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Multiple Aspects of Self-Regulation Uniquely Predict Mathematics but Not Letter–Word Knowledge in the Early Elementary Grades

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Abstract

The relation of self-regulation measured prior to school entry to developing math and reading ability in prekindergarten through the second grade was examined in a prospective longitudinal sample of 1,292 children and families in predominantly rural and low-income communities in 2 regions of high poverty in the United States. Direct assessments of executive function, effortful control, and stress response physiology (indexed by resting levels of cortisol and alpha amylase obtained from saliva) were measured at child age 48 months and parents and teachers reported on children's effortful control using temperament rating scales at child age approximately 60 months. Math and reading ability, as measured by the Woodcock-Johnson III applied problems and letter–word subtests, respectively, were measured at prekindergarten through the second grade. Effects for self-regulation measures were seen primarily for initial level and to some extent growth in both mathematics and reading, even when controlling for family demographic characteristics that represent relevant selection factors into higher levels of both self-regulation and academic achievement. These effects persisted for mathematics but not for reading with the inclusion of child cognitive abilities, vocabulary, and speed of processing measured in prekindergarten, concurrent with the first time point for the academic measures. Results are interpreted as indicating a role for self-regulation in learning ability generally, likely through support for attention and reasoning abilities that are most specific to the assessment of mathematics in this

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analysis. Implications for instruction and for assessment and the best ways to support the development of early math and reading ability for children at risk for school failure are discussed.

Keywords

self-regulation; executive functions; mathematics; child development; academic achievement

Interest in self-regulation across the life span (Vohs & Baumeister, 2011), developmentally (Blair & Raver, 2012), and in response to training and intervention efforts (Berkman, Graham, & Fisher, 2012) is strong. Theoretical (Blair, 2002; Raver, 2002) and empirical (Duckworth & Seligman, 2005; Fuhs, Nesbitt, Farran, & Dong, 2014; McClelland et al., 2007) literatures provide support for relations of various aspects of self-regulation to academic outcomes in early and middle childhood. For the most part, studies provide strong inference about self-regulation and academic achievement by controlling for baseline achievement and relevant variables (Duncan et al., 2007). A number of questions, however, remain. These include the extent to which various aspects of self-regulation are uniquely predictive of academic outcomes; the time course of the relation of self-regulation to academic ability; the extent to which effects are present for indicators of early reading ability as well as for early math; and the extent to which effects for self-regulation are observed over other aspects of child cognitive ability, particularly for children in poverty. It is well established that poverty affects both children's academic preparedness for school (Brooks-Gunn & Duncan, 1997) and self-regulation development (Noble, McCandliss, & Farah, 2007) and differentiating effects of general cognitive and self-regulation influences on achievement can inform early educational practice.

Defining Self-Regulation

Self-regulation is a molar construct that can be defined as the volitional and nonvolitional management of attention, emotion, and stress response physiology for purposes of goal-directed action, primarily through executive function abilities. We have previously addressed the theoretical basis for distinguishing among aspects of self-regulation in a number of publications (Blair, 2014; Blair & Ursache, 2011) and briefly revisit this theory here. Self-regulation is composed of multiple influences that are hierarchically organized and integrated, ranging from the genetic to the social-cultural. Within this hierarchy are higher level processes, including executive functions and effortful control that are primary indicators of self-regulation. Although similar in many respects (Liew, 2012), executive functions are manifestly cognitive and intentional, involving the maintenance of attention and task set or focus in the face of distracting or interfering information. As such, executive functioning includes working memory and the flexible control of the focus of attention, as well as an inhibitory dimension shared with effortful control. In contrast, effortful control can be seen as a more general temperamental and behavioral disposition and therefore less overtly intentional.

Although distinct, executive functions (EF) and effortful control (EC) are both higher level processes and as such dependent on lower level components of the self-regulation system; namely activity in stress response physiology and resulting hormones including

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norepinephrine and cortisol, associated with the sympathetic adrenal and hypothalamic-pituitary-adrenal (HPA) systems respectively (Gunnar & Quevedo, 2007). These hormones potentiate activity in neural substrates that underlie attentional alerting and orienting, and emotional reactivity and regulation. The stress response is composed of relatively fast sympathetic and slow HPA responses and as a result, peripheral indicators of activity in these systems detectable in saliva (alpha amylase and cortisol) are often inversely related, or asymmetrical; that is, when one is high, the other is low (Gordis et al., 2006; Nater et al., 2007). This is relevant in that the association between stress hormones and self-regulation is generally that of an inverted U shape curve (Arnsten, 2009). At moderate levels of stress, hormonal increase potentiates activity in neural substrates that enhance the volitional regulation of attention and emotion and support higher order executive functions and the temperamental characteristic of effortful control. Given the fast and slow nature of the stress response, however, a moderate increase is often seen in one or the other indicator, amylase or cortisol, with a correspondingly low level in the other. Such a pattern has been observed for executive function at age 3 years with children in this data set (Berry et al., 2012) and in others examining behavior problems (El-Sheikh et al., 2008) and general mental ability (Keller et al., 2012).

Self-Regulation and Mathematics Ability

Although self-regulation processes likely underlie learning generally, self-regulation may be most directly relevant to early mathematics. 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, Knipe, & Gamson, 2008; Bull & Lee, 2014) as well as by longitudinal and correlational analyses relating measures of executive functions in early childhood to mathematics achievement (Bull & Scerif, 2001; Clark, Pritchard, & Woodward, 2010; McClelland et al., 2007). The executive function demand of early mathematics is also seen in research on the neurobiology of mathematical thinking (Nieder, 2005; Rosenberg-Lee, Barth, & Menon, 2011) and in the types of activities that children encounter in early mathematics as represented 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.

Research on effortful control also suggests unique relations of this construct with mathematics ability but has tended to focus on academic outcomes more generally. A prior study with children in the third grade has shown that a teacher report measure of the ability to maintain and focus attention, a construct very similar to effortful control, is strongly associated with multiple aspects of mathematics competence over and above measures of cognitive ability including working memory, processing speed, and reasoning ability (Fuchs et al., 2006). Several studies have also linked parent and child reported effortful control using temperament questionnaires to a variety of indicators of academic competence, including grade point average, attendance, and teacher ratings of ability (Fabes, Martin, Hanish, Anders, & Madden-Derdich, 2003; Valiente, Lemery-Chalfant, Swanson, & Reiser, 2008). Notably, few studies have included direct measures of effortful control. One that did,

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in a predominantly low income sample, found associations between direct assessment of effortful control in first grade and reading but not math in third grade (Liew et al., 2008) while another in a Swiss sample found that when controlling for executive function ability, direct assessment of effortful control was unrelated to both math and reading (Neuenschwander et al., 2013). Although questionnaire based measures of effortful control can be moderately associated with direct assessments, they are by no means synonymous. Studies incorporating both types of measures are needed. In addition, studies using questionnaire measures have most frequently used parent report. It is also important to also consider teacher report given that parent and teacher report of temperament are usually only moderately correlated. It may be that teacher reported effortful control is a particularly effective predictor of achievement.

Self-Regulation and Early Reading

Although the foregoing review highlights relations of higher order self-regulation constructs to mathematics learning it is of course relevant to the development of academic competence more generally, including early reading. Here, however, it is useful to attend to the specific aspects of academic ability that are being assessed. As noted above, assessments of mathematics typically contain reasoning-based items that make substantial demands on working memory, attention, and inhibitory control. Assessments of early reading ability can also make such demands, as in assessments of phonological awareness in which children recognize smaller units of meaning embedded within larger words, such as the word tooth in toothbrush. This ability requires the flexible shifting of attention and control of inhibition. Many assessments of early reading ability, however, focus less on comprehension, which can be difficult to assess in young children, and focus on knowledge based aspects of reading, such as knowledge of letters, sounds, and words. These knowledge-based skills, such as we measure here, rely on semantic memory and tend not to involve executive processes when assessed.

Longitudinal Data Analysis

In this analysis we examine multiple aspects of self-regulation, including stress response physiology as well as measures of executive functions and effortful control, in a predominantly low-income sample of children. Our goal is to estimate the unique and combined contributions of aspects of self-regulation measured prior to school entry to academic outcomes in reading and math measured longitudinally from prekindergarten through the second grade. We do so while including a comprehensive set of covariates, both demographic characteristics as well as cognitive covariates. Prior studies have used various approaches to the analysis of self-regulation and academic outcomes, usually as determined by the number of measurement time points available and whether self-regulation variables are measured concurrently with or in advance of academic outcomes. For data in which academic outcomes are available at only two time points, autoregressive models have been used in which the later time point is regressed on the earlier time point with covariates and predictors assumed to adjust for time invariant aspects of the academic outcome and for factors that might lead to selection into relatively higher or lower levels of achievement. Such an analysis strengthens inference about the role of self-regulation and provides a

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relatively strong test of the hypothesis that self-regulation contributes to achievement over and above fixed aspects of achievement. Several prior studies examining relations of self-regulation measures to academic outcomes have been of this type (e.g., Blair & Razza, 2007; Duncan et al., 2007; McClelland et al., 2007; Welsh, Nix, Blair, Bierman, & Nelson, 2010).

By and large, prior studies support the hypothesis that self-regulation is associated with academic outcomes with small to moderate effect sizes. With some notable exceptions (Duncan et al., 2007), however, few studies have used longitudinal approaches to examine the extent to which effects of early self-regulation on later academic outcomes might be shared with or accounted for by other aspects of child ability or background. Further, although the autoregressive model addresses a specific question about the relation of self-regulation to academic ability, it is less appropriate for analyzing growth in ability, particularly when three or more time points are available (Grimm, Steele, Mashburn, Burchinal, & Pianta, 2010). With multiple time point data, growth curve models can be used to address questions about the relation of self-regulation to both initial levels of ability (when the intercept is centered at prekindergarten, the first time point) and to growth in ability over and above any association with the intercept. Accordingly, we use growth modeling to examine change in academic ability from prekindergarten (child age approximately 60 months) through the second grade in a sample of children and families followed longitudinally from birth.

The primary contribution of this analysis is the examination of multiple aspects of self-regulation in the longitudinal prediction of academic ability in a predominantly low-income sample. Few studies have included direct assessments of both executive functions and effortful control measured prior to school entry. Further, no studies to our knowledge have also included teacher as well as parent report of child effortful control. Several studies have examined parent reported effortful control, but given that parent and teacher reports of child temperament can be distinct, it may be that teacher report adds uniquely to the prediction of academic outcomes. Finally, we are unaware of any studies that have included measures of stress response physiology assessed prior to school entry. We have previously shown in this data set that executive function ability measured in the preschool period is related to academic ability measured in prekindergarten (Willoughby et al., 2011) and that salivary cortisol and alpha amylase measured in infancy and toddlerhood (7–24 months) interact to predict both executive functions at age 3 years and academic ability in prekindergarten (Berry et al., 2012). In this analysis, we build on these prior findings to examine effortful control as well as executive function at age 48 months and also the interaction of cortisol and alpha amylase at child age 48 months as predictors of initial levels and growth in early math and reading ability.

Method

Recruitment

The Family Life Project (FLP) was designed to study families in areas of high child rural poverty in two states (North Carolina and Pennsylvania). Complex sampling procedures were used to recruit a representative sample of 1,292 families at the time of the target child's birth, with low-income families in both states being over-sampled and African Americans

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oversampled in North Carolina. Further details of FLP sampling plan and recruitment procedures are available in Vernon-Feagans, Cox, and the FLP Investigators (2013). Seventy percent of families had an average income of less than 200% of the poverty line; 41% of mothers had 12 years of schooling or less, and only 16% had at least 4 years of postsecondary education. The sample was 43% African American and 51% male.

Procedures

The data for this analysis were collected from home visits at child ages 2, 7, 15, 24, 36, and 48 and at school visits between prekindergarten and the second grade. At all home visits for data collection, primary caregivers provided demographic information and information on numerous aspects of family life and work. At 48 months of age, children participated in task batteries to assess executive functions and effortful control, and provided three saliva samples. The visit procedure involved collecting physical measurements followed by the collection of the first saliva sample. Children then completed the executive function battery, followed by the collection of the second saliva sample at the completion of the executive function battery, on average 1 hr ($M = 61.1$ min, $SD = 18.9$). Children then completed tasks designed to assess effortful control and a third saliva sample was collected, approximately 30 min after the second sample ($M = 30.8$ min, $SD = 21.7$). Following the home visit, data collectors provided ratings of a variety of aspects of the home and neighborhood environment.

Children were also assessed in school settings in the spring of prekindergarten (PreK), kindergarten (K), first grade, and second grade. During the school visits, children participated in a variety of tasks including assessments of math and reading ability. At the prekindergarten visit, children were also administered a measure of receptive vocabulary and teachers completed ratings of children's effortful control. Parents completed ratings of children's effortful control at child age 60 months.

Measures

Math and reading achievement—Math achievement was assessed using the Woodcock-Johnson III (WJ III) Tests of Achievement Applied Problems subtest in which children are asked to solve mathematical word problems. Reading achievement was assessed using the letter–word identification subtest of the WJ III. In this test, children are asked to identify letters and then to fluently read words of increasing difficulty. The WJ III is a conormed set of tests for measuring general scholastic aptitude, oral language, and academic achievement. The validity and reliability of the WJ III Tests of Achievement are well established (Woodcock, McGrew, Mather, & Schrank, 2001). W scores were analyzed at each grade as these scores are most appropriate for examining individual level change over time (Jaffe, 2009).

Self-regulation—Executive function tasks were presented in an open spiral bound flipbook (8″ × 14″). RAs established that the child knew colors and numbers and administered training trials and up to three practice trials as needed. If children failed to demonstrate an understanding following practice trials, the examiner discontinued that task. Full details regarding the administration rules, psychometric properties, and scoring

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approach for the battery are available in Willoughby, Wirth, and Blair (2011). The battery included three inhibitory control tasks (Simon-like Spatial Conflict, Stroop-like Silly Sounds, and Farm Animal go/no-go), two working memory tasks (a span-like task and a self-ordered pointing task), and one attention shifting task (item selection modeled on the Dimensional Change Card Sort task; Jacques & Zelazo, 2001). Item response theory was used to generate expected a posteriori (EAP) scores for each task (see Willoughby, Wirth, Blair, & FLP Investigators, 2012). EAP scores were averaged to form a composite measure of EF ability. As is typical in executive function research (e.g., Wiebe, Espy, & Charak, 2008), individual tasks were only moderately correlated ($r = .08–.27$). Although the reliability coefficient for the composite was relatively low, $\alpha = .55$, we opted to use this composite rather than a confirmatory latent variable composite given current understanding executive function measurement and theory (Willoughby, Holochwost, Blanton, & Blair, in press).

Effortful control (EC) was directly assessed at child age 48 months using the Dinky Toys task following procedures established by Kochanska, Murray, and Harlan (2000). Children were informed of eligibility to choose a prize from a special box but to do so following specific rules; namely, to look but not touch the toys when presented with the box and to keep their hands either on their knees or on the table. After deciding which toy to take, children inform the experimenter verbally which toy they would like. Two trials were administered and child response was coded 0 = grabs the toy or box, 1 = touches toy but does not remove it, 2 = points to toy but does not touch it, 3 = removes hands from knees/table but does not touch toy or box, 4 = hands move from knees/table but remain away from box, 5 = hands remain immobile. Children also completed the Tongue Task and a Delay task using procedures developed by Hongwanishkul, Happaney, Lee, and Zelazo (2005). Examination of data from these tasks indicated minimal variability. Therefore, we combined the two Dinky Toys trials (Kendall's $\tau = .66$) and used the mean composite as the direct assessment of effortful control.

At approximately child age 60 months, the child's prekindergarten teacher and the child's parent both independently reported on child effortful control using the Children's Behavior Questionnaire (CBQ), an adult report measure of temperament in children 3 to 7 years of age (Rothbart, Ahadi, Hershey, & Fisher, 2001). Two CBQ dimensions most directly related to effort control were assessed. Attentional Focusing (seven items), for example, "When picking up toys or other jobs, usually keeps at the task until it's done," and Inhibitory Control (five items), for example, "Can lower his or her voice when asked to do so." Teachers and parents rated each item, using a 7-point Likert scale ranging from *extremely untrue of the child* to *extremely true of the child*. Reliability estimates in this sample for Attentional Focusing were $\alpha = .77$ for teachers and $\alpha = .65$ for parents. Estimates for Inhibitory Control were $\alpha = .78$ and $\alpha = .64$. These are very similar to those reported by Rothbart, Ahadi, Hershey, and Fisher (2001). The scales were highly correlated within reporter, $r = .77$, $p < .001$ for teachers, $r = .63$, $p < .001$ for parents, and were combined into a single indicator of EC. Teacher report EC was moderately correlated with parent report, $r = .33$, $p < .001$.

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Cortisol and alpha amylase were obtained through unstimulated whole saliva collected using hydrocellulose absorbent material and expressing sample by centrifugation. Samples were immediately frozen at −20 C, shipped to the laboratory packed in dry ice, and subsequently frozen at −80 C. All samples were assayed for salivary cortisol using a highly sensitive enzyme immunoassay (Salimetrics, State College, PA). The test used 25 μl of saliva, had a range of sensitivity from 0.007 to 3.0 μg/dl, and average intra-and interassay coefficients of variation less than 10% and 15%, respectively. All samples were assayed in duplicate and the average of the duplicates was used in all analyses. Natural log transformations were applied to the cortisol values to correct for positive skew.

Samples were also assayed for alpha amylase using a commercially available kinetic reaction assay (Salimetrics, State College, PA). The assay employs a chromagenic substrate, 2-chloro-p-nitrophenol, linked to maltotriose. The enzymatic action of sAA on this substrate yields 2-chloro-p-nitrophenol, which can be spectrophotometrically measured at 405 nm using a standard laboratory plate reader. The amount of alpha-amylase activity present in the sample is directly proportional to the increase (over a 2-min period) in absorbance at 405 nm. Results are computed in U/ml of alpha-amylase using the formula: [absorbance difference per minute × total assay volume (328 ml) × dilution factor (200)]/[mM absorptivity of 2-chloro-p-nitrophenol (12.9) × sample volume (.008 ml) X light path (.97)]. Square root transformations were used to reduce positive skew.

Cognitive covariates—At the data collection in prekindergarten at approximately 60 months of age, children were administered the Peabody Picture Vocabulary Test, fourth edition (PPVT-4; (Dunn & Dunn, 2007) to measure receptive vocabulary. The child's task is to select the picture from a set of 4 that best illustrates the meaning of a stimulus word presented orally by the examiner. The sets are progressively more difficult. Children were also administered the coding and symbol search subtests of the Wechsler Preschool and Primary Scales of Intelligence (WPPSI; Wechsler, 2002). In the symbol search task, the child scanned a search group and indicated whether a target symbol matched any of the symbols in that group. After determining that the child understood the task, he or she was given 120 s to complete the test items. The number of correct responses and number of incorrect responses were recorded, as well as seconds taken to complete the task. In the coding task, the child copied symbols that were paired with simple geometric shapes. The child drew each symbol in its corresponding shape using a key. After determining that the child understood the task, he or she was given 120 s to complete the test items. The total of all correct responses were summed and the total raw score was the number of correctly drawn symbols. The composite score for the Processing Speed Quotient was based on the mean of the age-corrected scaled scores of Symbol Search and Coding, $r = .57$, $p < .001$. Higher scores represent faster processing speed.

Household demographics—Primary caregivers reported on the highest level of education completed at each home visit for data collection. Caregiver education was calculated as the mean education (number of years the mother reported spending in school) across all time points. Mothers also reported income from all sources and household members at each home visit for data collection. Mean income to need (total household

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income divided by the federal poverty threshold for each year of assessment adjusted for the number of persons in the household) was calculated across time points.

Chaos—A composite of household chaos developed by Vernon-Feagans, Garrett-Peters, Willoughby, and Mills-Koonce (2011) was used to assess household chaos. This measure was used to control for household characteristics and experiences that might be related to both self regulation and later child outcomes. Data from 10 indicators collected at 2, 7, 15, 24, 36, and 48 months were factored using principal components analysis into two dimensions: *household instability* included people in the household, number of moves in and out, number of household moves, number of changes in primary caregiver, and number of changes in secondary caregiver. *Household disorganization* included household density, hours of TV viewing, preparation for home visits, cleanliness of the home, and neighborhood noise. Disorganization and instability were correlated, $r = .41$, $p < .001$.

Missing Data

We limited our sample to children who had achievement data available for one of four time points. ($N = 1{,}099$). On average, children had achievement scores available at 3.64 time points, resulting in person–time point sample sizes of 3,995 for applied problems and 3,998 for letter–word. Full information maximum likelihood with robust standard errors was used for all model estimation in Mplus 6.12 in order to deal with potential bias arising from missing predictor data.

Analytic Plan

We used multilevel growth models to examine relations of self-regulation to reading and math achievement across prekindergarten, kindergarten, first grade, and second grade. To first determine the shape of the growth trajectory, we fit unconditional growth models to examine linear and quadratic slopes as well as random variation in intercept and growth parameters. Age at each assessment varies across children and we correspondingly used age as our time variable. Next, we examined the extent to which predictors were associated with differences in prekindergarten achievement and examined the extent to which all between level predictors in the model were associated with differences in linear growth of achievement across the early elementary years. In constructing the final models, reported below, we retained all predictors of linear growth, whether statistically significant or not. Retaining all predictors of linear growth allows us to interpret intercept effects as effects on prekindergarten achievement. We repeated the model three times, first controlling only for child and family demographic characteristics assessed prior to the measures of self-regulation, second, adding additional controls of processing speed and receptive vocabulary measured in prekindergarten, and third adding the additional time varying covariate of the achievement measure that is not being predicted (math when predicting reading and vice versa). In all models, age was centered at the prekindergarten assessment. All predictors were grand mean centered. Means and distributions for each of the study variables are presented in Table 1 and correlations among variables are presented in Table 2. Table 2 indicates moderate correlation among the composite measures of self-regulation and between the measures of self-regulation and the cognitive covariates. To further empirically evaluate differentiation among these constructs we examined internal consistency

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reliabilities obtained when combining the self-regulation composites with the cognitive covariates. In all instances, reliabilities for the self-regulation composites were degraded substantially (e.g., > 75% reduction) with the addition of each of the cognitive covariates. As expected, reliabilities did not change appreciably and even increased slightly when combining the self-regulation composites. For theoretical reasons and empirical purposes, we chose to examine prediction from each of the self-regulation composites separately.

Results

Math

Unconditional means model—In the unconditional means model, there were significant positive linear (B = 27.53, *SE* = 0.55, $p < .001$) and negative quadratic (B = −1.72, *SE* = 0.16, $p < .001$) trends for math achievement from prekindergarten through the second grade. Random intercepts, (B = 416.79, *SE* = 36.22, $p < .001$), linear, (B = 76.57, *SE* = 18.39, $p = .001$), and quadratic slopes, (B = 3.81, *SE* = 1.54, $p = .013$), were retained across all subsequent models. The intercept was negatively correlated with the linear slope and positively correlated with the quadratic slope indicating that higher math ability at prekindergarten was associated with less linear change (slower growth) and greater quadratic change (faster deceleration). The linear and quadratic slopes were negatively correlated. We analyzed predictors of the linear slope only, given the small size of the quadratic effect.

Demographic controls—Model A in Table 3 presents results for relations of multiple aspects of self-regulation to mathematics ability, controlling for child and family demographic characteristics. Executive function at 48 months was positively associated with math ability at the prekindergarten assessment (B = 13.46, *SE* = 1.65, $p < .001$, ES = .34), and with less rapid acquisition of math ability during the early elementary years (B = −1.07, *SE* = 0.47, $p < .05$, ES = .06). Effortful control as measured by direct assessment was also positively associated with math achievement at prekindergarten (B = 1.73, *SE* = 0.34, $p < .001$, ES = .16) but was unrelated to acquisition of math skills during the elementary years. In contrast, effortful control as rated by the prekindergarten teacher (B = 2.12, *SE* = 0.55, $p < .001$) and parent (B = 1.67, *SE* = 0.74, $p < .05$) were positively associated with math ability at prekindergarten and also associated with more rapid acquisition of mathematics through the second grade for teacher (B = 0.38, *SE* = .19, $p < .05$) but not for parent report. Given the similarity in the coefficients and the moderate correlation between the measures, we created a single composite for use in this and all further analyses. The combined teacher and parent report of effortful control was significantly related to both the intercept (B = 2.03, *SE* = 0.42, $p < .001$, ES = .18) and slope (B = 0.38, *SE* = 0.14, $p < .01$, ES = .08).

The interaction of cortisol and alpha amylase was unrelated to math ability at prekindergarten and to growth in math ability. Given our hierarchical model of self-regulation described in the introduction and prior finding of the effect of this interaction in the infant and toddler periods on executive function in early childhood, we reran the model without terms for executive function and effortful control in the equation. Findings were essentially unchanged, with a slightly larger regression coefficient leading to a marginally

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significant effect of the interaction on math growth, such that the combination of low resting cortisol and low resting amylase was associated with faster growth in math.

Child and household demographic characteristics were also associated with math achievement. With self-regulation variables in the model, boys were no longer different from girls in math ability at prekindergarten but continued to exhibit more rapid growth in math achievement (B = 1.36, *SE* = 0.36, $p < .001$, ES = .16). In contrast, African American children continued to have lower math achievement relative to White children at the prekindergarten assessment (B = −4.39, *SE* = 1.24, $p < .01$, ES = .22) but consistent with the negative correlation between intercept and slope, demonstrated faster growth in math ability across the early elementary grades (B = .94, *SE* = .43, $p < .01$, ES = .11). Similarly, children in more chaotic homes had lower math achievement at prekindergarten (B = −4.33, *SE* = 1.05, $p < .001$, ES = .14) but exhibited more rapid acquisition of math skills across the elementary years (B = 1.21, *SE* = 0.35, $p < .001$, ES = .09). Household instability was unrelated to mathematics and was excluded from further analyses. Children of more highly educated primary caregivers also had higher math achievement at prekindergarten (B = 0.74, *SE* = 0.29, $p < .05$, ES = .10) while primary caregiver education was unrelated to acquisition of math skills. Household income to needs ratio prior to preschool was not uniquely related to math achievement at the prekindergarten assessment and was unrelated to growth.

Cognitive covariates—In the next model specification (Model B), we added cognitive skills measured at prekindergarten, receptive vocabulary and speed of processing. Processing speed at the prekindergarten assessment was positively associated with math achievement at this assessment (B = 0.22, *SE* = 0.06, $p < .001$, ES = .14) but was not related to the acquisition of math skills. Receptive vocabulary in prekindergarten was also positively associated with math achievement at prekindergarten (B = 0.62, *SE* = 0.06, $p < .001$, ES = .48) and with marginally less rapid acquisition of these skills through the second grade (B = −0.04, *SE* = 0.02, $p < .05$, ES = .08).

With the addition of the cognitive covariates, effects for measures of self-regulation on the intercept continued but were reduced by approximately 50%; executive function (B = 5.30, *SE* = 1.52, $p < .001$, ES = .14), directly assessed effortful control (B = 1.03, *SE* = 0.30, $p < .001$, ES = .09), and combined teacher and parent report of effortful control (B = 0.94, *SE* = 0.38, $p < .05$, ES = .08). Effects on the slope were reduced completely for executive function and for directly assessed effortful control. The positive association of the combined teacher and parent report of effortful control with growth in mathematics ability, however, remained unchanged (B = 0.41, *SE* = 0.15, $p < .01$, ES = .08).

After including the cognitive covariates, child race and caregiver education were no longer related to math achievement. Boys continued to exhibit more rapid acquisition of math skills (B = 1.40, *SE* = 0.36, $p < .01$, ES = .16). Household chaos continued to be associated with the intercept (B = −2.86, *SE* = 0.94, $p < .01$, ES = .09) and with more rapid acquisition of math skills (B = 1.11, *SE* = 0.35, $p < .01$, ES = .08).

Addition of letter–word knowledge as a time varying covariate—In Model C, we added performance on the letter–word subtest of the WJ battery as a time varying predictor of math achievement to control for reading achievement at each time point. As expected reading achievement was positively associated with math achievement (B = 0.21, *SE* = 0.01, $p < .001$, ES = .29). Effects for executive function, effortful control direct assessment, and effortful control by parent and teacher report were essentially unchanged. The effect of receptive vocabulary on the intercept was reduced by 25%, (B = 0.47, *SE* = 0.05, $p < .001$, ES = .36), while the negative effect on the slope remained unchanged (B = −0.05, *SE* = 0.02, $p < .01$, ES = −.08). Processing speed was no longer related to math achievement.

The pattern of results for gender, caregiver education, and income to needs ratio remained the same as in Model C. Unexpectedly, however, African American ethnicity reemerged as a significant predictor of lower prekindergarten math achievement (B = −3.34, *SE* = 1.12, $p < .01$, ES = .16).

Reading

Unconditional means model—The unconditional means model for letter and word knowledge was characterized by positive linear (B = 62.83, *SE* = 0.88, $p < .001$) and negative quadratic (B = −6.39, *SE* = 0.24, $p < .001$) trends for the acquisition of this aspect of reading skill. Random intercepts (B = 713.28, *SE* = 46.27, $p < .001$), linear slopes (B = 284.36, *SE* = 32.37, $p < .001$), and quadratic slopes (B = 10.51, *SE* = 2.28, $p < .001$), were retained across all subsequent models. The intercept was negatively correlated with the linear slope and positively correlated with the quadratic slope. The linear and quadratic slopes were negatively correlated.

Demographic controls—In Model D of Table 4, executive function at 48 months of age was positively associated with reading achievement at prekindergarten (B = 9.60, *SE* = 2.08, $p < .001$, ES = .19) but was unrelated to the acquisition of letter–word knowledge skills across the elementary years. Effortful control as rated by parent and teacher was positively associated with letter–word knowledge at prekindergarten (B = 1.90, *SE* = 0.66, $p < .01$, ES = .13) while direct assessment of EC was not. Both were unrelated to growth. As with the prediction of mathematics ability, the interaction of cortisol and alpha amylase was unrelated to reading ability at prekindergarten, and to growth in reading ability. Also, similar to the prediction of mathematics, in a model without executive function and effortful control, the regression coefficient for the interaction increased slightly such that there was a marginal effect of the interaction on growth in reading, again in which the combination of low resting cortisol and low resting amylase was associated with faster growth in reading.

Gender and household income to need were not uniquely related to reading achievement, however, caregiver education was positively related (B = 1.67, *SE* = 0.45, $p < .001$, ES = .16) and household chaos was negatively related to letter–word knowledge at prekindergarten (B = −8.41, *SE* = 1.74, $p < .001$, ES = .21). As with mathematics, household chaos was also associated with more rapid acquisition of reading skills across the early elementary years (B = 1.56, *SE* = 0.59, $p < .05$, ES = .06). Also, as with mathematics, household instability was unrelated to reading and excluded from further analyses. Surprisingly, with adjustment for demographic and self-regulation variables, African American children had higher letter–word knowledge at prekindergarten (B = 9.27, *SE* = 1.89, $p < .001$, ES = .35), and exhibited

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less rapid acquisition of this knowledge across the early elementary years (B = −2.18, *SE* = 0.68, $p < .001$, ES = .13). To further investigate this unexpected effect, we examined mean differences in models without covariates and confirmed that in unadjusted models the mean for African American children was significantly lower than that for Whites (B = −3.45, *SE* = 1.54, $p < .05$). With the addition of the demographic covariates, the effect reversed in favor of African American children and became larger with the addition of the self-regulation variables.

Cognitive covariates—In Model E in Table 4, processing speed (B = 0.53, *SE* = 0.08, $p < .001$, ES = .24) and receptive vocabulary (B = 0.56, *SE* = 0.07, $p < .001$, ES = .33) were both positively associated with letter–word knowledge at prekindergarten. Processing speed was associated with less rapid acquisition of knowledge of letters and words (B = −0.15, *SE* = 0.03, $p < .001$, ES = .11) while receptive vocabulary was unrelated to growth in letter–word knowledge.

With the addition of the cognitive covariates, executive function and the combined parent and teacher rated effortful control were no longer related to letter–word knowledge. With the inclusion of the cognitive covariates, the pattern of results for race, gender, caregiver education, income to needs ratio and household chaos remained the same as in the prior model specification.

Addition of math as a time varying covariate—As expected, in Model F math achievement was positively associated with letter–word knowledge (B = 0.40, *SE* = 0.03, $p < .001$, ES = .31). Results for self-regulation measures and cognitive covariates were unchanged. Household chaos remained negatively related to letter–word knowledge at prekindergarten (B = −5.11, *SE* = 1.58, $p < .001$) but was no longer positively associated with growth of this knowledge during the early elementary years.

Discussion

Results from this analysis indicate that distinct but related aspects of self-regulation measured for the most part prior to school entry, at child age 48 months, make unique contributions to mathematics and reading ability as measured by specific achievement subtests in prekindergarten through the second grade. Notably, the analysis included direct assessments of executive function and effortful control, and combined report of prekindergarten teacher and parent on the effortful control subscale of a widely used measure of temperament, as well as indicators of child stress response physiology, cortisol, and alpha amylase. Prior studies have demonstrated correlational and short-term longitudinal associations between individual measures of self-regulation and academic ability in children (Fuhs et al., 2014; Valiente et al., 2008). This study is the first to our knowledge to examine multiple aspects of self-regulation simultaneously with a comprehensive set of covariates and to demonstrate that these measures are distinctly related to initial levels and to a lesser extent growth in early academic ability in increasingly stringent models.

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Differentiating the Effect of Self-Regulation on Math as Opposed to Reading

Notably, effects for self-regulation measures on academic outcomes in initial models were observed for both math and reading with moderate effect sizes. With the addition to the equation of the cognitive covariates, processing speed, and vocabulary measured in prekindergarten at approximately 60 months, effects for executive function and effortful control on mathematics declined by one half or more, while effects of these variables on reading were reduced completely. These findings indicate that, as expected, associations between self-regulation measures and mathematics are robust but share variance with other aspects of cognitive ability. Similar to our findings, prior studies have demonstrated that effects for self-regulation, executive function abilities in particular, on mathematics that persist when controlling for aspects of cognitive ability that are related both to executive function and to outcome variables (Bull & Scerif, 2001; Espy et al., 2004; Welsh et al., 2010).

Although associations of self-regulation, particularly executive functions, with mathematics are somewhat widely reported, relatively fewer studies have examined early reading. In one study with a low-income sample, a composite measure of executive function tasks predicted fall to spring change in prekindergarten on a comprehensive assessment of reading as well as math; and continued to predict both aspects of academic ability into the kindergarten year (Welsh et al., 2010). Similarly, a second study, again with a low-income sample, found that a single measure of self-regulation, the head-to-toes task, predicted fall to spring change in ability in prekindergarten for knowledge of letters and words and vocabulary as well as math (McClelland et al., 2007). More recently, analysis of a large middle income sample assessed longitudinally indicated that executive function abilities were associated with letter and word knowledge during the prekindergarten but not kindergarten year (Fuhs et al., 2014). Relations between executive functions and oral (language) comprehension, however, were present both in prekindergarten and kindergarten, and were reciprocal.

Effects for multiple measures of self-regulation on academic outcomes in the early elementary grades likely represent general preparedness for learning associated with the ability to sustain attention, to organize complex information, and to inhibit impulsive responding. These effects as they relate to mathematics as assessed here also likely represent the association of self-regulation, particularly executive functions, with reasoning abilities (Blair, 2006). The applied problems subtest of the WJ, the outcome variable for mathematics, makes numerous demands on reasoning abilities. Self-regulation, including effortful control and stress response physiology as well as executive functions, provides a foundation for reasoning. The association of reasoning with executive functions is clear as these domain general processes, including the ability to hold information in short-term store, to operate on it, to inhibit highly learned or automatic associations when needed, and to shift attention between distinct but related elements of a given problem, undergird problem solving. Similarly, effortful control supports reasoning through the predisposition to high levels of sustained attention and regulation of emotional reactivity. This temperamental trait facilitates reasoning by promoting persistence and inhibiting anxiety, boredom, and frustration when faced with cognitively challenging material.

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In contrast to the measure of mathematics, the measure of reading ability, the letter–word subtest of the WJ, assesses knowledge more so than reasoning. Consequently, primary predictors of reading as measured by letter–word knowledge were, not surprisingly, measures of receptive vocabulary and information processing speed. Both of these aspects of mental ability are relevant to but distinct from reasoning. Essentially they refer to aspects of mental ability that are for the most part stable through the life span and referred to as crystallized as opposed to fluid abilities (Ferrer & McArdle, 2004; McArdle et al., 2002). Importantly, it would be incorrect to conclude from this analysis that self-regulation is unimportant for reading ability, only that it is unrelated to knowledge-based aspects of reading skill assessed here but related to other aspects of reading achievement, as seen in the analyses of Fuhs, Nesbitt, Farran, and Dong (2014) and Wels, Nix, Blair, Bierman, and Nelson (2010). Further illustration of this point is seen in two studies that examined relations of self-regulation to reading comprehension in children in the middle or later elementary grades (Altemeier, Abbott, & Berninger, 2008; Kieffer, Vucovic, & Berry, 2013). Both found moderate sized effects on comprehension for measures of attention shifting and inhibitory control aspects of executive function. Notably, in the study by Kieffer, Vucovic, and Berry (2013) these effects on reading comprehension were not observed on a measure of word reading and were present over and above effects for processing speed.

Differentiating Effects on the Intercept From Effects on the Slope

Although our findings are generally consistent with the prior literature, our approach and results are unique in several ways. Prior studies have primarily analyzed data using autoregressive or residual change models in which later academic outcomes are conditioned on earlier academic ability. In contrast, our analysis examined self-regulation and academic outcomes using growth models. Initial analyses indicated effects of self-regulation measures on both the intercept and to some extent growth for math and for reading. With increasingly stringent model specifications, however, effects of self-regulation measures on growth were almost uniformly reduced. The notable exception was the effect for the combined parent and prekindergarten teacher report of effortful control, which although small and constrained in size by the large effect of the intercept on the slope, continued to positively predict growth in mathematics even in the most stringent model. Notably, this variable was one of few to predict growth in academic ability in this data set and the only psychological characteristic to positively predict both the intercept and slope.

The finding for effortful control might reflect the idea that effortful control as reported on temperament questionnaires represents a more trait-like aspect of self-regulation while executive function and direct assessments of effortful control are liable to state-like influences. In addition, the inclusion of teacher as well as parent report might have increased the relevance of the measure to the context of schooling. It is also import to recall, however, that the parent and teacher ratings were collected at the prekindergarten assessment, at approximately child age 60 months. Other assessments of self-regulation, executive functions and direct assessment of effortful control using the Dinky Toys task, were collected at child age 48 months and in the child's home. It could be that differences associated with age and context are most relevant. Alternatively, research and theory on executive functions (Blair, 2010; Willoughby et al., in press), suggest that the executive

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cognitive abilities can be highly influenced by state and idiographic characteristics, leading to increased variability and reduced internal consistency. It is also important to note that effortful control as assessed by the temperament questionnaire was measured with greater precision than executive functions. The internal consistency reliability of parent and teacher report of effortful control is high while that for executive function is low. In addition, the Dinky Toys task was the sole direct measure of effortful control and the only one of three tasks that were used to assess this construct that demonstrated sufficient variability.

Other variables predicting growth in math and reading included vocabulary, chaos in the home, African American ethnicity, and male gender. The effect of these variables on the slope, however, was opposite their effect on the intercept. Children from more chaotic homes prior to school entry started out behind their more advantaged peers but increased in ability at a faster rate. Similarly for the prediction of growth in reading, speed of processing was positively associated with the intercept but negatively related to growth. Children from more chaotic homes or who were less efficient at processing information were at a relative disadvantage at prekindergarten but were able to make up for lost ground, so to speak, in kindergarten and the early elementary grades. Although these effects are consistent with the negative general relation between the intercept and the slope for both math and reading in this analysis, they would seem to be, for the most part, encouraging findings. They suggest that schooling is working in a compensatory fashion in this predominantly low-income sample, assisting children who for reasons related to the home environment and or to other characteristics are at a relative academic disadvantage in prekindergarten.

Of considerable interest in this respect is the unexpected finding of a sizable advantage in favor of African American children on the intercept for letter and word knowledge of approximately one third of a standard deviation. This finding indicates that when controlling for demographic, self-regulation, and cognitive covariates, which are each individually related to poverty and ethnicity, African American children have a higher not lower level of letter and word knowledge and, similar to other variables with a positive relation to the intercept, have slower growth. This finding indicates that even when facing substantial socioeconomic and school readiness disadvantage, as is the case with the predominantly low-income sample participating in this study, African American children are achieving at higher levels than would be expected given the risk factors they are facing. Although perhaps specific to this sample in certain respects, this finding is not without precedent, having been observed by Grimm, Steele, Mashburn, Burchinal, and Pianta (2010) in an analysis of the National Longitudinal Survey of Youth data set, a representative population-based sample. In that analysis the positive effect of African American ethnicity on the intercept is small while the negative effect on linear growth is large, the opposite of the pattern observed here.

Comprehensive Assessment of Self-Regulation

Effects for multiple aspects of self-regulation on early academic ability provide some tentative support for the integrated theoretical model of self-regulation outlined in the introduction. In that model, self-regulation is characterized by activity at successive levels of functioning from the physiological (cortisol, alpha amylase), to the attentional and emotional

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(effortful control), to the volitional and explicitly cognitive (executive functions). The analysis of stress physiology, cortisol and alpha amylase, is perhaps most novel in that no prior study of which we are aware has examined the relation of stress response physiology to academic ability in the early elementary grades using a prospective longitudinal design. Unlike our prior finding noted in the beginning of the article (Berry et al., 2012), the interaction of cortisol and alpha amylase at child age 48 months, as opposed to the infancy and toddlerhood period did not interact to predict academic ability. In that prior analysis, lower levels of executive functioning and consequently academic ability, as assessed by a composite of the WJ applied problems, letter–word, and quantitative concepts subscales, were observed among children in which resting level of amylase and cortisol were either simultaneously low or simultaneously high, indicating physiological under or over arousal at ages 7, 15, and 24 months.

Limitations, Implications, and Conclusions

Overall, results provide longitudinal evidence in support of the relevance of self-regulation to early competence in school but are limited in several ways. In addition to potential limitations in measures, further limitations of this analysis concern the fact that the sample is predominantly low-income and that no information is included about the type and quality of classroom instruction that children are receiving. Both of these factors likely limit the generalizability of findings. The low-income nature of the sample likely restricts the range of both independent and dependent variables and resulting estimates of effect sizes may be underestimates. As well, the absence of information on instructional quality may decrease or increase the estimates of effects depending on the extent to which quality might interact with child characteristics to influence outcomes. Classroom quality and relationships with teachers have been shown to influence academic outcomes in diverse samples of children. High-quality instruction might benefit children with lower skills or fewer opportunities as has been shown in a recent review (McCartney & Berry, 2009).

The pattern of findings also raises several points relating to ways in which to support the development of early academic ability in children. Notably, a prior analysis of six longitudinal data sets with information on the development of early academic ability by Duncan et al. (2007) found that early academic abilities were better predictors of later academic abilities than were behavioral measures, some of which tapped aspects of self-regulation such as the ability to sustain attention. Furthermore, in that analysis, early mathematics ability was a better predictor of later reading, as well as later math, than was early reading ability. Our findings, along with those of the analysis by Grimm et al. (2010) of three of the data sets originally analyzed by Duncan and collaborators shed further light on this conclusion and provide additional interpretation of those prior findings. Our analysis suggests that some of the explanatory power of mathematics in the prediction of later academic outcomes might be attributable to self-regulation measured prior to school entry. Although Duncan et al. (2007) found minimal support for the prediction of academic outcomes from measures of behavior problems, the authors did find effects for measures of attention on later math and reading over and above early math and reading across six data sets. Our measures of self-regulation are more comprehensive than those available in the data sets analyzed by Duncan et al. (2007) and capture emotional and physiological aspects of the construct as well as well as the more cognitive aspects. Furthermore, as with Grimm et al. (2010), the use of growth curve modeling in our analysis as opposed to residual change models in which later academic outcomes are conditioned on earlier academic ability provides a more sensitive technique for examining change. Notably, however, our findings primarily indicate effects of self-regulation on the intercept not growth. By centering the intercept at prekindergarten, we interpret these effects as influences on ability at school entry but they are essentially general effects on achievement. In addition, although our analysis cannot directly address the question of whether early math is a stronger predictor of later reading than is early reading, the effect size for math in the prediction of reading is similar in size to that of the effect size for reading in the prediction of math. Both, however, are remarkably similar to the ES of .33 obtained in the meta-analysis of Duncan et al. (2007). In our analysis, however, vocabulary ability at child age 48 months was a stronger predictor of the intercept for both math and reading than all other measures. Similar, to the findings of Duncan et al. (2007), effects for self-regulation were smaller than the academic ability measures, considerably so in the prior analysis but less so here.

Generally speaking, results provide some specific support for a focus on self-regulation abilities in early childhood as precursors to the development of academic abilities. Chief among the priorities for this area of inquiry, however, is the need for experimental research to determine the extent to which self-regulation development is causally related to the development of academic abilities. Most studies examining effects of self-regulation on later academic achievement have been correlational. Only four experimental studies have demonstrated increases in executive functions in experimental evaluations of prekindergarten school readiness curricula using randomized controlled trial designs (Bierman, Nix, Greenberg, Blair, & Domitrovich, 2008; Diamond, Barnett, Thomas, & Munro, 2007; Raver et al., 2011; Weiland & Yoshikawa, 2013). Of these, only two examined mediation of program effects on academic outcomes through effects on executive functions with strong effects reported in one (Raver et al., 2011) and limited effects in the other (Bierman et al., 2008). Further research with innovative programs is clearly needed. Here, it is perhaps important to also consider the extent to which associations between academic competence and self-regulation may be recursive. As ability advances in one domain, so it likely does in the other. Longitudinal designs that model transactional pathways between measures of academic abilities and measures of self-regulation are needed to strengthen inference about relations between constructs (Fuhs et al., 2014; Welsh et al., 2010). Analyses using randomized designs and as well as with longitudinal data over multiple time points can address central questions about relations between multiple aspects of self-regulation and academic outcomes and influences on both.

In conclusion, although limited in specific ways, this analysis of math and reading ability in the early elementary grades provides unique information about the relation of self-regulation and cognitive abilities to academic development during a critical time in children's early schooling. Efforts to support children's academic progress in the early grades can profitably focus on support for child self-regulation and reasoning ability. Current theory and research suggest that learning environments that allow for structured, scaffolded, self-directed learning opportunities for children are associated with higher levels of executive function

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and related self-regulation skills and that these are associated with higher academic ability at school entry.

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Table 1

Descriptive Statistics

	N	Mean	*SD*
Letter–word prekindergarten	968	339.85	27.47
Letter–word kindergarten	1,058	394.42	27.04
Letter–word Grade 1	994	440.79	30.41
Letter–word Grade 2	978	468.08	28.10
Applied problems prekindergarten	966	407.20	22.35
Applied problems kindergarten	1,058	431.51	19.89
Applied problems Grade 1	993	454.76	19.66
Applied problems Grade 2	978	472.01	20.58
Black	1,099	44%	—
Male	1,099	50%	—
Chaos	1,031	0.01	0.66
Caregiver education	1,099	14.77	2.60
Income to need	1,099	1.77	1.34
Cortisol 48 months	937	−2.11	0.69
Alpha amylase 48 months	816	7.21	2.85
Executive function 48 months	983	0.62	0.16
Effortful control direct 48 months	1,003	2.03	1.83
Effortful control teacher preK (60 months)	828	5.02	1.24
Effortful control parent preK (60 months)	1,061	4.80	0.92
Vocabulary preK (60 months)	964	93.96	15.80
Processing speed preK (60 months)	768	96.80	12.33

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Table 2

Correlation among covariates and self-regulation variables

	1	2	3	4	5	6	7	8	9	10	11	12
1. Black	—											
2. Male	.01	—										
3. Chaos	.29**	.01	—									
4. Education	−.21**	.02	−.59**	—								
5. INR	−.40**	.03	−.60**	.59**	—							
6. Cortisol	.14**	.02	.08*	−.07*	−.12**	—						
7. sAA	−.08*	−.05	−.04	.02	.01	−.05	—					
8. EF	−.34**	−.14**	−.32**	.31**	.30**	−.05	.08*	—				
9. EC direct	−.23**	−.16**	−.23**	.23**	.23**	−.10*	.05	.41**	—			
10. EC teacher	−.24**	−.22**	−.24**	.25**	.24**	−.05	.07	.40**	.29**	—		
11. EC parent	−.16**	−.08**	−.28**	.31**	.24**	−.05	.04	.31**	.22**	.33**	—	
12. Vocabulary	−.44**	−.05	−.40**	.39**	.43**	−.06	.04	.58**	.39**	.40**	.31**	—
13. Speed	−.17**	−.19**	−.27**	.27**	.26**	−.05	−.07	.45**	.28**	.34**	.27**	.43**

* $p < .05$.

** $p < .01$.

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Table 3

Growth Curve Models Predicting Applied Problems Mathematics Ability

	Model A		Model B		Model C	
	B (*SE*)	ES	B (*SE*)	ES	B (*SE*)	ES
Within						
Intercept	387.01 (4.27)***		398.02 (3.79)***		414.62 (3.37)***	
Age	23.51 (1.53)***		23.05 (1.54)***		10.96 (1.63)***	
Age sq	−1.64 (0.16)***		−1.61 (0.16)***		−0.31 (0.18)†	
Letter–word					0.21 (0.01)***	0.29
Between						
Black	−4.39 (1.24)**	0.22	−0.45 (1.19)		−3.34 (1.12)**	0.16
Male	1.14 (1.04)		1.04 (0.95)		1.07 (0.86)	
Household chaos	−4.33 (1.05)***	0.12	−2.86 (0.94)**	0.09	−1.61 (0.85)†	0.05
Caregiver education	0.74 (0.29)*	0.10	0.33 (0.25)		0.1 (0.22)	
Income to needs ratio	−0.55 (0.76)		−0.42 (0.51)		−0.52 (0.44)	
Cortisol	0.18 (1.02)		−0.08 (0.89)		−0.22 (0.83)	
Alpha amylase	0.06 (0.23)		0.14 (0.2)		0.05 (0.18)	
Cortisol * Alpha amylase	−0.16 (0.4)		−0.02 (0.33)		0.09 (0.29)	
Executive function	13.46 (1.65)***	0.34	5.3 (1.52)***	0.14	5.35 (1.39)***	0.14
Effortful control direct	1.73 (0.34)***	0.16	1.03 (0.3)***	0.09	1.04 (0.27)***	0.09
Effortful control report	2.03 (0.42)***	0.18	0.94 (0.38)*	0.08	0.77 (0.33)*	0.07
Vocabulary			0.62 (0.06)***	0.48	0.48 (0.05)***	0.37
Processing speed			0.22 (0.06)***	0.14	0.09 (0.06)†	0.05
Effects on slope						
Black	0.94 (0.43)*	0.11	0.6 (0.46)		0.9 (0.45)*	0.10
Male	1.36 (0.36)***	0.16	1.4 (0.36)***	0.16	1.48 (0.35)***	0.17
Household chaos	1.21 (0.35)***	0.08	1.11 (0.35)**	0.08	0.95 (0.35)*	0.07
Caregiver education	−0.01 (0.09)		0.03 (0.09)		0.05 (0.09)	
Income to need ratio	0.20 (0.17)		0.24 (0.17)		0.22 (0.16)	

	Model A		Model B		Model C	
	B (*SE*)	ES	B (*SE*)	ES	B (*SE*)	ES
Cortisol	−0.44 (0.32)		−0.44 (0.31)		−0.26 (0.3)	
Alpha amylase	−0.02 (0.07)		−0.02 (0.08)		0.04 (0.07)	
Cortisol * Alpha amylase	0.17 (0.12)		0.17 (0.12)		0.12 (0.11)	
Executive function	−1.07 (0.47)*	0.06	−0.62 (0.51)		−0.78 (0.51)	
Effortful control direct	−0.16 (0.11)		−0.11 (0.11)		−0.12 (0.11)	
Effortful control report	0.38 (0.14)*	0.08	0.41 (0.15)***	0.08	0.3 (0.14)*	0.06
Vocabulary			−0.04 (0.02)†	0.08	−0.05 (0.02)*	0.09
Processing speed			−0.001 (0.02)		0.03 (0.02)	
Variances						
Intercept	208.29 (20.96)***		146.12 (16.72)***		113.96 (14.42)***	
Linear slope	55.48 (17.28)**		55.19 (17.19)***		65.47 (18.52)***	
Quadratic slope	1.94 (1.42)		1.98 (1.42)*		3.78 (1.56)*	
Intercept with linear slope	−35.87 (14.72)*		−27.3 (13.12)*		−33.29 (13.31)*	
Intercept with quadratic slope	5.37 (4.02)		4.05 (3.57)		5.83 (3.69)	
Linear with quadratic	−10.26 (4.84)*		−10.34 (4.84)**		−15.02 (5.25)**	
Within residual variance	89.31 (4.75)***		89.6 (4.78)***		88 (4.7)***	

Note. Effect sizes were calculated as B * *SD* (x)/ *SD* (y) where *SD* (y) was based on the variance terms for the intercept and slope from the unconditional growth model.

† $p < .01$.

* $p < .05$.

** $p < .01$.

*** $p < .001$.

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Table 4

Growth Curve Models Predicting Letter and Word Reading Ability

	Model D		Model E		Model F	
	B (*SE*)	ES	B (*SE*)	ES	B (*SE*)	ES
Within						
Intercept	320.91 (6.58)***		333.99 (6.29)***		352.5 (5.89)***	
Age	59.15 (2.63)***		58.3 (2.64)***		48.9 (2.74)***	
Age sq	−6.41 (0.24)***		−6.41 (0.2***4)		−5.72 (0.25)***	
Applied problems					0.4 (0.03)	0.31
Between						
Black	9.27 (1.89)***	0.35	12.82 (1.82)***	0.48	13.34 (1.66)***	0.50
Male	−1.35 (1.68)		−0.86 (1.59)		−1.21 (1.46)	
Household chaos	−8.41 (1.74)***	0.21	−6.43 (1.65)***	0.16	−5.12 (1.53)**	0.13
Caregiver education	1.67 (0.45)***	0.16	1.23 (0.42)**	0.12	1.07 (0.38)**	0.11
Income to needs ratio	0.53 (0.92)		0.18 (0.85)		0.58 (0.67)	
Cortisol	1.05 (1.38)		1.08 (1.3)		1.06 (1.19)	
Alpha amylase	0.26 (0.37)		0.48 (0.36)		0.42 (0.32)	
Cortisol * Alpha amylase	−0.76 (0.59)		−0.55 (0.56)		−0.51 (0.5)	
Executive function	9.6 (2.08)***	0.19	1.65 (2.07)		−0.4 (1.86)	
Effortful control direct	0.92 (0.55)	0.06	0.09 (0.54)		−0.34 (0.49)	
Effortful control report	1.9 (0.66)*	0.13	0.61 (0.63)		0.12 (0.57)	
Vocabulary			0.56 (0.07)***	0.32	0.33 (0.07)***	0.20
Processing speed			0.53 (0.08)***	0.24	0.45 (0.07)***	0.21
Effects on slope						
Black	−2.18 (0.68)***	0.13	−2.15 (0.69)***	0.13	−2.31 (0.67)***	0.14
Male	−0.08 (0.59)		−0.42 (0.59)		−0.91 (0.57)	
Household chaos	1.56 (0.59)*	0.06	1.33 (0.58)*	0.05	0.76 (0.58)	
Caregiver education	−0.07 (0.15)		−0.02 (0.15)		−0.05 (0.14)	
Income to need ratio	0.09 (0.22)		0.06 (0.21)		−0.1 (0.2)	

	Model D		Model E		Model F	
	B (*SE*)	ES	B (*SE*)	ES	B (*SE*)	ES
Cortisol	−0.7 (0.51)		−0.82 (0.51)		−0.65 (0.48)	
Alpha amylase	−0.22 (0.13)		−0.27 (0.13)		−0.26 (0.12)	
Cortisol * Alpha amylase	0.34 (0.22)†		0.3 (0.22)		0.27 (0.2)	
Executive function	−0.05 (0.76)		0.67 (0.81)		0.97 (0.79)	
Effortful control direct	0.07 (0.18)		0.14 (0.19)		0.16 (0.18)	
Effortful control report	0.38 (0.25)		0.45 (0.26)†		0.29 (0.25)	
Vocabulary			0.01 (0.03)		0.02 (0.03)	
Processing speed			−0.15 (0.03)***	−0.11	−0.14 (0.03)***	0.10
Variances						
Intercept	556.27 (38.42)		461.31 (34.58)***		377.28 (31.79)***	
Linear slope	286.99 (34.63)		285.98 (34.63)***		256.79 (30.29)***	
Quadratic slope	10.74 (2.52)		11.11 (2.49)***		10.4 (2.31)***	
Intercept with linear slope	−90.03 (26.93)		−70.56 (25.08)**		−76.2 (22.7)***	
Intercept with quadratic slope	−1.81 (6.5)		−3.68 (6)	−1.01 (5.39)		
Linear with quadratic	−53.75 (8.95)		−54.61 (8.91)***		−49.84 (8)***	
Within residual variance	138.93 (7.28)		138.17 (7.09)***		142.27 (7.37)***	

Note. Effect sizes were calculated as B * *SD* (x)/ *SD* (y) where *SD* (y) was based on the variance terms for the intercept and slope from the unconditional growth model.

† $p < .01$.

* $p < .05$.

** $p < .01$.

*** $p < .001$.

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