilities (Ferrer et al. 2007, Welsh et al. 2010). In the parlance of Vygotskian theory, a growing knowledge base will expand the child's zone of proximal development. It will allow the child to engage in more elaborate and complex processing of information, which has strong implications for the value of content-rich curricula in the areas of language, math, and science for young children.

In this context, the homologous distinction between fluid (executive functions) and crystallized (acquired knowledge) aspects of intelligence (Blair 2006) and between controlled and automatic processes in dual-process models of cognition is useful (Evans et al. 2007). Both fluid and crystallized skills develop rapidly early in the life span but follow distinct trajectories into middle and later adulthood, with crystallized abilities remaining generally robust and steady while fluid abilities decline with age (Horn & Cattell 1967, McArdle et al. 2002). This distinction is reflected in the fact that different brain systems underlie these two general classes of ability. Fluid abilities, essentially executive functions, as noted above, are associated with PFC and related brain areas. PFC is slower to mature and faster to decline than other brain areas (Toga et al. 2006, Zelazo & Lee 2010). Concomitantly, fluid skills are chronometrically slow and physiologically effortful, such that repeated use can deplete executive skills. In contrast, crystallized, acquired abilities are chronometrically fast and more automatized and are associated with perceptual processes and memory retrieval of the temporal, parietal, and occipital lobes (Colom et al. 2009). In general, these brain areas develop rapidly and show less typical age-related decline. A long-standing hypothesis in intelligence research, referred to as the investment hypothesis, posits that fluid abilities, e.g., executive functions, enable or pave the way for the acquisition of acquired knowledge. In developmental research within the context of education, the investment hypothesis has some longitudinal support indicating that fluid intelligence developmentally predicts later academic knowledge, particularly quantitative ability, and that this relation is strongest in childhood (Ferrer & McArdle 2004). In short, investments in both classroom practices and curricula that build executive function *and* layer on cognitively challenging and content-rich curricula are likely to provide young children with support in building both those skills alternately characterized as fluid and crystallized.

The second related point for school readiness research is that there is, of course, considerable variability in the course of the development of school readiness: Just as children enter school with very different levels of language ability and knowledge of letters and numbers, children also enter early educational settings with clear individual differences in executive function and associated emotional self-regulatory skill. Again, a central point is the interrelatedness of development. As children make progress in self-regulation skills, they set the stage for concomitant progress in the growth of academic ability, and vice versa. Support of early learning that focuses jointly and recursively on self-regulation and on academic content can most effectively promote school readiness, particularly for children for whom support for both is low, as in the context of poverty.

SELF-REGULATION MAY BE A PRIMARY MECHANISM THROUGH WHICH POVERTY AFFECTS SCHOOL READINESS

The developmental systems approach to school readiness highlights risks that are more likely to be experienced by children from high-poverty homes and that are associated with adverse early rearing conditions and poor quality child care. It is well known that children in poverty are far less likely than their higher-income counterparts to enter school ready to learn (Magnuson et al. 2004). Children in poverty have less access to higher-quality care outside the home and a significantly lower probability of attending preschools that are emotionally and cognitively supportive of optimal self-regulation (McCartney et al. 2007). Children in poverty also have fewer opportunities for exposure to learning activities, such as exposure to reading and to rich and varied language that can promote literacy and vocabulary development (Brooks-Gunn & Duncan 1997, Fernald et al. 2013).

Children in poverty are also less likely to experience family, home, and neighborhood environments that foster prototypically optimal self-regulation, and as a consequence, the impact of available learning opportunities is reduced. In addition to reduced opportunities for learning, the physical as well as psychosocial conditions of poverty, including experiences with caregivers, influence self-regulation development (Blair et al. 2011a,b; Evans 2003; Raver et al. 2013). A key finding here is that the conditions of poverty are associated with allostatic alterations of stress response physiology in children, as seen through levels of catecholamines and cortisol. Given the relation of stress physiology to activity in brain areas central to self-regulation, including executive functions and reactivity and regulation of emotion and attention, the implication is that early adversity is shaping the self-regulation system in ways that are adaptive for an aversive context but not conducive to a high level of adaptation to the demands of the context of school. The central implication of this research is that, in addition to potentially providing less opportunity for the learning of language and development of early academic ability, the environment of poverty-related risk and early adversity also impacts self-regulation development in ways that impede the development of school readiness.

Evidence for the negative impact of poverty-related adversity on children's executive function indicates that it is biologically embedded and mediated by the quality of children's interpersonal relationships with caregivers. Data from the longitudinal study known as the Family Life Project demonstrate that higher levels of poverty and material hardship predict children's self-regulation, as indicated by levels of salivary cortisol as well as by executive function abilities (Blair et al. 2011a). Importantly, parental caregiving partially mediates the effects of poverty on both cortisol and executive function. That is, a higher level of poverty was associated with a lower level of prototypically sensitive parenting. Lower sensitive parenting was in turn associated with a higher resting or basal level of cortisol in children, which was then associated with a lower executive function ability in children at age 3 years. These findings are consistent with neurobiological studies indicating that the PFC, the seat of executive functions, is highly influenced by the physiological response to stress and demonstrates pronounced deficits in the context of chronic adversity (Cerqueira et al. 2007, Liston et al. 2011).

Given that well over 20% of children in the United States live in poverty and that early self-regulation sets the stage for later opportunities for learning, the impact of economic hardship on young children's school readiness represents a major source of long-term social, economic, and educational inequality in the United States and the developed world (Blair & Raver 2012). These gaps may be further magnified for young children from families recently immigrating to the United States and for whom English is a second language (De Feyter & Winsler 2009, Glick et al. 2010). For example, Hispanic, recently immigrated English-language learners enter kindergarten substantially lagging behind their monolingual, native-born, English-proficient peers in key school readiness domains emphasizing math and language skills but not in domains emphasizing socioemotional skills (Crosnoe 2007, Quirk et al. 2013). Importantly, those differences can largely be ascribed to immigrant families' lower material and social capital, including their greater likelihood to struggle to make ends meet financially (Glick et al. 2010). Results from a nationally representative sample of over 22,000 children in the United States indicate that the gap in language and math scores at kindergarten entry found between Mexican first-generation immigrant children and their white native-born counterparts is largely attributable to a dramatically greater likelihood of family poverty status as well as less time spent in center-based child care (Crosnoe 2007). As a greater fraction of the nation's young children is enrolled in early childhood settings and with increased investment in universal forms of early education, both developmental and educational researchers grapple with ways to structure classroom practices and curricula to decrease rather than magnify educational inequities.

FOSTERING SELF-REGULATION IS A PRIMARY WAY OF FOSTERING SCHOOL READINESS

Given the association of poverty with the double jeopardy of reduced opportunities for learning and reduced support for self-regulation development to foster learning and engagement, what are the best ways in which to promote school readiness? What types of activities and experiences both prior to and during kindergarten and the early elementary grades are likely to work well for children at risk of early school failure? Findings of pioneering early-intervention studies, including the Perry Preschool Project, the Abecedarian Project, and the Chicago Parent-Child Centers, indicated that high-quality care, beginning as early as age 6 months but as late as age 3 or 4 years, is associated with increased academic achievement. Most impressive in these foundational early-intervention studies is that effects on academic achievement were sustained into the secondary grades, even in the absence of sizable sustained effects on intelligence, which suggests improvements in self-regulation as a potential mechanism of effects (Heckman et al. 2012). In addition, effects were observed on a variety of life outcomes indicative of improvements in self-regulation, such as stability in employment and relationships and reduced criminality and incarceration (Reynolds & Temple 2008).

In keeping with an emphasis on self-regulation, more recent programs to foster school readiness for children in poverty have focused specifically on executive functions and emotion regulation as direct proximal mechanisms through which children's learning experiences in preschool will lead to enhanced readiness in kindergarten. These programs represent innovative efforts to leverage improvements in the quality of the classroom settings to counteract the negative sequelae of poverty-related risk. A primary example of this approach is the randomized controlled trial known as the Chicago School Readiness Project (CSRP). The CSRP was composed of several primary programmatic components to improve low-income preschool-aged children's self-regulation. These programmatic components included 30 hours of teacher training in classroom management strategies (e.g., rewarding positive behavior, redirecting negative behavior) that were hypothesized to provide children with more effective regulatory support (Webster-Stratton et al. 2001, 2008). Classroom consultants also worked one-on-one with three to five children who exhibited the most challenging behavioral problems. Analyses of the impact of CSRP suggested that this classroom-based intervention led to clear reductions in children's emotional and behavioral difficulty (Raver et al. 2009). For example, children in the treatment group were reported by their teachers as having significantly fewer internalizing (or sad and withdrawn) behavior problems than did their control group enrolled counterparts by spring of the Head Start year. Children in the treatment group were also reported by their teachers to show significantly fewer externalizing (or aggressive, disruptive, and acting out) behaviors than were children in the control group in the spring of the Head Start year. Most importantly, analyses provided clear evidence of CSRP's benefit for young children's self-regulation and opportunities for learning. These analyses confirmed that CSRP improved low-income children's executive function skills, as indexed by assessors' ratings of children's attention and impulse control as well as on direct assessments of inhibitory control and working memory, from fall to spring of the Head Start year. Analyses also suggested significant benefits of CSRP for children's academic skills as measured by direct assessments of children's vocabulary, letter-naming, and math skills (Raver et al. 2011). Effect sizes (ESs) of this intervention were substantial, ranging from 0.34 to 0.63. From a policy perspective, these findings provide clear support for specific steps that programs might take to improve school readiness for children through a classroom-based approach targeting children's self-regulation. When targeted through classroom-based intervention, changes in self-regulation also lead to socioemotional and academic gains for children facing high poverty-related risk.

Another key example of an approach to readiness focused on self-regulation is the randomized controlled trial known as the REDI (REsearch based, Developmentally Informed) project. This program combined enhanced language and literacy experiences for preschool children that emphasized interactive reading and conversation between teachers and children with a curriculum focused on awareness of emotion and the regulation of behavior. Findings from the evaluation of this comprehensive program indicated benefits to children's vocabulary and early literacy development as well as to children's emotion knowledge and social problem-solving skills in the spring of the preschool year (Bierman et al. 2008a). Effects on self-regulation were seen on some measures of the construct, including executive function and inhibition, and in keeping with the model of self-regulation and readiness, these measures of self-regulation were found in some instances to mediate or moderate effects of the curriculum on posttest outcomes (Bierman et al. 2008b). Specifically, a direct measure of executive function and an observer rating of children's orientation to a set of tasks were shown to partially mediate effects of the program on children's early literacy development. Intervention effects on teachers' perceptions of children's social competence were found to be greatest for children with low levels of task orientation. In addition, follow-up in kindergarten indicated some sustained effects of the program on language and effects on social competence that were moderated by kindergarten classroom and school characteristics (Bierman et al. 2014).

A further example, one not necessarily specific to the experience of children in poverty, is seen in the comprehensive curriculum known as Tools of the Mind. Unlike CSRP and REDI, which were developed primarily within the research context to address specific hypotheses about program components likely to enhance readiness for children at risk for school failure, Tools of the Mind was developed within the framework of Vygotskian pedagogical theory that emphasizes the role of executive function development through intentional, child-directed activities. Activities in Tools of the Mind are designed to foster reflective thinking in children, primarily through structured sociodramatic play and cooperative activities with classmates. A full description of the curriculum and its basis in the fundamental insights of Vygotsky, Luria, and post-Vygotskian scholars can be found in a number of sources (e.g., Bodrova & Leong 2007). For present purposes, a small-scale randomized evaluation of the preschool version of Tools with a sample of children who were English-language learners from Spanish-speaking low-income homes found evidence of an effect of the curriculum on executive function measures (A. Diamond et al. 2007) and on classroom climate, with some tentative evidence for effects on language development (Barnett et al. 2008). However, a randomized evaluation of the prekindergarten version of the curriculum with a larger, more diverse sample found no effects of Tools on any aspect of academic ability or any aspect of self-regulation, including direct assessments of executive functions and teacher ratings of emotion regulation (Wilson & Farran 2012). In contrast, a recently completed large-scale cluster randomized-controlled trial of the kindergarten version of the curriculum found widespread positive effects of the program on children's academic and self-regulation abilities (Blair & Raver 2015). Findings from this evaluation, which included schools spanning the range of socioeconomic status from low to high, indicated substantial effects (ES = 0.30–0.80) of the curriculum on vocabulary, reasoning, and attention among children in high-poverty schools as indicated by the percent of children eligible for free or reduced-price lunch. Effects of the curriculum were also seen on measures of stress response physiology, specifically salivary cortisol and alpha amylase, for children in high-poverty schools, suggesting a higher level of physiological engagement, consistent with the inverted U-shaped curve described above. Smaller effects of the curriculum were seen in all low-poverty as well as high-poverty schools on measures of reading, mathematics, and working memory. Most importantly, sustained effects on growth in reading and vocabulary were seen for all children into the first grade.

SELF-REGULATION AS A FRAMEWORK FOR EFFECTIVE TEACHING PRACTICES IN READING AND MATH

Similar to an emphasis on self-regulation development in comprehensive approaches to the promotion of school readiness in CSRP, REDI, and Tools of the Mind, approaches to readiness focusing specifically on emergent literacy and mathematics are also consistent with an understanding of school readiness as self-regulation. A key example is seen in the approach to early reading instruction known as dialogic reading. Dialogic reading refers to a method of reading to children characterized by numerous opportunities for the child to engage in conversation with the reader. In the method, the adult becomes an active listener, asking questions and prompting language use and reflection on information contained in the story. Evaluations of dialogic reading demonstrate moderate to large effects on child literacy and vocabulary growth in middle-income samples (Whitehurst et al. 1988) and small to moderate effects in low-income samples (Whitehurst et al. 1994). A meta-analysis of read-aloud interventions, of which dialogic reading is an example, found moderate to large effects on multiple aspects of literacy development including phonological awareness and vocabulary (Swanson et al. 2011). Although generally not couched in terms of self-regulation development, the approach is manifestly associated with turn taking in conversation, with positive social relationships with adults, and with reflective thinking and the use of language for purposes of regulating and organizing information. Of specific relevance to the use of such read-aloud techniques for children in poverty is the fact that language stimulation in the home and in child care prior to school entry can be very low (Dickinson & Tabors 2001). As such, additional support for book reading and conversation strategies is needed to maximize the benefit of read-aloud approaches in these contexts (Wasik et al. 2006).

Approaches to school readiness focusing specifically on the development of letter and number knowledge can also be understood within the framework of child self-regulation. Examples of early mathematics instruction are particularly relevant. Effective mathematics instruction for preschool children builds on children’s initial conceptions of quantity and change. One approach uses games that provide experience with specific understandings, such as comparing quantities or counting, and then integrates these understandings through increasingly complex activities. Another builds on children’s everyday experience to foster competence in number, spatial, and geometric concepts. Evaluations of these strategies indicate that they are effective in building mathematical knowledge in children at risk for poor school readiness due to poverty (Clements & Sarama 2011). From the perspective of readiness as self-regulation, these approaches are effective by introducing an appropriate level of complexity to support children's reasoning and executive function skills. By implicitly or explicitly formulating activities within the young child's zone of proximal development, these structured learning activities for children function within the framework of readiness as self-regulation. Future evaluations of these and similar programs might profitably incorporate measures of executive functions and motivation and engagement as expected indicators of the efficacy of these approaches in promoting children's readiness for school.

CONCLUSION

Definitions of school readiness challenge us at many levels. They challenge our understanding of children's development, our understanding of the best ways in which to create learning environments for children, and our understanding of the general goals of education in our society. Most importantly, definitions of school readiness challenge our understanding of and commitment to equality of opportunity and to the assurance of the ability of every child to succeed through free and universal public education despite initial disadvantage. As the framing of school readiness as self-regulation makes all too clear, the effects of poverty on children's chances of success in school begin early and can persist for years. The experiential shaping of self-regulation and the biological embedding of experience in the context of poverty, combined with the fact that children from poverty homes are more likely to attend under-resourced and challenged schools, indicate the need for sustained and immediate action. The very encouraging news is that scientific understanding of early learning and the development of self-regulation, coupled with promising evaluations of innovative programs focused on self-regulation, indicate a way forward. An approach to the promotion of school readiness by fostering the development of self-regulation offers the potential to remake early education in a way that is effective for all children. It can help to level the playing field and restore equality of opportunity. In this endeavor, the developmental systems approach to school readiness is distinct from but allied with efforts to increase readiness that focus only on specific child skills and capabilities (e.g., phonemic awareness) that are associated with good or poor performance in specific academic domains (e.g., reading). The approach is also distinct from but informed by a focus on specific school setting or system characteristics such as the context of the classroom, characteristics that are of course important but cannot be divorced from the totality of the developmental system. Either-or models of early learning and school readiness are of decreasing utility and have not generally yielded approaches that are sufficiently comprehensive and informative for meaningful educational intervention and policy. A focus on self-regulation development helps to unite multiple influences within a coherent framework that can serve as a basis for action and the structuring of educational experiences from prekindergarten through the early elementary grades to support and foster progress in school for diverse groups of children. It would seem that the path through the wilderness is clear; it only remains to be taken.

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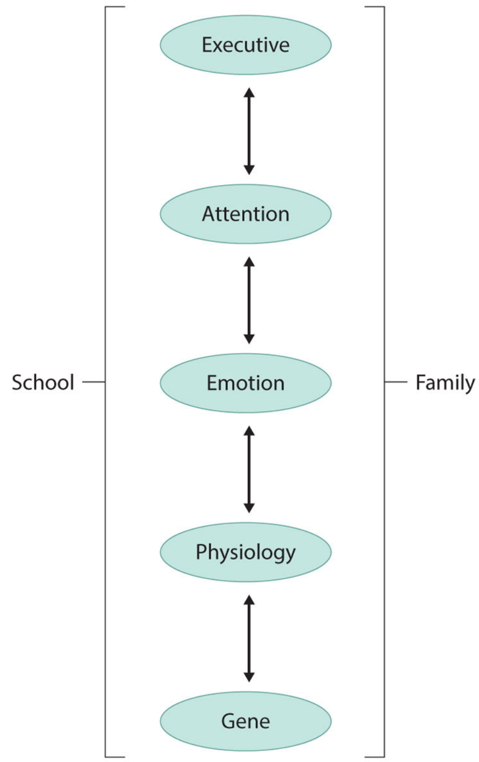

Figure 1.
The architecture of self-regulation.