Deconstructing the Foundations of Learning in Early Childhood:

Complementing Theory with Methodology

A Dissertation

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Doctor of Philosophy

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by

Helyn Kim

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ABSTRACT

This dissertation presents three independent studies that are linked in their focus on exploring efforts to deconstruct the foundations of learning in early childhood. The first study evaluated the psychometric properties of the Motor Skills Rating Scale (MSRS), a teacher-reported measure of children's classroom motor skills. A confirmatory factor analysis supported the validity of the three-factor structure, and each of the three subscales of the MSRS, Classroom Fine Motor, Shapes and Letters, and Body Awareness, was differentially associated with children's academic and behavioral outcomes. The second study explored longitudinal and reciprocal relations among visuo-motor integration, attention, fine motor coordination, and mathematics skills in the early elementary school years, from kindergarten through second grade. Associations among constructs were intricate and dynamic in nature, with more cross-lagged effects in kindergarten that diminished over time. The third study investigated the extent to which children's behavioral self-regulation predicts academic and relational outcomes by incorporating both variable- and person-centered approaches. Integrating both approaches offered complementary perspectives on the important role that behavioral self-regulation plays in school functioning. Collectively, these three studies provide a multi-dimensional approach to understanding the nature and interplay among the foundational skills that support children's learning and development in early childhood.

Department of Leadership, Foundations & Policy (EDLF)
Curry School of Education
University of Virginia
Charlottesville, Virginia

APPROVAL OF THE DISSERTATION

This dissertation, ("Deconstructing the Foundations of Learning in Early Childhood Complementing Theory with Methodology"), has been approved by the Graduate Faculty of the Curry School of Education in partial fulfillment of the requirements of the degree of Doctor of Philosophy.

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Dr. Sara Rimm-Kaufman

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Dr. David Grissmer

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Dr. Jennifer Locasale-Crouch

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Dr. Jessica Whittaker

____
Dr. Claire Cameron

__________________________Date

DEDICATION

This work is dedicated to my family and loved ones for their never-ending support, encouragement, patience, and sacrifice, so that I may pursue my passion.

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Deconstructing the Foundations of Learning in Early Childhood: Rationale and Conceptual Link

Helyn Kim

University of Virginia

The Three Manuscript Dissertation Overview

This dissertation presents a line of research exploring efforts to deconstruct the foundations of learning in early childhood. The dissertation adheres to the manuscript-style dissertation option, as outlined in the Curry School of Education Ph.D. Dissertation Manual (2015). In accordance with these guidelines, I am the first author on all three of the studies. Additionally, Study 1 has been submitted and published in *Journal of Psychoeducational Assessment*, and Study 2 has been submitted and is in the revision process at *Child Development*. All three manuscript-style studies are conceptually linked while representing a unique contribution to the field. The remainder of this dissertation discusses the rationale for the current line of research and the theoretical framework shared by the three studies. Additionally, each of the three manuscripts is presented in its entirety.

Conceptual Link: Deconstructing the Foundations of Learning in Early Childhood

Educating our children and preparing them to be successful in a competitive global marketplace has been a continuous commitment of our nation (e.g., Kagan & Kauerz, 2007; Pianta, Cox, & Snow, 2007). Since 1989, when then President George Bush and the state governors established six education goals for our nation, with the first education goal being that "by the year 2000, every child must start school ready to learn" (*Readiness Goal*; National Governors' Association, 1990, p. 3), there has been increased national emphasis on children's school readiness. In recent years, concerns about wide variability in children's readiness for the demands placed on them when they enter formal schooling (see Duncan & Murnane, 2011 for review), as well as growing evidence that early childhood experiences are intricately linked to later school success (e.g., Barnett, Epstein, Friedman, Boyd, & Hustedt, 2008; Magnuson, Ruhm, & Waldfogel, 2007), there has been renewed interest in making sure all children are ready to learn when they enter kindergarten (Cappelloni, 2013).

Children's successful transition to formal schooling, as well as their later achievement in school, depends on the coordination of many different early foundational skills (e.g., Boivin & Bierman, 2014; Pianta et al., 2007). Considerable investments in time and money have been devoted to better understanding the complex interplay of the different areas of development and the early foundational skills that are necessary for school and lifelong success. Language and literacy, cognition and general knowledge, approaches to learning, physical development and health, and social and emotional development, are considered five essential school readiness domains that are important for later academic success (National Education Goals Panel, 1995). These different domains of development and learning cannot be discussed as separate entities, but rather as parts that interact and influence each other (e.g., Diamond, 2007). Yet, the underlying processes involved in development and learning, as well as the transactional associations among different developmental domains and the cognitive processes that are implicated in achievement, remain unclear. This may be due, in part, to limitations in statistical approaches, as well as in the ways that constructs are theoretically conceptualized and studied.

Informed by developmental, educational, and cognitive psychology, this dissertation pursues three lines of inquiry to explore individual differences in several specific cognitive processes that underlie learning and school readiness for young children, as well as the interrelatedness of these critical foundational processes. The first paper of my dissertation (**Study 1**) strives to accurately assess children's classroom motor skills, as reported by their teachers, by examining the psychometric properties of the Motor Skills Rating Scale. The second paper of my dissertation (**Study 2**) strives to better understand the developmental trajectories and the longitudinal and reciprocal interplay among three cognitive processes involved in children's mathematics skills. Finally, the third paper of my dissertation (**Study 3**) integrates variable-and person-centered approaches to capitalize on the unique strengths of each method to gain a more complete understanding of the development of children's behavioral self-regulation and its role in school functioning. These three studies, together, provide a varied lens in understanding the complexity of children's development and learning through three distinct methods.

Study 1: Psychometric Properties of the Teacher-Reported Motor Skills Rating Scale

An important aspect of studying children's early foundational skills, as well as understanding mechanism, is the ability to accurately assess these skills using psychometrically validated measures that are appropriate for the study sample. Lacking such measures hinders our ability to test theoretical questions and makes us question the validity of the construct being measured (Willoughby, Wirth, & Blair, 2011). On the other hand, well-validated measures can increase the precision in the measurement of children's early foundational skills, facilitate our understanding of the development of these skills, and clarify how they relate to other important outcomes. Well-validated measures can also inform experimental interventions that promote developmental skills in young children.

Informal assessments of children's skills occur throughout the year, as teachers attempt to identify how best to individualize instruction to support students' learning. Recent evidence points to the importance of assessing children's classroom motor skills (e.g., Cameron, Chen et al., 2012). While motor skills are not often taught directly in the classroom, research has established a robust connection between children's early motor skills and their achievement, even after controlling for demographic variables (Cameron, Brock et al., 2012; Carlson, Rowe, & Curby, 2013; Grissmer, Grimm, Aiyer, Murrah, & Steele, 2010). Thus, motor skills may be strong indicators of other related difficulties. However, there are no validated teacher-report measures of classroom motor abilities of children without disabilities. Therefore, in Study 1, *Psychometric Properties of the Teacher-Reported Motor Skills Rating Scale* (Kim et al., 2015), I evaluated the psychometric properties of the Motor Skills Rating Scale (MSRS; Cameron, Chen et al., 2012), a relatively new 19-item measure of children's teacher-reported motor skills in the classroom, using a confirmatory factor analysis (CFA) in a structural equation modeling approach.

Two main findings emerged from this study. First, my study further established construct validity of the MSRS, providing stronger evidence for the validity of the teacher-reported motor skills measure. The MSRS includes three related, but distinct subscales: Classroom Fine Motor, Body Awareness, and Shapes and Letters. Convergent and divergent validity was also established and provided some interesting insight into what the three subscales of the MSRS may be measuring. Specifically, Classroom Fine Motor was strongly associated with direct cognitive assessments that require visuospatial and attention components, whereas Body Awareness was strongly associated with other teacher-reported measures of classroom social skills and problem behaviors. Shapes and Letters, despite being positively correlated with Classroom Fine Motor, was most strongly related to direct measures that required a sensorimotor component. Second, the three subscales of the MSRS were differentially associated with children's academic outcomes, such that only Classroom Fine Motor was strongly and positively related to direct measures of children's academic knowledge and mathematics achievement, after controlling for the other two subscales. This study extends our understanding of teacher-reported classroom motor skills and establishes, within a typically-developing population, variation in children's individual motor skills in the classroom that explains their cognitive and achievement skills.

Based on the first study, there is little clarity, however, regarding how children's motor skills and the underlying cognitive processes supporting those movements develop in the early school years; and when and to what degree these processes contribute to mathematics achievement. Given that mathematics achievement is multifaceted, cumulative, and developmental, a thorough understanding of the early motor and cognitive skills that support mathematics learning and performance is required. The multi-faceted nature of mathematics learning also entails an integrated longitudinal approach that considers complex interactions among a variety of related antecedents (e.g., Boivin & Bierman, 2014). The possibility of bi-directional and transient relations among multiple school readiness constructs complicates the task of identifying the cognitive skills that are foundational for mathematics achievement. Consequently, the developmental trajectories and dynamic interplay between these skills during the early school years and their relative importance in predicting mathematics achievement at different points in time remain unclear. Study 2 was designed to address this issue.

Study 2: Developmental Relations Among Motor and Cognitive Processes and Mathematics Skills

Early mathematics learning is one of the strongest predictors of later achievement (Duncan et al., 2007) and, in the long-term, for success in an increasingly competitive job market (National Mathematics Advisory Panel, 2008). In recent years, the cognitive processes of fine motor coordination, attention, and visuomotor integration have been linked to children's early and long-term mathematics achievement (e.g., Cameron, Brock et al., 2012; Carlson et al., 2013; Grissmer et al., 2010; Sortor & Kulp, 2003). Yet, beyond well-established associations among these processes, the unique and combined contributions that each cognitive process may make towards the development of mathematics skills remain largely unknown. Therefore, in Study 2, *Developmental Relations Among Motor and Cognitive Processes and Mathematics Skills* (Kim, Duran, Cameron, & Grissmer, in revision), I examined the longitudinal and reciprocal contributions of fine motor coordination, attention, and visuomotor integration to mathematics skills in a diverse sample of kindergarten and first grade children across two years of school using an auto-regressive, cross-lag (ACL) approach.

Two main findings emerged from this study. First, developmental relations among fine motor coordination, attention, visuomotor integration, and mathematics skills are transactional in nature, with more "cross-talk", or bi-directional contributions, occurring in kindergarten than in first and second grades. Second, these motor and cognitive processes are differentially and intricately linked to mathematics skills over time. For example, children's attention and visuomotor integration consistently and directly contributed to their mathematics development, whereas fine motor coordination and mathematics skills were indirectly linked through visuomotor integration. In general, these findings extend previous work establishing linear relations of early cognitive skills, in particular visuomotor integration and attention, to elementary-age students' mathematics achievement (e.g., Cameron, Brock et al., 2012; Carlson et al., 2013; Decker, Englund, Carboni, & Brooks, 2014; Duncan et al., 2007; Grissmer et al., 2010) and other work emphasizing that basic motor coordination skills precede more complex development (Korkman, Kirk, & Kemp, 1998). Examining the separate contributions of three interrelated motor and cognitive processes to mathematics skills longitudinally allowed for a better understanding of the independent components that combine and coordinate to form the skills that are, in part, necessary for school success (Cameron, Brock et al., 2012; Duncan et al., 2007). Additionally, the results further emphasized the complexity of the construct of mathematics and the need for continued efforts to understand its developmental foundations. Study 3 was designed to understand the important role that behavioral self-regulation plays in children's school functioning.

Study 3: Patterns of Behavioral Self-Regulation in Low-Income Kindergarten Children: Integrating Variable- and Person-Centered Approaches

For young children, the transition to formal schooling is a critical time period that presents not only increased academic demands, but behavioral challenges as well (Entwisle & Alexander, 1998; La Paro, Rimm-Kaufman, & Pianta, 2006; McClelland et al., 2007). Behavioral self-regulation, which involves integrating the components of executive functions to produce contextually-relevant behaviors, is well-established as a promotive factor for academic achievement and school adjustment more broadly, especially for children from high-risk backgrounds (Cameron Ponitz, McClelland, Matthews, & Morrison, 2009; Eisenberg, Valiente,

& Eggum, 2010; Raver, 2012; Sektnan, McClelland, Acock, & Morrison, 2010). In early childhood, there is much variability in children's self-regulatory abilities, even within the same age group (Cameron Ponitz et al., 2009), and where children are in their development of behavioral self-regulation may be meaningful for how they function in the classroom setting.

The majority of the research examining associations between behavioral self-regulation and school adjustment outcomes has been obtained from a variable-centered perspective. In recent years, person-centered approaches have been used in developmental studies to complement and extend traditional variable-centered research (Lanza & Cooper, 2016). Study 3, *Patterns of Behavioral Self-Regulation in Low-Income Kindergarten Children: Integrating Variable- and Person-Centered Approaches*, combined a variable-centered approach with a person-centered approach, focusing on identifying distinct response profiles, to obtain a fuller picture of children's behavioral self-regulation and relations to school outcomes. Two main findings emerged. First, within this sample of kindergarten children from low-income families, four distinct profiles were identified based on children's response patterns on a single administration of a well-validated behavioral self-regulation task: Integrated Self-Regulators, Conscious Regulators, Effortful Regulators, and Poor Regulators. This finding suggests that, despite their similar backgrounds, there is substantial variability in children's development of behavioral self-regulation.

Second, integrating both variable- and person-centered approaches capitalized on each method's unique strengths to further enrich our knowledge of children's behavioral self-regulation near school entry. The variable-centered approach, in general, confirmed findings from prior research concerning positive associations between behavioral self-regulation and school adjustment. The person-centered approach extended these findings by identifying and comparing certain groups of children based on their response patterns. These response patterns, in turn, may be uncovering something about children's behavioral self-regulation development that is not fully captured in a single summed score. By incorporating both approaches, I was able to conclude that regardless of the analytic approach, the ability to seamlessly integrate the cognitive components to self-regulate is critical for academic learning. However, for student-teacher relationships, the developmental process of behavioral self-regulation may be particularly worth exploring.

Summary

Promoting children's readiness for the transition to formal schooling has been and continues to be a pressing issue in the United States, further amplified by the increasing demands on education systems to provide children with the tools to succeed in rapidly and constantly changing social and economic conditions (Boivin & Bierman, 2014). Recent efforts have focused on improving children's early competency and learning skills to improve long-term educational outcomes (Duncan et al., 2007; La Paro & Pianta, 2000). The complex interplay among children's early foundational skills and their associations with later outcomes is not well-understood, however. Thus, theoretical and methodological work is necessary to understand the interactive and combined effects of the underlying cognitive processes that contribute to children's learning and development. Together, the three studies presented in this dissertation provide a multi-dimensional approach to a stronger understanding of the nature and interplay among the cognitive processes that support children's learning and development in the early years of school. Even though this body of work is primarily child-focused, findings across the three studies allude to contextual factors that would be helpful to incorporate to better support children's development.

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Psychometric Properties of the Teacher-Reported Motor Skills Rating Scale

Helyn Kim, William M. Murrah, Claire E. Cameron, Laura L. Brock, Elizabeth A. Cottone, &

David Grissmer

University of Virginia

Abstract

Children's early motor competence is associated with social development and academic achievement. However, few studies have examined teacher reports of children's motor skills. This study evaluated the psychometric properties of the Motor Skills Rating Scale (MSRS), a 19-item measure of children's teacher-reported motor skills in the classroom. Results of a confirmatory factor analysis support the validity of the three-factor structure of MSRS. The subscales of the MSRS were also associated with child academic and behavioral outcomes, with differences in the associations depending on the subscale. Only the *Classroom Fine Motor* skills subscale was uniquely associated with academic knowledge and mathematics achievement, whereas *Body Awareness* and *Shapes and Letters* were not significantly associated with either of the academic outcomes. Implications of the findings are discussed.

Keywords: teacher-report, confirmatory factor analysis, psychometric properties, measure validation, academic achievement, Motor Skills Rating Scale

Psychometric Properties of the Teacher-Reported Motor Skills Rating Scale

Children's successful transition to formal schooling depends on the coordination of many different skills (Pianta & Kraft-Sayre, 2003). With the advent of neuroimaging and further study of both clinical and typically-developing populations, awareness has grown that the development of motor skills and cognitive processes are intricately intertwined (Diamond, 2000; Floyer-Lea & Matthews, 2004). While motor skills are not often taught directly in the classroom, research has established a robust connection between children's early motor skills, especially fine motor skills, and their achievement, even after controlling for demographic variables (Cameron, Brock, et al., 2012; Carlson, Rowe, & Curby, 2013; Duncan et al., 2007; Grissmer et al., 2010; Son & Meisels, 2006). The development of fine motor skills requires functional networks that substantially overlap with the neural structures underlying the cognitive skills that are important for self regulation, including attentional control, working memory, and inhibition (Floyer-Lea & Matthews, 2004).

Given this, motor skills may be strong indicators of other related difficulties. For instance, Pagani and Messier (2012) found that strong motor abilities co-occur with better social skills and task-oriented behaviors in the kindergarten classroom. Kindergarteners with poor fine motor skills exhibited greater levels of hyperactive-inattentive behavior, whereas strong gross motor, fine motor, and perceptual-motor skills were all associated with positive classroom behaviors, including prosocial behaviors and classroom engagement. These findings establish the importance of fine motor skills, not just for cognitive skills, which has been established in previous research, but also children's overall functioning in the classroom. Informal assessments of children's skills occur throughout the year, as teachers attempt to identify struggling students; however, there are no validated teacher-report measures of children's classroom motor abilities to our knowledge. Using a confirmatory approach, the current study establishes the psychometric properties of a relatively new teacher-report motor skills measure that shows early promise.

Although a large body of research exists regarding children's motor skills and how they relate to academic achievement, most studies have used direct neuropsychological assessments, such as the Developmental NEuroPSYchological Assessment (NEPSY; Korkman, Kirk, & Kemp, 1998) and Beery Visual Motor Integration (VMI; Beery, Buktenica, & Beery, 2010). However, these measures can be time-consuming and expensive and are usually administered by clinicians. Therefore, a quality measure is needed that teachers can use in the classroom to evaluate children's motor abilities, and this measure should also be related to other school-related skills, including academic performance.

Cameron, Chen, et al. (2012) developed the Motor Skills Rating Scale (MSRS), an observer-report survey of children's classroom-related motor behaviors that can be observed by teachers. Factor structure of the MSRS was obtained using EFA. The 19 items on the measure loaded onto three distinct, but related factors: *Shapes and Letters* (measures specific aspects of visual motor integration), *Classroom Fine Motor* (measures dexterity and the ability to carry out everyday classroom tasks), and *Body Awareness* (measures mainly gross motor skills). Children's scores on the MSRS, specifically *Classroom Fine Motor* skills subscale, correlated as expected with NEPSY measures of motor and cognitive skills and also related to mathematics achievement (for more information, see Cameron, Chen et al., 2012).

Although this seems promising, MSRS is a newly developed measure, and therefore, needs to be scientifically validated to demonstrate relevance (MacCallum & Austin, 2000; Sekino & Fantuzzo, 2005). In addition, factor structures obtained by exploratory factor analysis (EFA) may fit poorly in confirmatory follow-up studies because EFA is driven by the data and involves decisions that tend to be subjective (Van Prooijen & Van Der Kloot, 2001). One way of cross-validating the factor structure of a measure is to perform a confirmatory factory analysis (CFA; Pedhazur & Schmelkin, 1991), to examine whether the factor structure matches what was found in the original study. A CFA tests a specified model that establishes the relations between observed variables and latent factors in advance, as well as the associations among the latent factors themselves (Van Prooijen & Van Der Kloot, 2001).

The purpose of this study was to establish construct and criterion-related validity of the MSRS. This study replicates and extends previous research in several ways. First, we conduct CFA and model-based regression analyses to validate the newly-developed MSRS measure. Second, we provide evidence of convergent and discriminant validity and establish concurrent validity by examining relations between MSRS and academic outcomes, within a structural equation modeling framework.

Method

Participants

Children attended three low-income urban schools in a southern state and were engaged in a larger study that tested the effects of participating in an after-school visuospatial skills program for early elementary students. A total of 144 students in kindergarten (56%; n = 81) and first grade (44%; n = 63) participated in the study and were randomly assigned to either the treatment or control group. Children ranged in age from 5.0 to 7.6 years (M=5.9 years). The sample included 73 girls (51%), and majority of the children were African American/Black (93%; n = 132). The remaining students were Caucasian/White (2.7%; n = 4), Hispanic (2.7%; n = 4), or Other (2.7%; n = 4). See Table 1 for descriptive statistics.

Procedure

Family and demographic information, teacher reports of children's classroom motor and self-regulation skills, and direct assessments of children's cognitive and motor skills were collected. Children were individually assessed in two 45-60 minute sessions in a quiet area of the school or classroom.

Measures

Teacher-Report Motor Skills Rating Scale (MSRS). The teacher-report Motor Skills Rating Scale (MSRS; Cameron, Chen et al., 2012), a 19-item questionnaire, consists of three subscales: *Shapes and Letters* (3 items); *Classroom Fine Motor* (8 items); and *Body Awareness* (8 items). The MSRS includes items pertaining to observable motor-related behaviors that are typically noticed by classroom teachers and is available for use in research by contacting the third author (see Figure 1 for items). Teachers are asked to read each item and think about how frequently the statement applies to the specific child and rate each item on a scale from 1 (*not at all*) to 4 (*very much*), with the option of also choosing 5 (*I have not observed*), which was treated as a missing value. For the analyses, the items on the MSRS were treated as categorical variables because of non-normal distributions, which can increase measurement error and attenuate correlations (B. O. Muthén, 1984).

Academic Knowledge. Academic knowledge was directly assessed using the Academic Knowledge subtest of the Woodcock-Johnson Tests of Achievement (WJ-III; Woodcock, McGrew, & Mather, 2001). Academic Knowledge measures children's knowledge in the sciences, history, geography, government, economics, art, music, and literature and includes three subscales: *Science* (27 total items), *Social Studies* (28 items), and *Humanities* (22 items). For each subscale, testing stops after the child gives six consecutive incorrect responses. This subtest, from the composite of the three subscales, has an internal reliability of .88 for 5- to 7-year olds (Mather & Woodcock, 2001).

Mathematics Achievement. Children's math skills were assessed using a composite of three subscales of the Basic Concepts domain of the Key Math 3, a comprehensive mathematics assessment for students 4½-21 years old (Connolly, 2008). The three subscales are *Numeration*, which measures early number awareness and number sense; *Geometry*, which measures understanding of spatial relationships and reasoning; and *Measurement*, which requires children to compare objects on different attributes. Questions and responses are given verbally, with most of the items involving a visual element, as well (e.g., pictures). One point is awarded for each correct response for a maximum of 125 points. The three subscales had high intercorrelations (r = .77-.91); and thus, the three subscales were averaged to form a composite variable.

Developmental NEuroPSYchological Assessment (NEPSY). The NEPSY (Korkman et al., 1998) is a comprehensive neuropsychological assessment battery for children 3-12 years old that assesses the cognitive processes that underlie motor skills. The NEPSY consists of three domains, including visuospatial (V), sensorimotor (S), and attention/executive (A/E), as well as seven subtests that fall under one of the three domains. These subtests include *Arrows* (V), which assesses the ability to judge line orientation and directionality; *Design Copy* (V), which assesses the ability to copy increasingly complex two-dimensional figures; *Imitating Hand Positions* (S), which assesses the ability to imitate hand and finger positions; *Visuomotor Precision* (S), which assesses fine motor speed and accuracy of eye-hand coordination; *Visual Attention* (A/E), which assess the speed and accuracy of a child's ability to focus on as well as maintain attention to visual targets within an array; *Auditory Attention and Response Set* (A/E), which assesses the ability to sustain selective auditory attention and shift and maintain a new set of responses; and

Tower (A/E), which assesses nonverbal planning and problem-solving abilities (see Korkman et al., 1998 for psychometrics).

Social Skills Information System (SSIS). The Social Skills Information System (SSIS; Gresham & Elliot, 2008) is a teacher-reported measure that assesses children's relationships and social behaviors in the classroom. This study used the first two of the three total subscales, *Social Skills* and *Competing Problem Behaviors* (see Gresham & Elliot, 2008 and Bronson, 1994 for psychometric information). Teachers are asked to read each statement, think about how frequently the statement applies to the specific child, and rate each item on a scale from 1 (*never*) to 4 (*almost always*). The NEPSY and SSIS were used in the current study as indicators of children's various classroom competencies for evidence of convergent and divergent validity with the MSRS.

Covariates. Children's age, gender, and treatment group status (whether child participated in the visuospatial skills intervention) were held constant.

Data Analysis

Structural equation modeling (SEM) was performed in *Mplus* version 7.0 (L. Muthén & Muthén, 2012) using the robust Weighted Least Squares (WLSMV; B. O. Muthén, du Toit, & Spisic, 1997) estimator, which is the recommended approach for the analysis of categorical variables (B. O. Muthén, 1984). SEM evaluates a measurement model and a path model and is a useful method for studying associations among different variables and testing models that include latent variables (Lei & Wu, 2007). Compared to multiple regression, SEM also asserts more flexible assumptions and calculates all parameters simultaneously, providing a test of overall model fit to the data (Farrell, 1994). For the current study, SEM was used to analyze the factor structures of the MSRS, examine convergent and divergent validity, and to evaluate the associations among the three subscales of the MSRS and school-related outcomes, including academic knowledge and mathematics achievement.

Construct validity. First, a CFA in a SEM framework was used to replicate the reported three-factor structure of the MSRS (Cameron, Chen et al., 2012) and to assess the adequacy of model fit, using Bentler's comparative fit index (CFI; Bentler, 1990), the Tucker Lewis index (TLI; Tucker & Lewis, 1973), and the root mean square error of approximation (RMSEA; Steiger & Lind, 1980). The chi-square values were also examined even though this statistic depends on degrees of freedom and sample size. The following values proposed by Yu (2002) for categorical data using WLSMV estimation method were used to assess model fit: CFI ≥ .96, TLI ≥ .95, and RMSEA ≤ .05. Of note, with relatively lower sample sizes, the cutoff values of fit indices can have low power for complex models (Yu, 2002), so even though cutoff criteria are satisfied, the accepted model still could have misspecification on factor loadings[*]. Therefore, results should be interpreted with caution. However, in a simulation study, Rhemtulla and colleagues (2012) found that, with four or five category models and a small sample size (N=100), the WLSMV estimations were robust.

Convergent/divergent validity. Convergent and divergent validity was investigated by examining the associations between each of the subscales of the MSRS and the subtests of both the NEPSY and SSIS. We hypothesized that strong, positive associations would exist between the *Classroom Fine Motor* and *Shapes and Letters* subscales and the NEPSY but that they might relate to the NEPSY subscales differently. We also hypothesized that strong associations would exist between *Body Awareness* and the subscales of the SSIS. Similarly, divergent validity was assessed by examining the associations between *Body Awareness* and the subscales of the

[*] The authors thank an anonymous reviewer for pointing this out.

NEPSY. Because *Body Awareness* is intended to measure gross motor skills, we hypothesized that there would be no associations between *Body Awareness* and the subscales of the NEPSY.

Concurrent validity. A SEM approach was next used to examine the unique associations among the three subscales of the MSRS (from the measurement model described above) and mathematics achievement and academic knowledge. The child outcome variables, which were allowed to covary, and the control variables, which were also allowed to covary, were incorporated into the measurement model of the MSRS (Figure 2).

Results

Preliminary Analyses

Overall, preliminary analyses, including descriptive statistics (Table 1), correlations among variables, distributional characteristics of indicators, multivariate outliers, and multicollinearity among variables, indicate the data met the necessary assumptions for carrying out the analytic plan.

Confirmatory Factor Analysis of the MSRS

None of the indicators were allowed to crossload in the CFA; however, the three factors were allowed to covary. Modification indices were examined, which indicated that some of the items within the Body Awareness subscale were correlated. The measurement model was modified accordingly, which significantly improved model fit $\Delta X^2_{(3)} = 50.34$, $p<.001$. Therefore, the modified model was used in subsequent analyses. Figure 1 shows the final CFA model that was tested.

Overall, the full measurement model provided good model fit, CFI = .97, TLI = .97, RMSEA = .08 with 90% CI lower bound = .064 and upper bound = .093, and $X^2_{(146)} = 275.96$, $p<.001$. All factor loadings were salient, ranging from .45 to .95, indicating that the items adequately captured their underlying latent factors (Sakiz, Pape, & Hoy, 2012). Furthermore, all of the factor loadings were statistically significant ($p<.001$), indicating that the indicators were significantly associated with their latent constructs. R^2 values were moderate to high, ranging from 0.20 to 0.90, suggesting that the manifest variables were reasonably reliable in measuring the latent variables in the model (Cohen, 1988).

The three subscales of the MSRS had good internal consistency reliabilities, suggesting that the responses were consistent across the items within each subscale (Kline, 2011): $\alpha = .90$ for *Shapes and Letters*, $\alpha = .86$ for *Classroom Fine Motor*, and $\alpha = .82$ for *Body Awareness*. In addition, bivariate Pearson correlations between the three subscales ranged from $r = .60$ to .69, indicating some overlap in the constructs; however, each scale seemed to measure a distinct construct.

Convergent/divergent validity. A regression model in a SEM framework was then conducted using the composite scores from each subscale of the MSRS and the scores from each of the subtests from the NEPSY and SSIS. Results indicated that the three subscales of the MSRS were differentially associated with the subtests of the NEPSY and SSIS measures (see Table 2). *Classroom Fine Motor* was positively associated with Design Copy ($\beta = 0.37$, $p < .001$) and *Tower* ($\beta = 0.32$, $p < .01$) subtests of the NEPSY, as well as the *Social Skills* ($\beta = 0.38$, $p < .001$) subscale of the SSIS, but *Classroom Fine Motor* was not significantly associated with any of the other NEPSY subtests or the *Competing Problem Behaviors* subscale of the SSIS. *Body Awareness* was not significantly associated with any of the NEPSY subtests; however, *Body Awareness* was positively associated with *Social Skills* ($\beta = 0.44$, $p < .001$) and negatively associated with *Competing Problem Behaviors* ($\beta = -0.73$, $p < .001$). *Shapes and Letters* was marginally associated with *Imitating Hands* ($\beta = 0.21$, $p = .07$) and significantly associated with

Visual Precision ($\beta = 0.22$, $p < .05$) subtests of the NEPSY but was not significantly associated with any of the other NEPSY subtests or with the two subscales of the SSIS. These regression models were also conducted using the estimated factor scores of the MSRS subscales, and the results were very similar, indicating the robustness of these findings.

Concurrent validity. Correlations among teacher ratings on the three subscales of MSRS and child outcomes were all positive and ranged from r =.13 to .69. The hypothesized full model provided good model-fit, CFI = .97, TLI = .96, RMSEA = .066, with 90% CI lower bound = .054 and lower bound = .078, and $X^2_{(234)} = 381.15$, $p<.001$. Two alternative models (a two-factor model and a hierarchical order model) using the same sample of data were also conducted; however, the original three-factor model was the most defensible model for the current data.

Teacher-reported *Classroom Fine Motor* skills were positively associated with both Academic Knowledge, ($\beta = 0.44$, $p < .001$) and Mathematics Achievement ($\beta = 0.32$, $p < .01$), beyond the effects of the covariates. In other words, controlling for age, gender, and treatment group status, children whose teachers rated them as having stronger *Classroom Fine Motor* skills also scored higher on the directly assessed measures of Academic Knowledge and Mathematics Achievement. In contrast, teacher-reported *Body Awareness* and *Shapes and Letters* were not significantly related to either Academic Knowledge or Mathematics Achievement. Overall, the structural model explained 27% of the variance in students' Academic Knowledge and 43% of the variance in Mathematics Achievement.

Discussion

Two main findings emerged from this psychometric study. First, results from the CFA supported the validity of the three-factor structure of the MSRS that was found in a previous study (Cameron, Chen et al., 2012). Second, MSRS subscales were associated with child outcomes; however, the three subscales showed different associations, with only *Classroom Fine Motor* skills showing strong and positive associations with both child outcomes.

MSRS is a Valid Measure of Children's Classroom Motor Skills

This study further establishes construct validity of the MSRS, which was developed to address the need for a practical assessment of children's motor behaviors that are relevant to the regular classroom setting and can be observed by teachers. The present, more robust CFA of the MSRS, provides stronger evidence for the validity of the teacher-reported motor skills measure. All three subscales, *Classroom Fine Motor*, *Body Awareness*, and *Shapes and Letters*, clustered together empirically, suggesting that these subscales appear to be measuring the intended constructs of the MSRS (Cameron, Chen et al., 2012). In addition, convergent and divergent validity was also established and provided some interesting insight into what the three subscales of the MSRS may be measuring. Specifically, *Classroom Fine Motor* was strongly associated with subtests of the NEPSY that required visuospatial and attention components, whereas *Body Awareness* was strongly associated with classroom social skills and problem behaviors, as measured by the SSIS. Finally, *Shapes and Letters*, despite being strongly correlated with *Classroom Fine Motor*, was strongly associated with subtests of the NEPSY that incorporated a sensorimotor component.

Comparisons of the current CFA results to the original EFA results that established the factor structures of the MSRS (Cameron, Chen et al., 2012) suggest the measure functions similarly regardless of sample characteristics. Notably, the factor structures replicated using the current sample, despite demographic differences from the original sample. In the previous study, 55% of children qualified for free/reduced lunch (FORL) status and were slightly older (on average 6.58 years old), whereas the current sample included younger children (on average 5.92

years old) from mostly low-income families, with 92% qualifying for FORL status. This suggests that the factor structure of the MSRS appears to be stable in multiple populations; however, the development and evaluation of the measure across various samples to determine appropriate norms is an important next research step.

Classroom Fine Motor Skills and Child Academic Outcomes

Our findings corroborate a body of literature that establishes early fine motor skills as important predictors of children's academic abilities (Cameron, Brock, et al., 2012; Carlson et al., 2013; Grissmer et al., 2010; Son & Meisels, 2006). To successfully carry out classroom tasks, children need to sequence their motor movements competently, such as picking up a writing utensil, holding onto the paper with the other hand, and writing legibly and proficiently. Furthermore, teachers appear to be reliable reporters of children's classroom fine motor skills, and their reports explain variance in two different academic outcomes. In addition, teachers appear to distinguish among subtly different skill sets that draw on different aspects of motor skills. For example, as hypothesized, teacher-reported *Body Awareness* was not related to the academic outcomes. Although these skills are important for learning, the specific skills in *Body Awareness*, such as sitting easily in a chair, are unrelated to Mathematics Achievement and Academic Knowledge. Finally, an interesting and surprising finding was that teacher-reported Shapes and Letters subscale was not significantly associated with either of the academic outcomes, after controlling for both *Classroom Fine Motor* and *Body Awareness*. Although being able to draw, trace, and copy different shapes and letters seems similar to the *Classroom Fine Motor* subscale tasks, the items on the *Shapes and Letters* subscale have a narrow, sensorimotor focus, rather than visuospatial and attention components. Prior research (e.g., Carlson et al.,

2013) has shown that visuospatial skills, but not sensorimotor or motor coordination skills, are strongly related to academic achievement.

Limitations

As with all studies, the current study has some limitations. First, the sample is not representative of the general population; and therefore, generalizability of the findings beyond our sample may be uncertain. Second, the MSRS is not a direct assessment of children's motor skills. Rather, it assesses teachers' perceptions of children's classroom motor skills, which may be influenced by other factors, such as their relationship with the child (Mashburn, Hamre, Downer, & Pianta, 2006). The correlational nature of the study also prevents causal conclusions regarding teacher-report motor skills and academic outcomes. In addition, it is possible that the final CFA model may be data driven, such that the nature of the construct being measured can shift depending on the indicators that were chosen to represent the latent variables, which in turn can influence the results and interpretation (MacCallum & Austin, 2000). Finally, this study assumes that motor skills concurrently predict academic outcomes; however, it may be that academic outcomes predict motor skills. Due to the analytic design, as well as the correlational nature, of the study, it is not possible to rule out alternative explanations.

Implications

Despite these limitations, this study extends our understanding of teacher-reported classroom motor skills, as well as the connections among different aspects of classroom motor skills and children's academic outcomes. Our findings have implications for researchers, school professionals, and policymakers. Even after examining alternative models, the three-factor structure of the MSRS fit the best using different data from the initial study. This robust pattern helps reiterate the importance of motor skills in the classroom for academic achievement.

Although education scholars and teachers are aware that children need to have a wide range of skills that extend beyond achievement to include motor competence, this has been difficult to translate into policy and practice. A valid measure like the MSRS can be useful for researchers and professionals working with children because the behaviors on the measure are concrete and can be easily observed. This measure also helps draw attention to school-related tasks that have a motor component as well as a cognitive component. Adults may overlook the importance of motor skills, which many young children have not yet automated in tasks like writing, moving about the classroom, and organizing their learning materials.

The MSRS is the first measure for teachers of typically developing children that asks about motor development. This study also establishes, within a typically developing population, variation in children's individual motor skills in the classroom that explains their cognitive and achievement skills. If a child is struggling in school, this quick and easy-to-administer measure could illuminate a potential source of difficulty that may be hidden otherwise; thus, a next research step is developing the MSRS as a screener. States are seeking out readiness screeners that go beyond achievement, such as children's self-regulation abilities, but these screeners are expensive and can be time-consuming to administer (Williford, Downer, & Hamre, 2013).

In conclusion, the results from the current study indicate that teachers' reports of their students' classroom motor skills are significantly related to students' academic skills and emphasize the importance of early measurement of classroom motor skills. Developing a better understanding of the interrelatedness of foundational skills for learning in relation to traditional academic outcomes may be useful in creating comprehensive approaches that will help children be more successful in school.

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Table 1.

Descriptive Statistics

	n	%	% Missing	*M*	*SD*	Min	Max
Treatment Condition	144		0				
Control Group	69	48.0					
Intervention Group	75	52.0					
Background							
Age of Child (Years)	144		0	5.9	0.61	5	7.6
Grade	144		0				
Kindergarten	81	56.3					
1st Grade	63	43.8					
Gender	144		0				
Boy	71	51.0					
Girl	73	49.0					
Ethnicity	144		0				
White	4	2.7					
Black	132	93.0					
Hispanic	4	2.7					
Other	4	2.7					
Free/Reduced Lunch	140		2.8				
No	8	5.6					
Yes	132	91.7					
Child Assessments							
Motor Skills Rating Scale (MSRS)							
Classroom Fine Motor	144		0.0	3.10	0.57	2	4
Body Awareness	143		0.7	3.13	0.55	2	4
Shapes and Letters	144		0.0	3.33	0.63	1	4
Mathematics Skills (Key Math 3)	141		2.1	21.62	8.40	2	54
Academic Knowledge (WJ-III)	140		2.7	29.93	5.28	6	43

Note. WJ-III = Woodcock-Johnson Tests of Achievement.

Table 2.

Regression Coefficients for Associations among MSRS Subscales and SSIS and NEPSY

Measure	Classroom Fine Motor	Body Awareness	Shapes and Letters
Design Copy	0.369***	0.009	0.028
Tower	0.317**	0.019	-0.092
Auditory Attention	0.119	0.067	-0.179
Arrow	0.088	0.056	0.073
Visual Attention	0.186	0.021	-0.033
Imitating Hands	-0.036	-0.009	0.207†
Visual Precision	0.069	-0.081	0.222*
Social Skills	0.380***	0.444***	0.043
Competing Problem Behaviors	0.013	-0.725***	-0.032

Note. NEPSY= Developmental NEuroPSYchological Assessment (Design Copy, Tower, Auditory Attention, Arrow, Visual Attention, Imitating Hands, and Visual Precision subtests); SSIS= Social Skills Improvement Scale (Social Skills and Competing Problem Behaviors subscales). ***p<.001; **p<.01, †p<.10

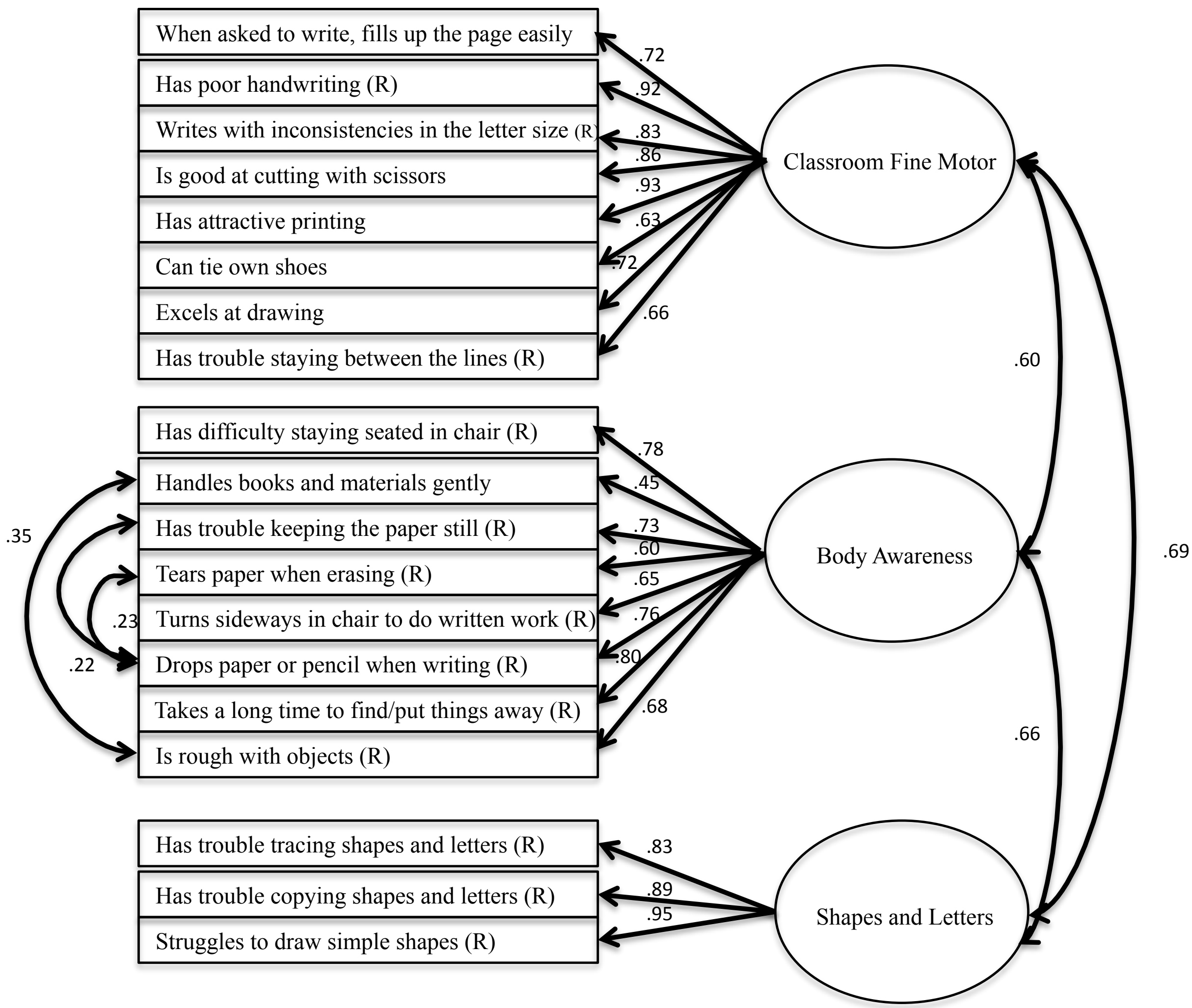

Figure 1. Confirmatory factor analysis of MSRS. Factor variances were fixed to 1.0 to identify and standardize the model. All estimated parameters were significant at $p<.001$; $n=144$; (R)=reverse-coded

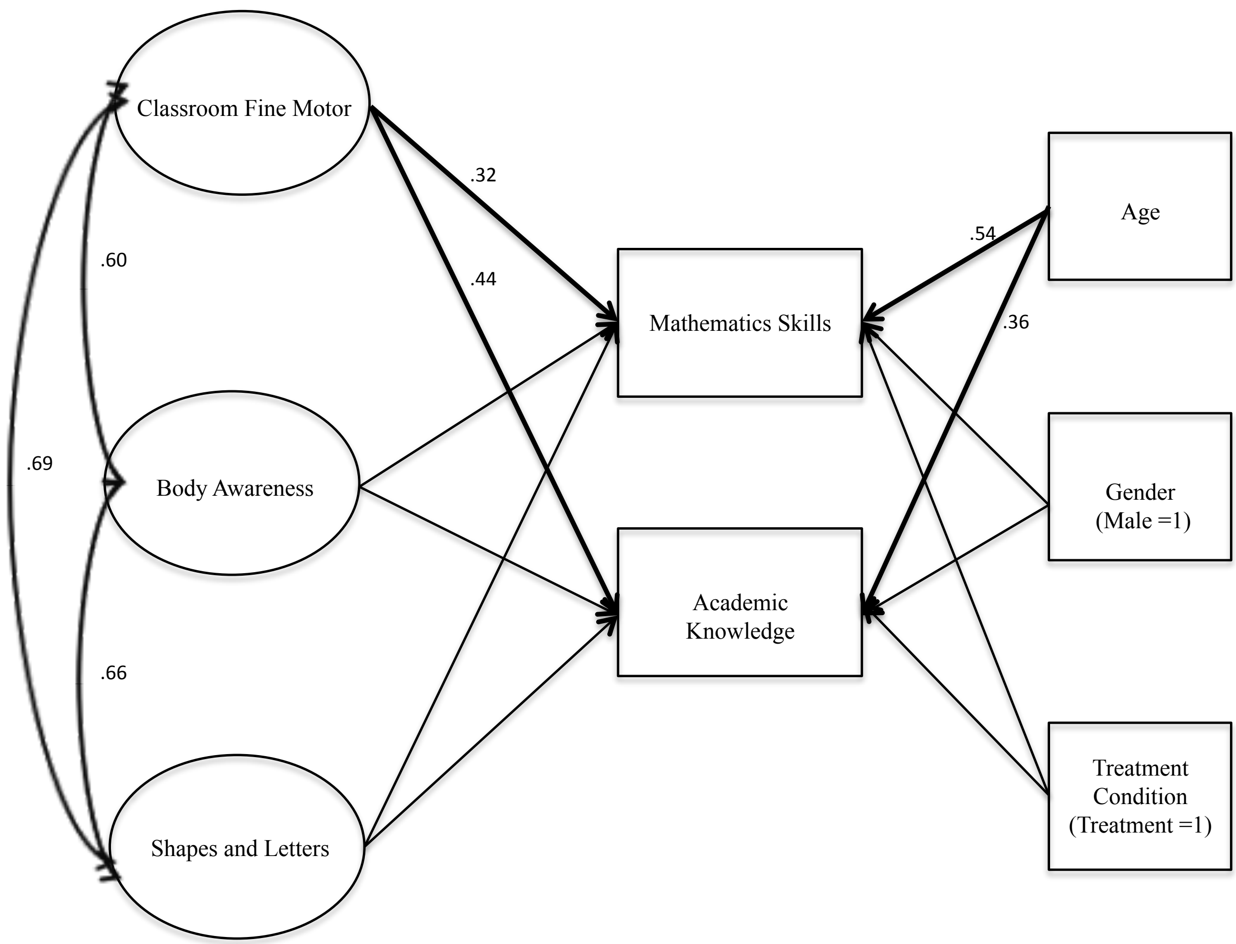

Figure 2. Structural equation model combining measurement model of the MSRS (not shown; see Figure 1) with path model to examine associations among motor skills and other child outcomes, while controlling for the effects of age, gender, and treatment condition. Child outcomes were allowed to covary, and covariates were allowed to covary. Only significant coefficients are provided; *n*=144.

Developmental Relations among Motor and Cognitive Processes and Mathematics Skills

Helyn Kim[1], Chelsea A. K. Duran[1], Claire E. Cameron[2], and David Grissmer[1]

[1]University of Virginia

[2]University at Buffalo, The State University of New York

Abstract

This study explored longitudinal and reciprocal associations among visuo-motor integration, attention, fine motor coordination, and mathematics skills in early childhood. A diverse sample of 135 5-year-olds (kindergarteners) and 119 6-year-olds (first graders) in the United States were followed over the course of two school years. Results revealed that longitudinal associations between constructs were transactional in nature, with more reciprocal transactions occurring in kindergarten than in first and second grades. Links between individual constructs and mathematics skills were intricate and dynamic, with cross-lagged effects strongest in kindergarten and diminishing over time. Implications of examining the hierarchical interrelations among the many motor and cognitive processes underlying the development of children's mathematics skills are discussed.

Keywords: attention, dynamic transactions, early elementary, fine motor coordination, mathematics skills, visuo-motor integration,

Developmental Relations among Motor and Cognitive Processes and Mathematics Skills

Mathematics learning during early elementary school provides the foundation for students' later academic achievement (Duncan et al., 2007) and, in the long-term, for success in an increasingly competitive job market that values quantitative abilities (National Mathematics Advisory Panel, 2008). In recent years, visuo-motor integration, attention, and fine motor coordination have been linked to children's early and long-term mathematics achievement (e.g., Becker, Miao, Duncan, & McClelland, 2014; Cameron et al., 2012; Carlson, Curby, & Rowe, 2013; Grissmer, Grimm, Aiyer, Murrah, & Steele, 2010; Sortor & Kulp, 2003). These processes have been featured centrally in studies assessing the possible role of motor skills in mathematics learning. Yet, beyond well-established associations among these processes, there is little clarity regarding when and to what degree they contribute to each other and to mathematics skills in early elementary school. Such contributions are difficult to discern because of their rapid and intertwined development during this period (Korkman, Kirk, & Kemp, 1998).

In addition, few studies have included multiple processes simultaneously across multiple time points to identify their dynamic, transient, and indirect effects. Thus, the unique and combined contributions that each process may make towards the development of mathematics skills remain largely unknown. This study examines the dynamic, longitudinal, and reciprocal contributions of visuo-motor integration, attention, and fine motor coordination to mathematics skills in a diverse sample of early elementary students, using an auto-regressive, cross-lag (ACL) approach. This study follows two cohorts of children over two years: in one cohort from kindergarten through first grade and in the other cohort from first through second grade.

Theoretical Perspectives on Interrelations Between Motor and Cognitive Development

Decades of psychological theory and research have established that motor and cognitive development are inextricably intertwined in infancy and early childhood (e.g., Adolph, 2008; Davis, Pitchford, & Limback, 2011; Diamond, 2007; Piaget, 1952). When approached from a dynamic systems perspective, individual processes are expected to exhibit both stability and change over time; furthermore, the changes in each skill are expected to reciprocally affect the trajectory of other skills, as the entire system seeks to coordinate among all skills (e.g., Thelen, 2005). Consistent with dynamic systems theory, recent advances in neuroscience and the science of human movement have uncovered compelling links between motor and cognitive development. For instance, the development of fine motor skills requires functional networks that substantially overlap with the neural structures underlying certain higher-order, abstract cognitive processes, including attentional control (Floyer-Lea & Matthews, 2004). Several theoretical accounts have been offered to explain how motor and cognitive development in particular are related. We explore two such accounts: reciprocity and automaticity. However, the scarcity of longitudinal work in this area makes it difficult to ascertain which of the theories may be plausible. Further, a single theoretical account may not on its own fully explain the associations. Thus, these accounts are useful for shaping our expectations regarding potential changes in relations among constructs over time but, are not presented as competing alternatives.

Reciprocity. The notion of reciprocity suggests that motor skills and cognition co-develop following experiences that support both as children interact with their environment (Campos et al., 2000). For instance, in infancy, learning to control, coordinate, and integrate multiple body movements into a coherent, organized system supports cognitive capacities, which in turn allows for the acquisition of more varied and complex motor skills (Adolph, 2008). As children acquire new behavioral and cognitive abilities, brain regions interact with each other, generating extensive patterns of connectivity early in development (Johnson, 2001). Furthermore, as children develop, motor and cognitive skills appear to differentiate as their neural substrates become highly structured and functionally specialized (Johnson, 2001); therefore, reciprocity between skills may be transient over time.

Automaticity. The notion of automaticity suggests that mastery in one foundational skill supports more complex task performance and development of other skills. From this perspective, co-development of motor skills and cognition reflects dependence of complex skills, such as mathematics, upon more rudimentary skills, such as motor competence. This theory assumes that when children are asked to simultaneously perform multiple tasks that have both motor and cognitive components (Cameron et al., 2012), both processes will compete for limited attentional resources. In a school setting, automaticity in a motor-based classroom task may free up attentional resources for learning complex concepts (Blair, Protzko, & Ursache, 2011; Cameron et al., 2015). Conversely, children lacking such automaticity may have to attend more carefully to the motor aspects of the task, placing a constraint on their learning.

It is possible that, depending on the skills in question or time in development, either reciprocity or automaticity applies. As children transition to formal school and move into more structured environments (La Paro, Rimm-Kaufman, & Pianta, 2006), they need to control their own bodies to accomplish behavioral and learning goals (Kim et al., 2015). Thus, using their motor skills to interact with the environment is a key means by which children come to understand the world and develop academically (e.g., Adolph, 2008). Therefore, the early elementary school years are an ideal time to investigate dynamic associations among specific skills.

Visuo-Motor Integration, Attention, Fine Motor Coordination, and Mathematics

In early childhood, children make great developmental strides in visuo-motor integration, attention, and fine motor coordination. This concurrent development suggests either co-developing, or perhaps even co-dependent, processes (Fuhs, Nesbitt, Farran, & Dong, 2014). These three processes are also a focus here because they are strong predictors of concurrent and long-term mathematics achievement, even after controlling for other predictors like demographic information and previous academic performance (e.g., Becker et al., 2014; Cameron et al., 2012; Carlson et al., 2013; Grissmer et al., 2010; Luo, Jose, Huntsinger, & Pigott, 2007).

Visuo-motor integration. Visuo-motor integration is a complex and multi-faceted construct that relies on both attention and fine motor coordination, as well as their integration, and as such, is critical to adjustment to multiple aspects of school performance including mathematics (e.g., Carlson et al., 2013). Visuo-motor integration skills are typically tested using design copying tasks, in which children are presented an object or image and attempt to replicate it using pencil and paper (Korkman et al., 1998). Design copying performance requires visual spatial processing, including the ability to see the object or image as a set of parts; flexibility in shifting attention back and forth between the parts of the object or image and the entire object or image as a whole; creating a mental representation of the object or image; as well as sequencing finger movements in recreating the object (Carlson et al., 2013).

Developmental course. As the name suggests, visuo-motor integration depends on visual and motor skills being in place before they can be integrated (Decker et al., 2011; Korkman et al., 1998). Age explains a large portion of visuo-motor integration, which develops rapidly between years 4-7 and more slowly through at least age 12 (Decker et al., 2011). Children use visuo-motor integration when working with manipulatives, writing, or drawing—activities that are prevalent in early elementary grades. Importantly, the “integration” component of visuo-motor integration may arise from attentional processes (Decker et al., 2011).

Relevance for mathematics. Visuo-motor integration is robustly linked to children’s concurrent and longitudinal mathematics achievement (e.g., Becker et al., 2014; Cameron et al., 2012; Carlson et al., 2013). In a cross-sectional sample of 5- to 18-year-olds, Carlson et al. (2013) found that visuo-motor integration was associated with mathematics achievement, even after controlling for gender, SES, fine motor coordination, and IQ. The strong association between visuo-motor integration and mathematics may arise because the components that are necessary for successful visuo-motor integration are also implicated in mathematics learning (Decker et al., 2011; Gunderson, Ramirez, Beilock, & Levine, 2012). For example, children need to discriminate between symbols (e.g., numbers and arithmetic signs) and copy math problems correctly, which involve some aspect of visuo-motor integration (i.e., visual, motor, spatial, and attentional processes). Understanding mathematics concepts also requires children to interact with physical objects (Ginsburg, 1977), form mental representations of objects and cognitively manipulate them (Hegarty & Kozhevnikov, 1999), spatially represent and interpret numerical information (Gunderson et al., 2012), and use adaptive strategies to solve problems (Geary & Burlingham-Dubree, 1989). Thus, having better visuo-motor integration may support development of certain mathematics skills.

In addition, neurobiological research indicates that the parietal cortex is an area of the brain that is particularly active during both visuo-motor integration tasks and numerical processing (Dehaene, 1992), such as when mentally representing numbers (Seron, Pesenti, Noel, Deloche, & Cornet, 1992). Relatedly, visuo-motor integration may contribute to the development of the mental number line (Gunderson et al., 2012) as well as in developing the understanding of part/whole relationships (Verdine et al., 2014), both of which are important for mathematics performance. When children are first learning how to count, they typically rely on their motor skills to physically touch each object. But, once this process becomes automated, they no longer have to touch the objects, and instead, are able to rely on mental spatial representations of the objects being counted (Assel et al., 2003).

Attention. Attention is a multi-dimensional construct considered part of executive functioning (EF)—a set of cognitive processes that help children coordinate their goal-directed responses to novel or complex situations (Garon, Bryson, & Smith, 2008). Attention comprises several sub-functions, such as selective focusing and sustaining of attention, regulation of arousal, and shifting or dividing attention (Ruff & Rothbart, 2001). Attentional processes are required to focus children's cognitive resources to execute goals, including complex learning tasks in the classroom (Zelazo et al., 2003). In the current study, attention refers to selective and sustained attention toward visual stimuli (Espy & Bull, 2005; Korkman et al., 1998).

Developmental course. The development of attention is a multi-stage process, in which different subfunctions develop at different times (Lehman, Naglieri, & Aquilino, 2009; Ruff & Rothbart, 2001). In general, the development of attention follows a roughly logarithmic trajectory, with rapid development between ages 4-7 (Carlson, 2005) and continued improvement through early adulthood (Beery & Beery, 2004). Longitudinal studies suggest that selective and sustained attention, as measured by the visual search task used herein, reach maturity as early as six years of age (Klenberg, Korkman, & Lahti-Nuuttila, 2001; Visu-Petra, Benga, & Miclea, 2007). Classroom activities constantly require children to use their attention, for instance, when shifting focus from one task to another, and also when sustaining attention for the length of a lesson to process and store information in the presence of distractions (Ruff & Rothbart, 2001).

Relevance for mathematics. Children's attentional abilities underlie development of mathematics skills (Geary, 2013), even after accounting for general intelligence (e.g., Blair & Razza, 2007). Mathematics tasks in early childhood typically require children to focus and shift their attention between distinct but closely related dimensions of objects, such as color and shape or between specific aspects of math problems (Blair, Knipe, & Gamson, 2008; Bull & Lee, 2014; Clements, Sarama, & Germeroth, 2016). The ability to control attention to hold information in mind while simultaneously engaging in other processes may be useful for coding mathematical rules, as well as interpreting and comparing information across multiple modalities, which facilitates efficient performance on math tasks (Geary, Hoard, Nugent, & Byrd-Craven, 2008; Kolkman, Kroesbergen, & Leseman, 2014; Zelazo et al., 2003). Moreover, explicit understanding of new mathematical concepts depends upon attentional resources carried out in the prefrontal cortex of the brain, which must develop in order to accommodate higher levels of abstraction (Geary, 2013; Rivera, Reiss, Eckert, & Menon, 2005).

As children mature and task performance becomes automated, activation in the prefrontal regions decreases (Rivera et al., 2005). In one study, attention contributed to 7- to 10-year-old children's mathematics above and beyond intelligence, fine motor coordination, and even visuo-motor integration, whereas the latter two did not contribute to mathematics after accounting for attention (Sortor & Kulp, 2003). But development in mathematics skills may also increase general executive processing (Watts et al., 2015; Welsh et al., 2010). For instance, Fuhs et al. (2014) found longitudinal bidirectional associations between EF and mathematics achievement in a sample of 4-year-olds. However, whereas EF continued to be a strong predictor of children's later mathematics gains at age 5, mathematics achievement was no longer a predictor of gains in EF (Fuhs et al., 2014). One reason for possible bi-directional associations between attentional processes and mathematics earlier in development may be because mathematics activities provide children with opportunities to exercise attentional processes, such as when shifting attention across elements of a problem while maintaining relevant mathematical rules in mind (Clements et al., 2016).

Fine motor coordination. Fine motor coordination encompasses muscle movements, including coordination and dexterity in the fingers, motor sequencing, and fine motor speed and accuracy (Cameron et al., 2015). Hence, though considered a motor rather than higher-order cognitive process here, fine motor coordination underlies child's overall level of cognitive and academic functioning (Decker, Englund, Carboni, & Brooks, 2011; Memisevic & Hadzic, 2013). As defined here and elsewhere, fine motor coordination refers to small muscle movements, but not the integration of these muscle movements with other input, such as visual-spatial information, from the environment (Carlson et al., 2013; Korkman et al., 1998).

Developmental course. Fine motor coordination develops rapidly early in childhood, following a roughly logarithmic trajectory, and continues to develop into early adulthood before declining in late adulthood (Beery & Beery, 2004). Fine motor coordination is an integral part of the school day in early childhood, with more than a third of the preschool day and more than 40% of the kindergarten day requiring fine motor skills (Marr, Cermak, Cohn, & Henderson, 2003). Children rely on fine motor coordination for a wide range of tasks, such as reaching for an object or tying their shoes (Memisevic & Hadzic, 2013), or holding and manipulating writing utensils.

Relevance for mathematics. Fine motor coordination is fundamental for interacting with and understanding the physical world, and in turn, developing mathematically-relevant skills, such as understanding concepts of shape, space, and numeracy (Newcombe & Frick, 2010). For instance, children with strong, compared to those with weak, fine motor coordination may be able to manipulate objects more efficiently, thereby increasing their understanding of spatial relationships and their ability to mentally represent objects (Luo et al., 2007). Thus, automaticity in basic coordination skills may provide an advantage in learning mathematics by allowing attentional resources to be directed toward learning higher-order concepts, rather than toward control of motor movements (LaBerge & Samuels, 1974).

Research suggests that rudimentary fine motor coordination may not directly contribute to mathematics skills, but rather may do so indirectly through other more complex skills, such as visuo-motor integration (Wassenberg et al., 2005). For instance, Sortor and Kulp (2003) found that fine motor coordination was no longer significantly related to mathematics after controlling for attention and visuo-motor integration in their sample of second through fourth graders. Similarly, fine motor coordination was not associated with mathematics achievement after controlling for visuo-motor integration in Carlson et al. (2013). Taken together, these studies suggest that, although fine motor coordination is important for providing immediate access to mathematical learning through interacting with the environment (Thomas, 2013), additional development beyond a certain skill level may not directly contribute to mathematics performance. Instead, fine motor coordination may be prerequisite for other higher-order cognitive processes, such as visuo-motor integration and attention, which are more directly important for mathematics.

Summary

Motor and cognitive development are dynamically interrelated from infancy through early childhood, with theory and evidence supporting notions of both reciprocal relations and dependency among motor and cognitive skills. Reciprocity does not necessarily continue indefinitely, nor does dependency in the form of automaticity in rudimentary skills supporting development of more complex skills. Visuo-motor integration, attention, and fine motor coordination are specific skills, which may share such complex relations with each other, as well as with mathematics skills, as they develop in early childhood. However, the dynamic relations among all of these constructs are not well understood.

Present Study

Using an auto-regressive cross-lag (ACL) approach, this study examined how visuo-motor integration, attention, and fine motor coordination were related to each other and to mathematics skills in a diverse sample of children across two years of early elementary school. We sought to address the following question: what are the longitudinal relations among visuo-motor integration, attention, fine motor coordination, and mathematics skills? While these analyses were exploratory, we did have some expectations, and these were shaped by the reciprocity and automaticity accounts of relations between motor and cognitive development. Generally speaking, more reciprocal effects were expected in early childhood than later on, given the gradual differentiation of cognitive processes and supporting brain structures over the course of development (Johnson, 2001). However, we also expected differences in relations to mathematics depending on the cognitive process in question.

For instance, we expected visuo-motor integration to significantly contribute to mathematics skills across all time points (Decker et al., 2011), and we expected these contributions to be stronger than those of fine motor coordination, but not necessarily those of attention (Carlson et al., 2013; Sortor & Kulp, 2003). Second, we expected a sustained contribution of attention to mathematics skills over time (Blair et al., 2008; Geary et al., 2008). Third, we expected that the direct contribution of fine motor coordination to mathematics skills might weaken over time. Further, we predicted fine motor coordination might eventually only indirectly contribute to mathematics skills through visuo-motor integration (i.e., mediation), as fine motor coordination becomes more automated with practice and maturation (Carlson et al., 2013). Finally, we expected bi-directional associations between mathematics, attention, and visuo-motor integration over time (Clements et al., 2016; Fuhs et al., 2014).

Method

The present study, which is observational by design, uses data from three experimental studies that tested the effects of an after-school fine motor skills intervention on young children's cognitive and academic skills. Over 3 years, children were recruited from eight schools across two different geographic sites (see descriptive statistics by site in Supporting Information, Tables 1 and 2). Children from the first site were recruited in Year One from one rural and four urban schools in a mid-Atlantic state; children from the second site were recruited in Years Two and Three from three urban schools in a southeastern state serving extremely low-income families. Following recruitment, all children then participated in the intervention (or control condition) for one year, and also had a follow-up assessment one year after the intervention period ended. Thus, the overall study period spanned four consecutive years, and each child's study participation spanned two consecutive school years.

Because the intervention was under development, the treatment groups' experiences differed significantly from one year to the next, in terms of activities, schedule, and dose. Of note, the intervention delivered to children recruited in Year 2 was the only intervention that produced significant effects on attention and visuo-motor integration, but not overall mathematics skills, for children in the treatment group (Grissmer et al., 2013). This means that only 17% (45 of 254) of children were assigned to a treatment condition in which the intervention had positive effects. Furthermore, we expected the intervention to generally improve children's motor and cognitive processes over a single school year—not to change how these processes related with each other and mathematics achievement over multiple years (the foci of the present study). Still, to control for the potential influence of exposure to the intervention on children's development of motor and cognitive processes and on mathematics skills, we included whether children received the intervention as a covariate in all analyses. Further, we performed sensitivity analyses to confirm our results were not driven by intervention status.

Participants

One hundred thirty-five kindergarten students were recruited to participate in the study, of which 46% were in the treatment group, 50% were in the control group, and 4% did not consent to randomization and, thus, were not randomized and did not receive treatment. One hundred nineteen first grade students were recruited, of which 52% were in the treatment group, 44% were in the control group, and 4% were not randomized and did not receive treatment. For ease of communication, we will henceforth refer to the children who began the study as kindergarteners as the "kindergarten cohort" and children who began as first graders as the "first grade cohort," even though each of these "cohorts" in reality comprises children from three separately recruited groups. All kindergarten (34% from site 1) and first grade (39% from site 1) students at both sites were eligible to participate, except those with severe disabilities that would prevent completion of the assessment battery.

Table 1 provides descriptive statistics for our sample by cohort. For the kindergarten cohort (50% male), children ranged in age from 5.0 to 6.8 years (*M* = 5.6 years, *SD* = 0.37) at the beginning of kindergarten. In the first grade cohort, children (54% male) ranged in age from 6.0 to 7.9 years (*M* = 6.7 years, *SD* = 0.43) at the beginning of first grade. Overall, families reported children's ethnicity and race as 71% African American or Black, 26% Caucasian or White, and 3% Other (Hispanic or Latino, Asian, or Multi-race). In both cohorts, most children (71%) were eligible for lunch subsidy and had attended preschool (84%).

Longitudinal Design and Procedure

Data for the current observational study were from three assessment time points across two school years, with the pretest assessments collected before the intervention at the beginning of the academic year and posttest assessments collected toward the end of the academic year. A second round of posttest assessments was collected approximately one year after the first posttest. Thus, data for the kindergarten cohort were collected during the first half of the kindergarten year (Time 1), at the end of kindergarten (Time 2), and at the end of first grade (Time 3); data for the first grade cohort were collected during the first half of the first grade year (Time 1), at the end of first grade (Time 2), and at the end of second grade (Time 3). See Figure 1 for the time points and corresponding grade levels for each cohort. Trained researchers individually administered assessments in a quiet area of the school or classroom. At each time point, assessments took place in two 45-60 minute sessions over two days.

Measures

The NEuroPSYchological assessment battery (NEPSY; Korkman et al., 1998) was used to measure children's motor and cognitive processes. The NEPSY is a comprehensive, reliable, direct neuropsychological assessment for children 3-12 years of age. The NEPSY comprises subtests organized into five functional domains, which have moderately high internal consistency, with coefficients ranging from .79-.90 depending on the age and domain (see Korkman et al. 1998 for more detailed psychometric information). For the present study, one subtest from each of three of the five domains (Visuospatial Processing, Attention/Executive Functions, Sensorimotor Functions)— *Design Copy, Visual Attention, and Visuomotor Precision*— were used to assess children's visuo-motor integration, attention, and fine motor coordination, respectively. Except where noted, study reliabilities, which we report for each measure, were similar to published reliabilities.

Visuo-motor integration. The *Design Copy* subtest falls under the Visuospatial Processing domain and requires integrating visuospatial and motor coordination skills. Children copied increasingly complex two-dimensional figures using pencil and paper. Each design was scored from 0-4 points, for a total of 72 possible points on 18 items. Test-retest reliability for the Design Copy subtest was r = .60 - .72 for the kindergarten cohort and r = .60 - .74 for the first grade cohort.

Attention. The *Visual Attention* subtest is part of the Attention/Executive Functions domain and assesses the speed and accuracy with which a child is able to focus selectively on and maintain attention to visual targets as they scan an array and locate a target. Children were asked to select a target picture (Trial 1) or pictures (Trial 2) out of a large array of similar pictures presented on a worksheet-style booklet. Accuracy scores were determined by subtracting the number of commission errors (number of non-target pictures marked) from the number of correctly identified target pictures. Time scores were calculated using the sum of time taken for both trials (maximum 180 seconds per trial). Final raw scores were based on both time and accuracy. For the current sample, test-retest reliability for the Visual Attention subscale was r = .40 - .57 for the kindergarten cohort and r = .59 - .72 for the first grade cohort.

Fine motor coordination. The *Visuomotor Precision* subtest is part of the Sensorimotor Functions domain and assesses speed and accuracy of eye-hand coordination. For each of two items, children were asked to draw a line inside a track within a time limit (180 seconds per item). The maximum time score is 360 seconds, and the maximum error (accuracy) score for ages 5-12 is 307. The total raw score considers both the speed and accuracy scores. The test-retest reliability in the current sample was r = .39 - .53 for the kindergarten cohort and r = .37 - .48 for the first grade cohort. These are lower than the published test-retest reliability for 5-6 year olds (r = .78), but higher than that for 7-8 year olds (r = .23; Korkman et al. 1998). It is noteworthy that time between tests for published reliabilities was between 2 and 10 weeks, whereas the time between tests for this study ranged from 4 months to a year, which may explain why reliability was somewhat lower than expected for younger children.

Mathematics skills. Children's mathematics skills were assessed using a composite of three subscales of the KeyMath-3 Diagnostic Assessment, a comprehensive and reliable assessment for children 4½-21 years of age (Connolly, 2008). *Numeration* measures children's number awareness and number sense (e.g., "add 3 dots to make 5"). *Geometry* measures children's ability to analyze two- and three-dimensional shapes, as well as their understanding of spatial relationships and reasoning (e.g., "point to shapes: circle, square"). *Measurement* measures children's ability to compare objects on a variety of attributes (e.g., "point to tallest & shortest plants"). The three subscales had high intercorrelations in our sample (r = .77-.91); therefore, in our analyses, we used the average of the three subscale scores as a composite score of children's mathematics skills at each of the three time points. For the current sample, composite score test-retest reliabilities were $r = .74 - .82$ for the kindergarten cohort and $r = .84 - .89$ for the first grade cohort.

Covariates. Covariates included child's age in years, gender (0 = female; 1 = male), study site (0 = Site 1; 1 = Site 2), lunch subsidy status (0= not eligible; 1 = eligible), and treatment group status (0 = control or non-randomized group; 1 = treatment group).

Analytic Approach

All analyses, including descriptive statistics, correlations, and auto-regressive cross-lag analyses, were conducted using Stata 14.1 (StataCorp., 2015).

Auto-regressive, cross-lagged models. An auto-regressive, cross-lagged (ACL) model was fit to the longitudinal data for each cohort. Based in a structural equation modeling (SEM) framework, the ACL model simultaneously tested multiple predictive associations among the three motor and cognitive processes and mathematics skills across three time points. Data collection for this study took place with relatively constant time-lag among participants for all variables within each cohort.

As previously stated, we expected the associations among the processes to change depending on the age of the child. Given the two age groups included in this study, we acknowledge that an accelerated longitudinal design would appear nicely suited to accommodate the aim of this paper (see Miyazaki & Raudenbush, 2000). Such a design would test a single model including the data from both cohorts; this initially appears possible, since both cohorts were tested at a common time point (i.e., Time 3 for kindergarteners and Time 2 for first graders, which both occurred at the end of first grade). However, this was the only time point shared between cohorts (see Figure 1), and experts argue that in an accelerated longitudinal design, at least two measurement occasions should overlap (Little, 2013). Further, a single model would have required modeling all non-shared time points (a majority) as latent variables, for which each would be missing data at a rate of about 50%. This inconsistency is an artifact of the design of the larger intervention study from which the data for the present study originate. Hence, the models for kindergarten and first grade cohorts were examined separately, but results are interpreted in terms of dynamic relations throughout the course of development from the beginning of kindergarten through the end of second grade.

In the ACL model, any path between any two variables across time points was estimated and unconstrained, and covariances between the residuals of each variable were allowed within each time point for all time points. The model was fully recursive in that paths directed only forward in time, and any variable assessed at an earlier point in time was used to predict all later variables. The fit of the model for each cohort was assessed using the following criteria: Tucker-Lewis index (TLI) and comparative fit index (CFI) greater than 0.95, the root-mean-square (RMSEA) less than or equal to 0.06 (Hu & Bentler, 1998).

To test potential hypothesized mediation effects, RMediation (Tofighi & MacKinnon, 2011) was used to conduct the empirical M-test (i.e. asymmetrical confidence interval). This method produces more accurate confidence limits compared to other methods that assume the product between two normally distributed variables is, itself, normally distributed (MacKinnon, Fritz, Williams, & Lockwood, 2007). The mediation effect is considered significant if the confidence interval does not include zero.

Missing data. Information on missing data is available in Table 1 with the greatest extent of missing data at the latest time points (Enders, 2010). Of the 254 participants, a total of 150 (59%; 78 kindergarteners and 72 first graders) had complete data across all study outcome variables at every time point. The design of the larger intervention study dictated that the third time point for approximately one third of the first grade cohort (22 participants; 9% of the entire sample) was not administered any of the cognitive measures at Time 3. Thus, study design explains about 25% of the missing data for Time 3; the rest of the missing data is due to participant attrition.

Attrition can lead to data that are not missing at random, which can bias parameter estimates, especially when traditional methods (e.g., listwise deletion) are used (Enders, 2010). Selectivity effects are of particular concern. Missing data analyses revealed more missing data for African American children and those eligible for free-reduced lunch. These differences were no longer significant after accounting for site, however, because demographic characteristics were significantly different across sites and a large portion of the missingness was explained by study design/site (as described above; see Supporting Information, Tables 1 and 2 for site-specific descriptives). Full Information Maximum Likelihood (FIML) estimation method was used to account for the missing data and to use all available information to obtain more efficient, less-biased estimates than deletion methods (Enders, 2010).

Results

Table 1 shows means, standard deviations, and ranges for kindergarten and first grade cohorts for all analytic variables. In general, performance improved on all four measures across the three time points for both kindergarten and first grade cohorts. Zero-order correlations among all variables were also examined and showed that across cohorts and time points, chronological age was positively related to all constructs (r = 0.09 to 0.46; see Supporting Information, Table 3). Thus, partial correlations controlling for differences in chronological age are presented in Table 2. Controlling for differences in chronological age did not substantially affect the overall pattern of associations among the variables, which rules out the possibility that age was an exclusive explanation for these zero-order correlations.

For both cohorts and at most time points, boys and children who qualified for free-reduced lunch had significantly lower scores on all constructs than girls and those not qualifying for free-reduced lunch, respectively. In addition, across grades and time points, all target constructs exhibited within-construct stability, and all correlations among these were positive. Correlations among visuo-motor integration, attention, and fine motor coordination at each time point were low to moderate in magnitude, suggesting both relatedness and distinctness among these constructs over time.

Developmental Associations among Motor and Cognitive Processes and Mathematics

Figures 2 and 3 present results for the model that tested the stability and transactional relations among visuo-motor integration, attention, fine motor coordination, and mathematics skills in the kindergarten and first grade cohorts, respectively. Covariates were age, gender, lunch subsidy status, site, and treatment condition. All fit statistics were well within the accepted ranges for indicating good fit for both cohorts (Hu & Bentler, 1998).

Summary of longitudinal associations. Consistent with expectations, we observed transactional relations among visuo-motor integration, attention, fine motor coordination, and mathematics skills in kindergarten, with the number of significant relations and strength of associations among the four constructs diminishing in first and second grades. Additionally, all four constructs showed stability over time, with positive and statistically significant autoregressive loadings between time points (βs = .35 to .63 in the kindergarten cohort; βs = .29 to .91 in the first grade cohort, ps < .05), with the exception of fine motor coordination between

Time 2 and Time 3 for the kindergarten cohort. Furthermore, as expected, contributions of visuo-motor integration, attention, and fine motor coordination to mathematics changed over time.

Visuo-motor integration. Visuo-motor integration and mathematics skills were positively and reciprocally related. Specifically, for the kindergarten cohort (Figure 2), the paths from visuo-motor integration to mathematics skills were consistently significant and positive ($\beta = 0.13$ from Time 1 to Time 2; $\beta = 0.14$ from Time 2 to Time 3, *p*s < .001), as were the paths from mathematics skills to visuo-motor integration ($\beta = 0.23$ and $\beta = 0.27$, respectively, *p*s < .05). This means that change over time in visuo-motor integration predicted change over time in mathematics skills; and vice versa. Similarly, for the first grade cohort (Figure 3), visuo-motor integration positively contributed to mathematics skills from Time 1 to Time 2 ($\beta = 0.21$, $p < .001$) and vice versa ($\beta = 0.26$, $p < .05$). However, this reciprocal relation diminished between Time 2 and Time 3, across which only visuo-motor integration contributed to mathematics skills ($\beta = 0.17$, $p < .01$), but not vice versa.

Attention. Attention contributed to mathematics skills across both time intervals for both the kindergarten cohort ($\beta = 0.13$ and $\beta = 0.10$, respectively, *p*s < .10) and the first grade cohort ($\beta = -0.15$ and $\beta = 0.13$, respectively, *p*s < .05). For the kindergarten cohort only, there was also a significant contribution of mathematics skills to attention ($\beta = 0.38$, $p < .001$) between Time 1 and Time 2, suggesting a reciprocal relation between these two constructs in the kindergarten year, which diminished thereafter.

The negative path loading from attention to mathematics skills from Time 1 to Time 2 in the first grade cohort was in the unexpected direction—despite strong positive correlations between attention and mathematics at those times points. A suppressor effect occurs when the direction of the beta weight changes when additional predictors are added (Burkholder &

Harlow, 2003). Suppression likely occurred here because of multicollinearity between attention, visuo-motor integration, and mathematics skills at Time 1, as well as mathematics skills at Time 2. Multicollinearity is particularly evident in the loading from mathematics skills at Time 1 to mathematics skills at Time 2 ($\beta = 0.91$, $p < .001$), which leaves very little variance in Time 2 mathematics skills to be explained by other constructs. This loading is much larger than any other loading observed in the model, and is about 50% larger than other loadings representing stability in mathematics skills in both cohorts. In a simple follow-up regression analysis in the first grade cohort, attention at Time 1 positively and significantly predicted mathematics skills at Time 2 ($\beta = .43$, $p < .001$). However, when mathematics skills at Time 1 was included in the regression, the association was still significant, but became negative ($\beta = -.12$, $p < .05$).

The coefficient in the kindergarten cohort from attention to mathematics skills over the most closely corresponding time interval (i.e., Time 2 to Time 3, end of kindergarten to the end of first grade) is positive. However, there was less collinearity among the constructs in the kindergarten cohort across this time interval compared to the first grade cohort, as just described, which may provide one explanation as to why multicollinearity affected the first grade coefficient, but not the kindergarten coefficient. Thus, we acknowledge that this multicollinearity warrants caution in any substantive interpretation of the loading from attention at Time 1 to mathematics at Time 2 for the first grade cohort. Nonetheless, given that the extent of multicollinearity between these constructs is much greater than for any other constructs and time intervals in the model and in both cohorts, we do not suspect that such caution is needed in the interpretation of other loadings in the model.

Fine motor coordination. For both cohorts, fine motor coordination did not directly predict mathematics skills at any of the time points, nor did it predict mathematics skills through contributions to other processes in first grade. For the kindergarten cohort only, however, fine motor coordination at Time 1 contributed significantly to visuo-motor integration at Time 2 (β = 0.18, $p < .01$), which was, in turn, significantly related to mathematics skills at Time 3 (β = 0.14, $p < .05$). In other words, fine motor coordination at the beginning of kindergarten indirectly contributed to mathematics skills at the end of first grade through its effect on visuo-motor integration at the end of kindergarten (CI^{95} = [0.001, 0.016], β = 0.025; SE = 0.016). The total effect, which includes both indirect and direct effects, of fine motor coordination at Time 1 on mathematics skills at Time 3 was β =0.05, and the direct mediated effect was β = -0.01. Thus, visuo-motor integration at Time 2 mediated 0.025/0.05 = 50% of the effect between fine motor coordination at Time 1 and math at Time 3.

Covariates. In general, effects of covariates on outcomes at Time 1, when significant, were in the expected direction, with children qualifying for free-reduced lunch (βs ranged from -.18 to -.35) and those from Site 2 (βs ranged from -.28 to -.55) having lower scores on most measures. Also, boys scored lower than girls in attention (β = -.16) and visuo-motor integration (β = -.20). Effects of covariates on outcomes at Time 2 were not significant except for gender on fine motor coordination (β = -.30, $p < .01$). Because Time 2 coincided with the end of the intervention, the lack of any significant effects of treatment condition at this time point is consistent with our presumption that the intervention did not significantly alter children's skills in the sample.

At Time 3, treatment condition was negatively related to fine motor coordination for both kindergarten and first grade cohorts (βs = -.22; -.25, $p < .05$, respectively); this is in the opposite direction from any reported treatment effects and on a measure which was not affected by the intervention (Grissmer et al., 2013). Yet, treatment condition was not significantly correlated with any of the variables included in the study (see Table 2). Moreover, in a simple follow-up regression analysis, treatment did not significantly predict fine motor coordination at Time 3 for either of the cohorts. Furthermore, lunch subsidy status was positively related to fine motor coordination among the first grade cohort ($\beta = .25$, $p < .05$); site was negatively related to fine motor coordination ($\beta = -.41$, $p < .01$) and attention ($\beta = -.31$, $p < .01$) in the first grade cohort. The positive relation between lunch subsidy status and fine motor coordination is in the unexpected direction, but may be due to a suppression effect of site, since children from site 2 were more likely to qualify for lunch subsidy status than site 2, and site was also controlled for in these analyses.

Sensitivity analyses. We were interested in whether our results were sensitive to participation in the three interventions, which differed by site, recruitment year, and impacts. Due to small sample size, we were unable to include a separate variable for each of the three interventions. However, we ran sensitivity analyses including site and treatment group (control versus treatment), as well as an interaction between Intervention at Year 2 and Treatment. These analyses were of particular interest given that the intervention in Year 2 was the only one that produced significant condition differences. Including the interaction term did not change the path coefficients in any way. For completeness, we also ran similar separate analyses including Intervention at Year 1 and Treatment and Intervention at Year 3 and Treatment, and these interaction terms did not change the results either. Thus, we are confident that our results are not dependent on or driven by children's participation in the interventions offered.

Our observation of cross-lagged relationships between attention and mathematics skills in the kindergarten year is in contrast with other studies suggesting such bi-directional relationships do not occur beyond the prekindergarten year (Fuhs et al., 2014). In order to determine whether this might be due to the relative disadvantage of our sample compared to Fuhs and colleagues (2014), we performed follow-up analyses testing the hypothesis that perhaps the cross-lag relations observed were due to the site 2 sample, which was more disadvantaged than the site 1 sample. In these analyses, we ran our kindergarten cohort model including an interaction effect between site and attention at Time 1 on mathematics skills at Time 2, as well as an interaction effect between site and mathematics skills at Time 1 on attention at Time 2. Results were mixed, such that the interaction terms did not significantly predict outcomes in these analyses, suggesting the loadings for these two sites did not significantly differ. However, the path from mathematics skills at Time 1 to attention at Time 2 was only statistically significant when site 2 was the reference group, which could either suggest that a larger sample from site 1 would also not have produced significant cross-lag relationships, or could simply be due to sample size.

Discussion

We examined dynamic relations among visuo-motor integration, attention, fine motor coordination, and mathematics skills in a diverse sample of kindergarten and first grade children across two academic years. Results showed differential and intricate links among these constructs over time. This study extends existing work by demonstrating a course of differentiation among these theoretically- and empirically-related skills, with more interrelations among processes observed in kindergarten than in first and second grades. This finding is consistent with theory suggesting that children's cognitive processes differentiate or "functionally specialize" as they develop (Johnson, 2001). In general, findings contribute to a growing literature linking early elementary children's motor and cognitive processes with their mathematics skills through specific pathways. Further, many of this study's findings are consistent with either the reciprocity and automaticity accounts of relations between motor and cognitive skills.

Visuo-motor Integration and Mathematics Skills Are Reciprocally Related

Even after controlling for attention and fine motor coordination, visuo-motor integration and mathematics skills exhibited ongoing reciprocity, with the exception of the time period between the end of first grade to the end of second grade for the first grade cohort. The perceptual, motor, and cognitive skills necessary for visuo-motor integration task performance contribute to basic learning skills associated with mathematics skills, including attending to and accurately perceiving numbers; visually discriminating similar symbols (e.g., "6" and "9") or diagrams presented on the board; visually maintaining one's place on the page or board; and integrating these abilities with fine motor coordination to form and reproduce the numbers accurately using paper and pencil (Sortor & Kulp, 2003).

In addition, visuo-motor integration and mathematics skills may be fostered through common activities. For instance, mathematics instruction in kindergarten often involves manipulating physical objects, and these hands-on instructional techniques appear to be particularly effective in kindergarten (Guarino, Dieterle, Bargagliotti, & Mason, 2013). At the same time, developments in mathematics skills may, in turn, support developments in visuo-motor integration, because these activities provide opportunities for children to practice integrating multiple processes. The fact that mathematics skills at Time 2 was no longer predictive of visuo-motor integration at Time 3 in the first grade cohort may be explained by the fact that visuo-motor integration is more useful for solving arithmetic problems, such as addition and subtraction (Rourke & Finlayson, 1978), but not in fact retrieval (Fletcher, 1985). Thus, our finding is reasonable as the mathematics skills measure emphasized numeration problems and mathematical concepts that, by the end of second grade, may involve more fact retrieval than in first grade or kindergarten.

Attention Consistently Contributes to Development in Mathematics Skills

Our study also demonstrated that development in attention over time contributes to increased mathematics skills across both kindergarten and first grade, even after controlling for visuo-motor integration and fine motor coordination. This pattern is consistent with several similar studies among 4- to 6-year-olds (Aunola, Leskinen, Lerkkanen, & Nurmi, 2004; Fuhs et al., 2014; Welsh, Nix, Blair, Bierman, & Nelson, 2010). More specifically, strong performance on the attention task in this study indicates that a child can inhibit distracting stimuli while simultaneously attending to task-relevant stimuli (Klenberg et al., 2001; Visu-Petra et al., 2007). These processes may be particularly relevant to mathematics learning in the early elementary years (Geary, 2013), which requires identifying and understanding the task goal, knowing where and when to attend for important information, sustaining attention to reach the goal, and carrying out a sequence of behaviors that will allow for efficient completion (Assel et al., 2003). For instance, compared to children who score low on the attention task, those who score higher on attention may be able to more quickly understand how to count objects (a rule-based process), which then allows more attentional resources to be devoted to learning complex skills, such as problem solving (Gersten & Chard, 1999). At the same time, poor counting skills may mean more counting errors, thereby strengthening the association between incorrect answers and the specific counting task, which may lead to difficulties in suppressing the retrieval of irrelevant associations (e.g., Aunola et al., 2004).

In the kindergarten year only, mathematics skills made unique, reciprocal contributions to the development of attention, which is consistent with our expectation that attention and mathematics skills might exhibit some degree of reciprocity, but perhaps not consistently over time. This likely indicates that attention is required for learning mathematics early in formal schooling but also that mathematics assessments are strong indicators of attention. This is in slight contrast to previous work finding bi-directional associations between mathematics skills and EF in the prekindergarten (4-year-old) year, but not in the kindergarten year (Fuhs et al., 2014). However, our sample was more disadvantaged overall, and it may be that experience is driving the transient reciprocity, rather than age. Indeed, our sensitivity analyses testing this hypothesis provided suggestive evidence that this may be the case. More advantaged children have key learning experiences earlier, which may provide them with skills that are at similar levels with older, less advantaged children; thus, our results may complement, rather than contradict, previous findings.

An alternative, but not mutually exclusive, explanation for our observation of a cross-lag relationship between attention and mathematics skills during kindergarten may be differences in how attention and mathematics skills were studied here compared to in Fuhs et al. (2014). Our study included a specific task tapping a specific aspect of attention and a composite score for mathematics skill measuring children's general mathematics skills (Connolly, 2008). It may be that a specific measure of attention may be more strongly linked to general mathematics skills in kindergarten than an aggregated measure of EF is to specific types of mathematics skills requiring complex thinking (i.e., problem solving); the latter of which were the focus of the study conducted by Fuhs and colleagues (2014).

Fine Motor Coordination Indirectly Relates to Mathematics Skills

For the kindergarten cohort, children's fine motor coordination and their mathematics skills were indirectly linked through visuo-motor integration over the course of the kindergarten year. This complements previous studies (e.g., Carlson et al., 2013; Grissmer et al., 2010) and other work highlighting that basic motor functions precede the development of more complex functions, which in turn, affect academic outcomes (Klenberg et al., 2001; Lehman et al., 2009; Wassenberg et al., 2005). In early childhood, having strong fine motor coordination may facilitate interaction with the environment and support development of higher-order cognitive processes, including visuo-motor integration (Campos et al., 2000). Once fine motor coordination is mastered and requires less attention, it is no longer strongly correlated with these other cognitive processes (Ackerman, 1988). Thus, these results are consistent with the automaticity account of the link between fine motor coordination to mathematics skills. However, they may also be consistent with the notion of a potential constrained effect (Paris, 2005); in other words, developing fine motor coordination beyond a certain threshold may not meaningfully contribute to more complex tasks or skills, such as mathematical learning.

Limitations

Several limitations are worth noting. First, despite inclusion of covariates to control for potential confounding factors (Selig & Little, 2011), results do not warrant causal claims and are better considered as a "stepping stone" in building an argument for a causal effect of these specific processes on mathematics skills and learning. Second, due to the data collection schedule, we could not investigate the longitudinal relations between variables from kindergarten through second grade in a single, parsimonious model. This resulted in some idiosyncratic differences between the two cohorts over time intervals, which seem to correspond (i.e., Time 2 to Time 3 for the kindergarten cohort and Time 1 and Time 2 for the first grade cohort). For example, we observe a strong relation between Time 2 fine motor coordination and Time 3 mathematics skills for the kindergarten cohort, but no such relation from Time 1 fine motor coordination to Time 2 mathematics skills. This and other differences could be due to the fact that the measurement of skills occurred at different times in development, the fact that there were different time lags between these two time points between cohorts, and/or even the fact that more constructs were being controlled for at Time 3 in kindergarten (i.e., all Time 1 *and* Time 2 constructs) than at Time 2 in first grade. In other words, such differences are idiosyncrasies possibly arising from the larger study design that should be addressed by future studies.

Third and relatedly, the more numerous occurrences of cross-lagged effects and stronger associations between processes in kindergarten, compared to the later grades, could simply reflect differences in time intervals between time points, rather than differentiation of skills, as we have suggested. In both cohorts, the time interval between Time 1 and Time 2 was about half the duration of that between Time 2 and Time 3, which could contribute to differences in the cross-lagged contributions of these constructs over time (Gollab & Reichardt, 1987). Nevertheless, our findings have strong theoretical support (e.g., Johnson, 2001), and we observed no cross-lag contributions in the first grade cohort between Time 1 and Time 2. Given that, the reduction in the number of cross-lagged contributions as children progress in early elementary school is likely due to more than just assessment timing.

Fourth, the stability of constructs across time points, as well as the interrelations among constructs, raises the issue of multicollinearity and a suppressor effect (Burkholder & Harlow, 2003), which may explain, for example, the absent autoregressive effect from Time 2 and Time 3 in fine motor coordination in the kindergarten cohort, as well as the negative association between attention and mathematics skills from Time 1 to Time 2 in the first grade cohort (Schroeder, Sjoquist, & Stephan, 1986). Fifth and finally, although well-established measures were used to assess children's motor and cognitive processes, only a single subtest was used as a measure of each of the constructs, and reliability varied for the measures in our sample. Reliability—in terms of test-retest correlation—was particularly low for the fine motor coordination and attention measures. This may indicate dynamic changes in these skills over the test periods, where children change dramatically disrupting relative individual differences among children. Low reliability would, however, attenuate rather than enhance the likelihood of finding significant associations, as well as the strength of associations. Still, it may be that variance in children's motor and cognitive abilities is related to other skills known to contribute to mathematics skills, but not measured here. Thus, future studies should include several measures of each skill to more fully capture the constructs, as well as of other cognitive processes that have been linked to mathematics skills, such as visuospatial working memory (e.g., Li & Geary, 2013) and EF (e.g., Blair et al., 2008).

Implications and Future Directions

The fact that cross-domain prediction of constructs was obtained, over and above the strong within-construct stabilities, lends support to the notion that these processes do not develop in isolation but are, in fact, interrelated and interdependent (Diamond, 2007). The development and integration of these skills is necessary to successfully complete classroom-related tasks and make academic gains (Cameron et al., 2015). Understanding complex interrelations among hierarchically related skills may help practitioners inform and sequence instructional priorities, especially for children struggling with complex skills like mathematics, which appear reliant upon skills like visuo-motor integration, which may in turn depend on fine motor coordination. Given that universal preschool programs appear just beyond the horizon in the United States, this research, and similar future studies with a young age group, could inform forthcoming policies governing curricular priorities, and more specifically, whether fine motor development is a worthwhile investment in early childhood.

The contribution of mathematics skills to visuo-motor integration over time raises a challenging question: Could academic or mathematical development transfer to general development in visuo-motor function? Certainly, many educational theorists would find this idea attractive, given that supporting child development in general has been considered by many to be part of education's purview (e.g., Montessori, Jr., 1976). Previous research suggests that improving children's mathematics skills through a promising age-appropriate mathematics intervention better prepares children for all school tasks (Sarama & Clements, 2004). However, to our knowledge, contributions of academic development to motor and cognitive development are largely unexplored, and yet, may have implications for the development of cognitive abilities throughout the lifespan. Taken together, the results of our study emphasize the complexity of the construct of mathematics skills and the need for continued efforts to understand its developmental underpinnings.

Conclusion

The present study offers novel empirical evidence on the reciprocal associations between visuo-motor integration, attention, fine motor coordination, and mathematics skills in the first years of formal schooling. Examining these associations over three time points in early childhood allowed us to describe the independent components that combine and coordinate to form the skills that are, in part, necessary for school success (Cameron et al., 2012; Duncan et al., 2007). In doing so, we recognize that not all motor or cognitive skills should be regarded as the same, conceptually, methodologically, or developmentally; yet, there is a codependency among skills that warrants consideration (Paris, 2005). In an age of accountability when direct instruction is often replacing more tactile- or sensorial-based learning activities in early grades (Bassok, Latham, & Rorem, 2016), understanding the role of motor and cognitive skills in supporting academic development is critical. Findings should motivate scholars, and any professionals working with children, to examine in greater depth the array of motor and cognitive skills that contribute to academic skills, including in mathematics.

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Table 1.

Descriptive Statistics by Grade

	Child Age (years)	Fine Motor Coordination			Attention			Visuo-motor Integration			Mathematics Skills		
		Time 1	Time 2	Time 3	Time 1	Time 2	Time 3	Time 1	Time 2	Time 3	Time 1	Time 2	Time 3
Kindergarten													
n	134	130	127	91	126	124	90	133	128	91	135	129	91
%													
% Missing	1%	4%	6%	33%	7%	8%	33%	1%	5%	33%	0%	4%	33%
M	5.61	10.83	15	19.96	8.23	10.31	14.13	33.84	39.5	44.36	14.44	20.72	28.38
SD	0.37	6.2	7.56	8.41	4.34	4.75	5.5	8.97	7.76	7.53	7.58	8.17	10.01
Min.	4.97	1	1	3	1	1	3	5	18	25	1	2	7
Max.	6.84	32	34	36	18	21	30	63	61	61	49	44	51
1st grade													
n	119	116	112	75	114	112	75	116	112	75	119	112	94
%													
% Missing	0%	3%	6%	37%	4%	6%	37%	3%	6%	37%	0%	6%	21%
M	6.7	16.26	20.49	22.71	10.52	14.65	16.95	41.18	45.13	48.87	23.17	32.65	40.59
SD	0.43	7.14	7.66	8.23	4.8	5.21	6.13	7.76	7.32	7.01	10.46	11.4	12.47
Min.	6	2	3	3	1	5	4	22	30	33	4	12	13
Max.	7.89	32	40	38	26	29	34	56	69	65	53	64	72

Note. Time 1 = Beginning of Kindergarten (kindergarten cohort) or 1st grade (first grade cohort); Time 2= End of kindergarten (Kindergarten cohort) or 1st grade (First grade cohort); Time 3 =End of 1st grade (Kindergarten cohort) or 2nd grade (First grade cohort)

Table 2.

Partial Correlations Controlling for Chronological Age for All Variables included in the Analyses for Kindergarteners (n =135; bottom half of table) and First Graders (n=119; top half)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Gender	-	.034	.018	-.064	-.103	-0.330**	-.158	-.049	-.006	-.101	-.145	-0.192*	.056	-.081	-.065	.000
2. FORL	.099	-	.026	0.547**	-0.261**	-0.261**	-.103	-.179	-0.192*	-0.241*	-0.271**	-0.235*	-0.245*	-0.475**	-0.401**	-0.309**
3. Treatment	.087	.001	-	.068	.033	-.051	-.094	.109	.098	.081	.093	.054	-.003	-.045	-.069	.066
4. Site	.019	0.783**	.046	-	-.099	-.168	-0.321**	-0.364**	-0.380**	-0.506**	-0.268**	-0.250**	-0.480**	-0.622**	-0.532**	-0.530**
5. FMC T1	-0.185*	-0.302**	-.021	-0.301**	-	0.370**	0.361**	0.192*	0.220*	.205	0.311**	0.264**	.186	0.236*	0.230*	0.208*
6. FMC T2	-0.226*	-0.311**	.073	-0.305**	0.530**	-	0.480**	.173	0.264**	0.231*	0.230*	0.365**	.131	.176	.145	.035
7. FMC T3	-.161	-.193	-.160	-.180	0.490**	0.392**	-	0.315**	0.279*	0.318**	0.262*	0.257*	0.294*	0.237*	.157	.151
8. Attention T1	-.155	-.145	-0.196*	-0.256*	.129	.126	.051	-	0.516**	0.515**	0.409**	0.286**	0.316**	0.475**	0.358**	0.377**
9. Attention T2	-.078	-0.265**	-.023	-0.205**	.124	0.212*	.116	0.365**	-	0.658**	0.359**	0.343**	0.364**	0.398**	0.338**	0.474**
10. Attention T3	-.115	-0.404**	.114	-0.465**	.148	0.340**	.115	0.369**	0.535**	-	0.400**	0.419**	0.392**	0.497**	0.412**	0.491**
11. VMI T1	-0.222*	-0.294**	-.037	-0.373**	0.377**	0.471**	0.313**	.146	0.343**	0.342**	-	0.717**	0.591**	0.567**	0.612**	0.580**
12. VMI T2	-.145	-0.321**	.031	-0.322**	0.434**	0.471**	0.479**	.148	0.327**	0.378**	0.688**	-	0.675**	0.529**	0.588**	0.579**
13. VMI T3	-0.308**	-0.306**	.106	-0.276**	0.360**	0.396**	0.403**	0.256*	0.408**	0.374**	0.576**	0.706**	-	0.541**	0.561**	0.669**
14. Math T1	-.080	-0.574**	.008	-0.552**	0.250**	0.382**	.175	.145	0.413**	0.492**	0.533**	0.511**	0.417**	-	0.891**	0.834**
15. Math T2	-.068	-0.558**	-.030	-0.589**	0.314**	0.383**	0.210*	0.261**	0.375**	0.423**	0.514**	0.519**	0.525**	0.796**	-	0.871**
16. Math T3	-.212	-0.571**	.097	-0.540**	.202	0.306*	.137	0.299*	0.445**	0.536**	0.575**	0.531**	0.448**	0.727**	0.801**	-

Note. Gender (male =1); FORL = Lunch subsidy status (yes =1); Treatment = treatment condition (0=control; 1=treatment); FMC = Fine motor coordination; VMI = Visuo-motor integration; Math = Mathematics Skills; T1 (Time 1)= Beginning of Kindergarten (kindergarten cohort) or 1st grade (first grade cohort); T2 (Time 2)= End of kindergarten (Kindergarten cohort) or 1st grade (First grade cohort); T3 (Time 3) =End of 1st grade (Kindergarten cohort) or 2nd grade (First grade cohort).
$^{*}p < .05$, $^{**}p < .01$

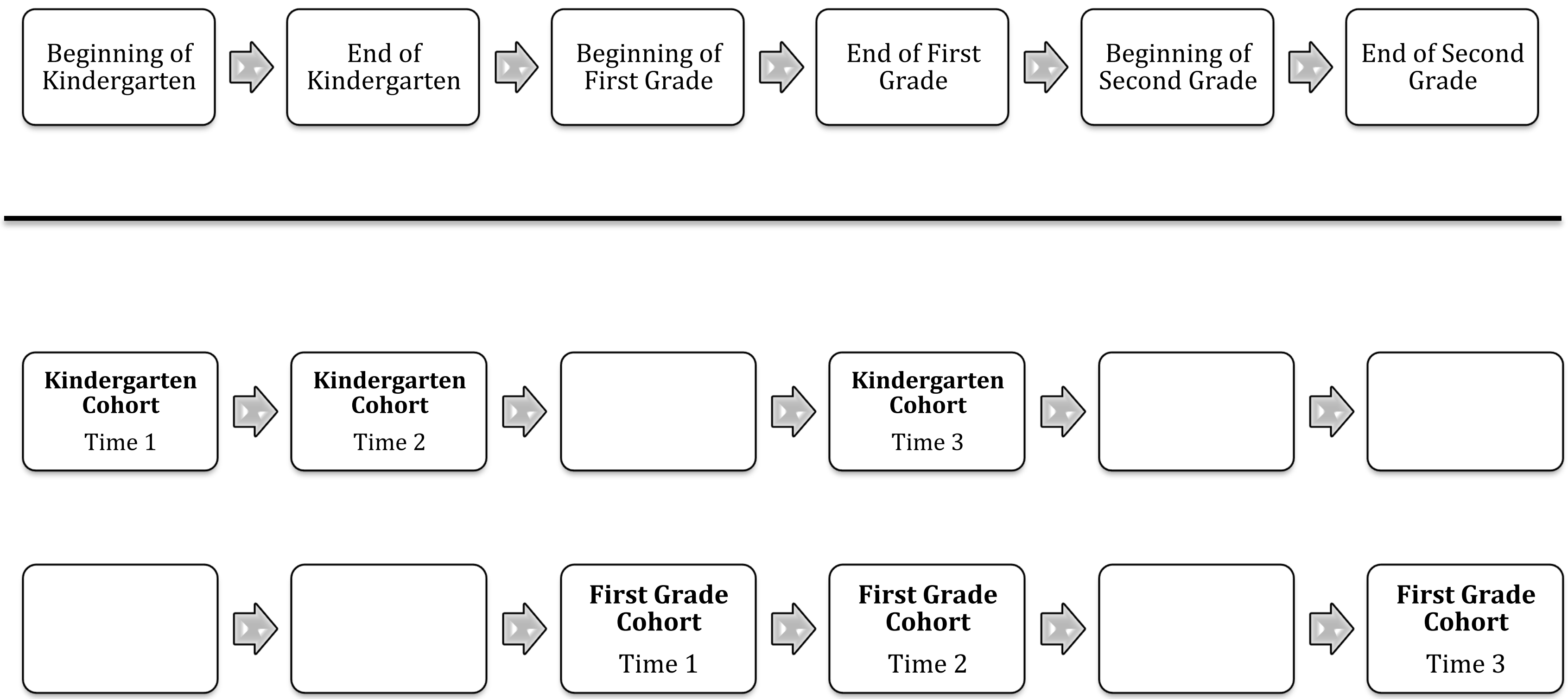

Figure 1. Data collection timeline for the kindergarten and first grade cohorts. The kindergarten cohort data were collected ta the beginning of kindergarten (Time 1), end of kindergarten (Time 2), and end of first grade (Time 3). The first grade cohort data were collected at the beginning of first grade (Time 1), end of first grade (Time 2), and end of second grade (Time 3). Due to these data collection constraints, with only one time point overlapping (end of first grade) between the two cohorts, cross-lagged models were run separately for the kindergarten and first grade cohorts.

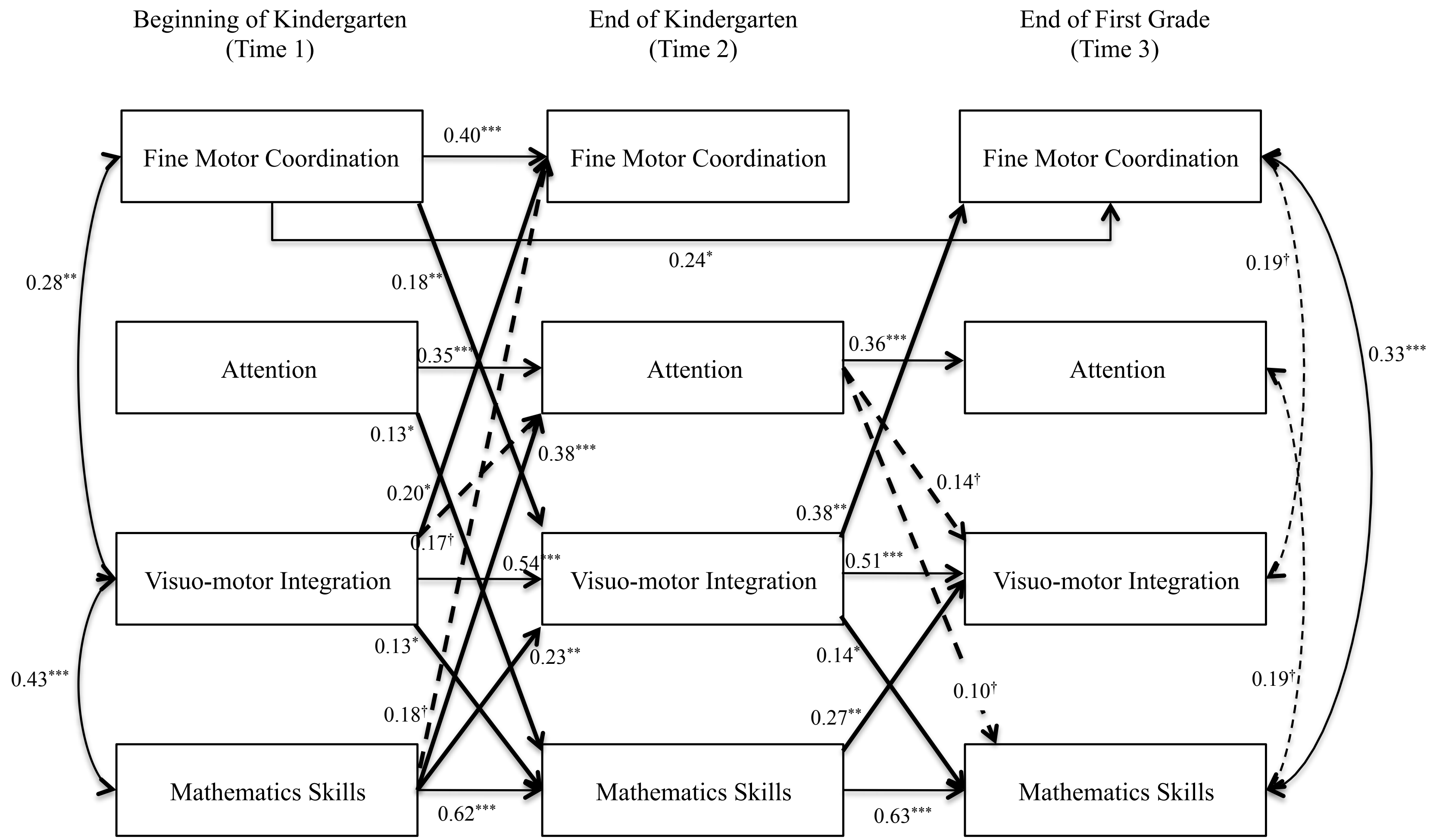

Figure 2. Autoregressive, cross-lag model depicting longitudinal, reciprocal relations between three cognitive processes (visuo-motor integration, attention, and fine motor coordination) and mathematics skills across two school years from beginning of kindergarten (Time 1) to end of kindergarten (Time 2) and end of first grade (Time 3), controlling for child's age, gender, lunch subsidy status, site, and treatment condition (full model; covariates not shown). All possible paths were included in the model. This model fit the data well, $\chi^2_{(12)} = 10.07$, $p = .61$, $N = 135$; comparative fit index (CFI) = 1.00; root mean square error of approximation (RMSEA) = 0.00; TLI = 1.025. Solid lines represent significant relations, dashed lines represent marginally-significant relations ($p < .10$), and nonsignificant relations are not shown. Bold lines represent significant cross-lag paths. $^{\dagger}p < .10$, $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

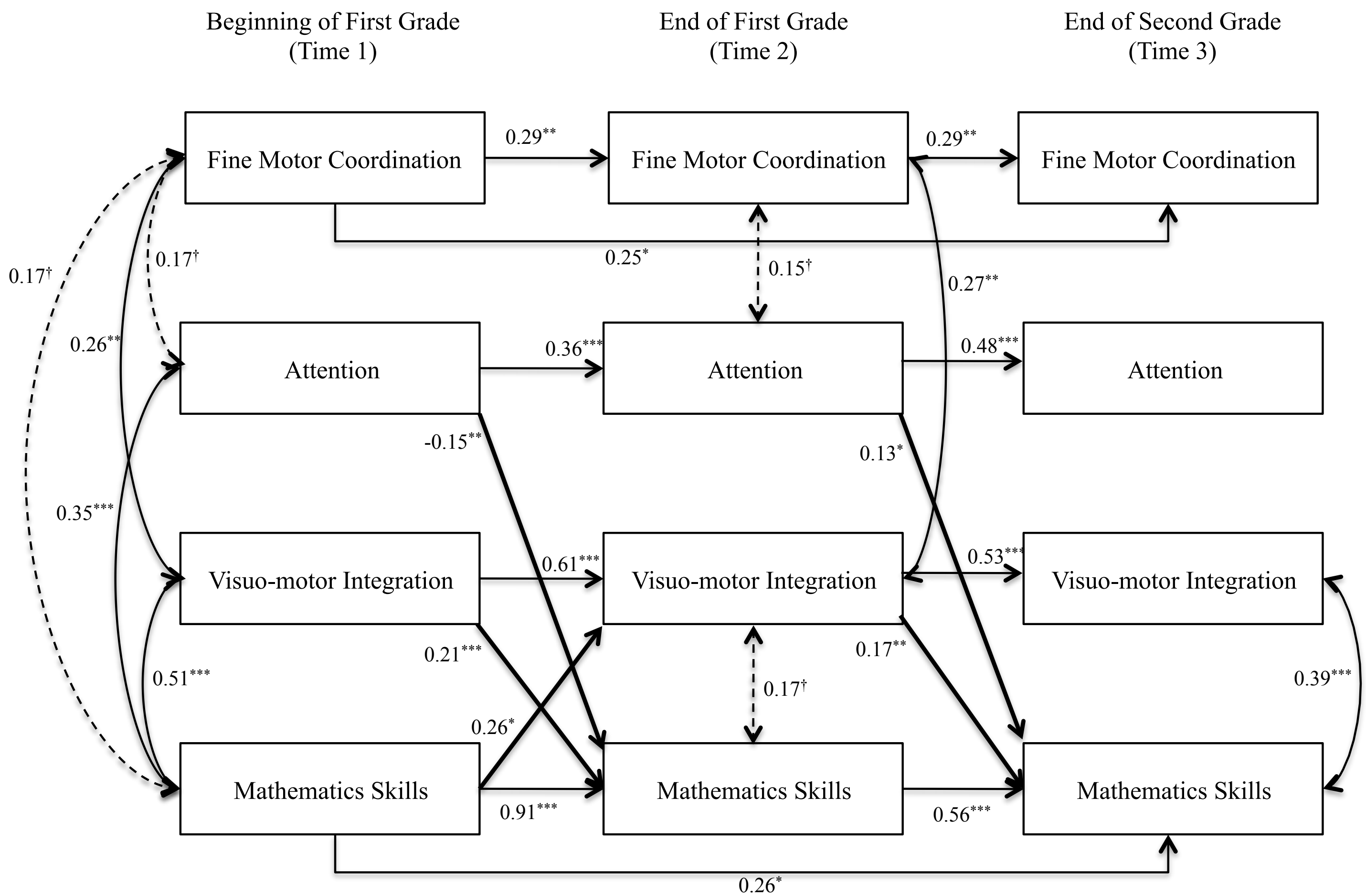

Figure 3. Autoregressive, cross-lag model depicting longitudinal, reciprocal relations between three cognitive processes (visuo-motor integration, attention, and fine motor coordination) and mathematics skills across two school years from beginning of first grade (Time 1) to end of first grade (Time 2) and end of second grade (Time 3), controlling for child's age, gender, lunch subsidy status, site, and treatment condition (full model; covariates not shown). All possible paths were included in the model. This model fit the data well, $\chi^2_{(12)} = 8.02$, $p = .78$, $N = 119$; comparative fit index (CFI) = 1.00; root mean square error of approximation (RMSEA) = 0.00; TLI = 1.046. Solid lines represent significant relations, dashed lines represent marginally-significant relations ($p < .10$), and nonsignificant relations are not shown. Bold lines represent significant cross-lag paths. $^{\dagger}p < .10$, $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Appendix A: Supporting Information

Table 1.

Descriptives Statistics by Grade for Site 1

	Child Age (years)	Child Gender		Lunch Subsidy Status		Treatment Condition		Fine Motor Coordination			Attention			Visuo-motor Integration			Mathematics Skills		
		M	F	Yes	No	T	C	Time 1	Time 2	Time 3	Time 1	Time 2	Time 3	Time 1	Time 2	Time 3	Time 1	Time 2	Time 3
Kindergarten																			
n	46	23	23	8	34	24	22	43	43	35	44	44	35	45	44	35	46	44	35
%		50%	50%	19%	81%	48%	52%												
% Missing	0%	0%		9%		0%		7%	7%	24%	4%	4%	24%	2%	4%	24%	0%	4%	24%
M	5.83							13.86	18.35	22.6	10.09	12.14	17.8	39.31	43.52	47.54	20.93	27.95	36.11
SD	0.37							6.26	8.17	8.02	3.51	5.1	4.09	8.95	8.14	7.35	7.59	7.66	6.94
Min.	5.28							2	3	4	2	1	10	15	31	30	8	6	21
Max.	6.84							29	34	36	18	21	30	63	61	58	49	44	51
1st grade																			
n	46	29	17	15	28	25	21	46	44	41	44	44	41	46	44	41	46	44	41
%		63%	37%	35%	65%	54%	46%												
% Missing	0%	0%		7%		0%		0%	4%	11%	4%	4%	11%	0%	4%	11%	0%	4%	11%
M	6.99							17.67	22.3	25.51	13.5	17.98	20.32	44.72	48.18	51.83	32.52	41	48.71
SD	0.36							7.05	8.61	7.62	4.93	4.97	5.36	7.85	7.88	6.42	9	11.18	10.73
Min.	6.39							3	3	8	2	5	9	22	30	36	14	15	30
Max.	7.89							32	40	38	26	29	34	56	69	65	53	64	72

Note. Gender: M = Male, F = Female; Treatment Condition: T = Treatment, C = Control; Time 1 = Beginning of Kindergarten (kindergarten cohort) or 1st grade (first grade cohort); Time 2= End of kindergarten (Kindergarten cohort) or 1st grade (First grade cohort); Time 3 =End of 1st grade (Kindergarten cohort) or 2nd grade (First grade cohort)

Table 2.

Descriptives by Grade for Site 2

	Child Age (years)	Child Gender		Lunch Subsidy Status		Treatment Condition		Fine Motor Coordination			Attention			Visuo-motor Integration			Mathematics Skills		
		M	F	Yes	No	T	C	Time 1	Time 2	Time 3	Time 1	Time 2	Time 3	Time 1	Time 2	Time 3	Time 1	Time 2	Time 3
Kindergarten																			
n	88	45	44	81	3	41	48	87	84	56	82	80	55	88	84	56	89	85	56
%		51%	49%	96%	4%	46%	54%												
% Missing	1%	0%		6%		0%		2%	6%	37%	8%	10%	38%	1%	6%	37%	0%	4%	37%
M	5.5							9.33	13.29	18.3	7.23	9.31	11.8	31.05	37.39	42.38	11.22	16.98	23.55
SD	0.32							5.63	6.65	8.29	4.43	4.26	5.01	7.62	6.68	7	4.94	5.48	8.5
Min.	4.97							1	1	3	1	2	3	5	18	25	1	2	7
Max.	6.31							32	29	36	18	20	24	47	55	61	21	30	49
1st grade																			
n	73	35	38	66	5	37	36	70	68	34	70	68	34	70	68	34	73	68	53
%		48%	52%	93%	7%	51%	49%												
% Missing	0%	0%		3%		0%		4%	7%	53%	4%	7%	53%	4%	7%	53%	0%	7%	27%
M	6.52							15.33	19.32	19.32	8.64	12.5	12.88	38.86	43.16	45.29	17.27	27.25	34.3
SD	0.36							7.1	6.78	7.76	3.65	4.15	4.27	6.82	6.24	6.01	6.13	7.72	9.86
Min.	6							2	7	3	1	5	4	25	30	33	4	12	13
Max.	7.62							30	32	36	18	24	19	56	63	58	32	54	65

Note. Gender: M = Male, F = Female; Treatment Condition: T = Treatment, C = Control; Time 1 = Beginning of Kindergarten (kindergarten cohort) or 1st grade (first grade cohort); Time 2= End of kindergarten (Kindergarten cohort) or 1st grade (First grade cohort); Time 3 =End of 1st grade (Kindergarten cohort) or 2nd grade (First grade cohort)

Table 3.

Zero-order Correlations for All Variables included in the Analyses for Kindergarteners (n =135; bottom half of table) and First Graders (n=119; top half)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. Child age in years	-	.173	-.350**	-.054	-.544**	.146	.092	.208	.395**	.415**	.403**	.286**	.244**	.124	.458**	.307**	.272**
2. Gender (male = 1)	.028	-	-.030	.008	-.147	-.075	-.308**	-.117	.024	.066	-.021	-.088	-.141	.076	.008	-.008	.047
3. Lunch Subsidy Status	-.286**	.087	-	.043	.621**	-.293**	-.276**	-.167	-.293**	-.309**	-.348**	-.343**	-.299**	-.271*	-.556**	-.465**	-.374**
4. Treatment Condition	-.088	.084	.026	-	.086	.025	-.056	-.103	.079	.067	.052	.074	.039	-.010	-.064	-.082	.049
5. Site	-.421**	.005	.801**	.079	-	-.161	-.190*	-.377**	-.495**	-.515**	-.608**	-.371**	-.336**	-.467**	-.713**	-.592**	-.576**
6. Fine Motor Coordination (Time 1)	.181*	-.177*	-.336**	-.037	-.345**	-	.378**	.380**	.232*	.259**	.244*	.336**	.289**	.201	.275**	.261**	.238*
7. Fine Motor Coordination (Time 2)	.103	-.222*	-.326**	.063	-.318**	.537**	-	.487**	.194*	.277**	.248*	.245**	.375**	.141	.198*	.166	.058
8. Fine Motor Coordination (Time 3)	.215*	-.151	-.242*	-.175	-.250*	.509**	.403**	-	.365**	.335**	.368**	.305**	.295*	.311**	.301**	.210	.199
9. Attention (Time 1)	.210*	-.146	-.196*	-.209*	-.315**	.162	.144	.094	-	.595**	.592**	.473**	.351**	.337**	.569**	.434**	.441**
10. Attention (Time 2)	.251**	-.069	-.317**	-.044	-.286**	.164	.230*	.163	.398**	-	.715**	.432**	.404**	.380**	.512**	.420**	.527**
11. Attention (Time 3)	.322**	-.100	-.459**	.079	-.535**	.196	.354**	.175	.409**	.572**	-	.466**	.471**	.406**	.589**	.483**	.542**
12. Visuo-motor Integration (Time 1)	.266**	-.206*	-.348**	-.059	-.438**	.406**	.479**	.352**	.193*	.386**	.397**	-	.736**	.597**	.614**	.646**	.612**
13. Visuo-motor Integration (Time 2)	.219*	-.136	-.362**	.011	-.377**	.456**	.480**	.503**	.187*	.363**	.420**	.706**	-	.680**	.568**	.617**	.607**
14. Visuo-motor Integration (Time 3)	.217*	-.294**	-.349**	.083	-.336**	.385**	.407**	.431**	.290**	.440**	.416**	.600**	.720**	-	.534**	.568**	.672**
15. Mathematics Skills (Time 1)	.339**	-.066	-.614**	-.022	-.613**	.293**	.392**	.234*	.205*	.461**	.548**	.573**	.544**	.456**	-	.895**	.838**
16. Mathematics Skills (Time 2)	.316**	-.056	-.598**	-.057	-.640**	.351**	.394**	.263*	.308**	.424**	.482**	.554**	.550**	.555**	.818**	-	.881**
17. Mathematics Skills (Time 3)	.208	-.201	-.594**	.076	-.566**	.232	.319*	.176	.329*	.474**	.563**	.597**	.552**	.473**	.739**	.809**	-

Notes. Child age in years; Gender (male =1); Lunch subsidy status (yes =1); Treatment = treatment condition (0=control; 1=treatment); Site (0 = Site 1; 1 = Site 2); Time 1 = Beginning of Kindergarten (kindergarten cohort) or 1st grade (first grade cohort); Time 2= End of kindergarten (Kindergarten cohort) or 1st grade (First grade cohort); Time 3 =End of 1st grade (Kindergarten cohort) or 2nd grade (First grade cohort); * $p < .05$, ** $p < .01$

Patterns of Behavioral Self-Regulation in Low-Income Kindergarten Children:

Integrating Variable- and Person-Centered Approaches

Helyn Kim

University of Virginia

Abstract

This study investigated the extent to which behavioral self-regulation predicts academic and student-teacher relationship outcomes in a sample of 251 kindergarteners from high-risk backgrounds. In addition to examining these associations from a traditional approach using a summed score of behavioral self-regulation, a person-centered approach was incorporated to identify profiles of children's behavioral self-regulation based on their item responses on a behavioral self-regulation task. Profile membership was then used to predict outcomes. In general, results reinforced the notion that behavioral self-regulation is important for school functioning. Moreover, based on person-centered analysis, there were four distinct profiles of children's response patterns, which were differentially related to outcomes. Integrating both traditional and person-centered approaches to examine children's behavioral self-regulation can offer complementary perspectives and add nuance to our understanding of the important role that behavioral self-regulation plays in school functioning. Implications of these findings are discussed.

Patterns of Behavioral Self-Regulation in Low-Income Kindergarten Children: Integrating Variable- and Person-Centered Approaches

It is well-established that poverty has adverse effects on numerous aspects of development in young children (Duncan & Murnane, 2011; Noble, McCandliss, & Farah, 2007). Growing evidence indicates that supporting children's early self-regulation is a promising means of promoting school adjustment in high-risk populations (e.g., Raver, 2012; Sektnan, McClelland, Acock, & Morrison, 2010; Ursache, Blair, & Raver, 2012). Specifically, *behavioral* self-regulation, which involves integrating executive functions (EF; i.e., working memory, inhibitory control, and attentional flexibility) to produce contextually-appropriate behaviors, is a robust predictor of a wide range of school-related outcomes (Cameron Ponitz, McClelland, Matthews, & Morrison, 2009; Eisenberg, Valiente, & Eggum, 2010; McClelland et al., 2014). In the classroom, children appropriately regulate their behavior when they switch attention from one task to another, remember and follow classroom rules, complete classroom activities, and inhibit inappropriate actions (McClelland, Cameron Ponitz, Messersmith, & Tominey, 2010).

The majority of research concerning behavioral self-regulation and its relations to school adjustment has been obtained from a variable-centered perspective. Relatively recent advances in statistical methods, specifically person-centered approaches, offer the opportunity to complement and extend traditional variable-centered research (Lanza & Cooper, 2016). Whereas a variable-centered approach allows us to order students along a continuum based on a total score, the person-centered approach can unpack that score further. Experts acknowledge that children are not uniform in how they exhibit behavioral self-regulation (McClelland & Cameron, 2012). Specifically, children who are the same age or grade may be at various stages of development, and this may be reflected not only in the total score but also in their patterns of response on an assessment. This study investigates the extent to which behavioral self-regulation predicts academic and relational outcomes in a sample of kindergarteners from high-risk backgrounds. In addition to examining these associations from a traditional, variable-centered approach, I introduce a person-centered approach as a method for identifying profiles of children's behavioral self-regulation and use profile membership to predict their achievement and student-teacher relationship quality. Integrating these techniques to capitalize on the unique strengths of each method may provide a more complete view of the important role that behavioral self-regulation plays in school functioning and identify specific groups of children who need targeted support (Magnusson, 2003).

Developmental Considerations of Behavioral Self-Regulation in Early Childhood

In early childhood, there is considerable variation in children's self-regulatory abilities, even within the same age group (Cameron Ponitz et al., 2009). Therefore, it is necessary to understand how children's self-regulation develops. Theories on cognitive-motor skill development (Zimmerman & Kitsantas, 1997), skill-acquisition (e.g., Ackerman, 1988), and developmental perspectives of the phases of self-regulation (Kopp, 1982) lay out a complex course for development. Self-regulation is dynamic (Rothman, Baldwin, Hertel, & Fuglestad, 2013) and progresses in phases (Kopp, 1982), and certain aspects may be limited in supply (Bauer & Baumeister, 2013). In general, the development of self-regulation is a gradual process, in which, over time, the physiological, social-emotional, and cognitive aspects of self-regulation that result in regulated behavior become hierarchically organized and reciprocally integrated (Best & Miller, 2010; Blair & Raver, 2012; Calkins, 2007; Diamond, 2002; Garon, Bryson, & Smith, 2008; Kopp, 1982). During the early childhood years, regulation shifts from inter-personal (development through co-regulation by others, often adult caregivers) to intra-personal (self-regulation) through maturational and experiential processes (Duckworth & Carlson, 2013; Kopp, 1982; Vygotsky, 1978). At the same time, as new skills are learned, self-regulation shifts from being conscious to being an integrated (or automatized) process, potentially freeing up cognitive resources for further development of the skills necessary for higher levels of self-regulation (Baumeister, Masicampo, & Vohs, 2011).

These gradual shifts—from co-regulation to self-regulation and from conscious to integrated—delineate two main phases during early childhood: the *self-control* phase to the *self-regulation* phase (Ackerman, 1988; Kopp, 1982; Zimmerman & Kitsantas, 1997). The progression to self-regulation from self-control phase begins around age three years and continues through the preschool period and beyond, as children are able to internally monitor their own behaviors (Kopp, 1982). The self-control phase is characterized by "compliance, and the emergent abilities to delay an act on request and to behave according to expectations in the absence of external monitors" (Kopp, 1982, p. 206). Children in the self-control phase are able to self-initiate modifying their behavior based on information they remember (Kopp, 1982). However, they have not yet fully integrated the underlying skills necessary for successful self-regulation (Montroy, 2014). Instead, they are consciously engaging in the basic processes, which places a strong demand on the cognitive-attentional system and constrains their ability to flexibly adapt their behaviors to meet new or different situational demands (Ackerman, 1988; Kopp, 1982; Zimmerman & Kitsantas, 1997). These children may fatigue in the context of a task or assessment as a result of needing to exhibit conscious effort and attention to certain aspects of their performance. When self-control becomes more automatic and flexible, children transition to the self-regulation phase. This phase is characterized by "the ability to use numerous contingency rules to guide behavior, to maintain appropriate monitoring for appreciable lengths of time and in any number of situations, and to learn to produce a series of approximations to standards of expectations" (Kopp, 1982; p. 210). Once self-regulation is achieved, children are able to quickly and accurately adapt their behaviors to a dynamically changing context with little attentional demands (Schneider & Fisk, 1982; Zimmerman & Kitsantas, 1997).

Where children are in the developmental phases of self-regulation may affect their performance on a behavioral self-regulation assessment, both in terms of their overall score as well as in their patterns of responding throughout the course of the task (Ackerman, 1988; Kopp, 1982; Zimmerman & Kitsantas, 1997). For instance, a child in the self-control phase may exhibit good performance at the beginning of the task, but because they are still consciously modifying their behavior to comply with the rules of a task, they may perform poorly or more sporadically at the end of the assessment due to fatigue. On the other hand, a child in the self-regulation phase is able to integrate the self-regulatory processes with little attentional demand; and therefore, his performance may be more consistent throughout the course of the task.

Importance of Children's Behavioral Self-regulation for Adjustment in School

For young children, the transition to formal schooling is a critical period that presents increased behavioral demands (Entwisle & Alexander, 1998; La Paro, Rimm-Kaufman, & Pianta, 2006; McClelland et al., 2007). Children's self-regulatory abilities play an important role in a successful transition to school by enabling children to engage in thoughtful, intentional, and context-appropriate behaviors in the classroom (Bodrova & Leong, 2008; McClelland & Cameron, 2012). This point is also reflected in teachers' opinions regarding self-regulation as a more important determinant of children's successful adjustment to school than their academic skills (Lin, Lawrence, & Gorrell, 2003; Rimm-Kaufman, Pianta, & Cox, 2000). Given this, it is no surprise that children's behavioral self-regulation has been positively linked to both achievement and relationship quality, specifically student-teacher relationships (e.g., Blair, McKinnon, & the Family Life Project Investigators, 2016; Liew, Chen, & Hughes, 2010). Although these associations have not been studied using a person-centered approach, where children are in the developmental progression of behavioral self-regulation may be meaningful for how they function in the classroom. To explore this, the current study utilized both variable-centered and person-centered approaches to uncover additional nuances in the development of behavioral self-regulation and its relations to achievement and relationship quality.

Behavioral self-regulation and achievement. Extensive research shows the importance of behavioral self-regulation for multiple academic outcomes, including emergent literacy and mathematics, across diverse samples of children, and even in the context of a combination of early risk factors (e.g., Becker, Miao, Duncan, & McClelland, 2014; Duncan et al., 2007; Fuhs, Nesbitt, Farran, & Dong, 2014; McClelland et al., 2007; Weiland, Barata, & Yoshikawa, 2014; Welsh, Nix, Blair, Bierman, & Nelson, 2010). Children who are able to control their impulses and engage in adaptive behavior in the classroom make more academic gains compared to children who have difficulties in these abilities (Blair et al., 2016; McClelland et al., 2014). Said differently, children in the self-regulation phase of development are able to successfully integrate the cognitive processes to regulate their behaviors. These children, compared to those in the self-control phase, may be better able to determine what is important to attend to, avoid irrelevant distractors, and inhibit the desire to respond too quickly or call out the answer. These self-regulating children can then devote much of their attention to learning new material and increasing their academic skills (McClelland & Cameron, 2012). In contrast, children who are still consciously regulating may allocate the majority of their cognitive resources towards regulating their behaviors instead of focusing on the lesson.

Behavioral self-regulation and student-teacher relationships. High quality student-teacher relationships are vital for positive school adjustment and achievement (Baker, 2006; Liew et al., 2010; Pianta, 1999) and contribute to children's social and cognitive skills in elementary school (Hamre & Pianta, 2001). In contrast, low-quality, or conflictual, relationships are thought to interfere with children's abilities to cope with the demands of the classroom and are associated with poor school functioning (Birch & Ladd, 1999; Pianta, 1999). Given the significance of student-teacher relationships, examining factors associated with relationship quality is important, as even small changes in quality can have large implications for school-related outcomes (O'Connor & McCartney, 2007).

Because self-regulation occurs within social contexts (e.g., classroom environment), the ability to regulate behavior is important not only for academic task performance, but also for social and interpersonal relationships (Eisenberg et al., 2010; Fitzsimons & Finkel, 2011). As such, children's behavioral self-regulation may contribute to the quality of student-teacher relationships, which is often measured from the perspective of the teacher (Pianta, 2001; Verschueren & Koomen, 2012). By school entry, children have developed numerous behavioral and relational strategies that can potentially affect their relationships with teachers (Jerome, Hamre, & Pianta, 2009; Rimm-Kaufman et al., 2002). Teachers' impressions of children are based on children's behavior, begin to form as soon as children enter the classroom, and are critical in the formation of relationships that develop over the course of a year (Myers & Pianta, 2008). In general, a child with low behavioral self-regulation may not be able to meet her teacher's behavioral expectations and may be more disruptive in the classroom (Rimm-Kaufman et al., 2002), which may negatively affect the quality of her relationship with her teacher (Eisenberg et al., 2010; Myers & Pianta, 2008). For instance, a teacher may become frustrated by a child who is unable to inhibit the impulse to yell out the answer to a question, or has trouble paying attention to and following directions, and in turn, this frustration may lead to anger or resentment toward such a child. On the other hand, a teacher may respond more positively to a child who can appropriately manage his behavior and attention to engage in a socially appropriate manner (Bronson, 2000), thereby fostering a close student-teacher relationship (Eisenberg et al., 2010).

Typical developmental changes, such as shifts from adult regulation to co-regulation to self-regulation of behaviors, likely reflect general trends in student-teacher relationships, as well (Jerome et al., 2009; Kopp, 1989). Compared to children who need to rely on their teachers to help them regulate in the classroom context, children who can self-regulate may be more independent and finish their tasks more quickly, thereby having more opportunities to be disruptive and talk with their peers. Thus, teachers may feel less close with these children than those who many be struggling behaviorally and “lean” on the teacher to help them co-regulate (Jerome et al., 2009; Pianta & Stuhlman, 2004). It is also possible that teachers may have a more positive view of children who are able to self-regulate, actively engage in learning, and have higher academic skills; and therefore, teachers may be more likely to invest in close relationships with these children (Jerome et al., 2009). Prior studies have shown that many different factors are associated with the quality of student-teacher relationships, including child, family, school, classroom, and teacher factors (e.g., Blair et al., 2016; Graziano, Reavis, Keane, & Calkins, 2007; O’Connor, 2010). However, less is known about how behavioral self-regulation, in particular, may predict relationship quality in children from high-risk backgrounds.

Poverty, behavioral self-regulation, and school-related outcomes. Evidence strongly suggests that poverty has serious negative effects on children’s development (Blair & Raver, 2012; Duncan & Murnane, 2011; Fitzpatrick, McKinnon, Blair, & Willoughby, 2014; Raver, 2012; Rimm-Kaufman et al., 2000; Sektnan et al., 2010; Yoshikawa, Aber, & Beardslee, 2012). Children from low-income families are often noticeably differentiated in their cognitive and behavioral skills compared to those from middle-income families (Blair & Raver, 2012). For instance, low family income and maternal education have been linked to lower levels of academic achievement and self-regulation (Howse, Lange, Farran, & Boyles, 2003; Raver, 2012) and more relational problems with their teachers (Pianta, La Paro, Payne, Cox, & Bradley, 2002).

In part, the development of children's regulatory skills relies on the environmental context and their having opportunities to practice the relevant behaviors (Evans & Rosenbaum, 2008). Nevertheless, considering the context of poverty only from a deficit-oriented perspective, in which children are viewed as lacking specific skills or inputs, does not take into account the presence of environmental aspects that shape development in ways that are adaptive for that context (Blair & Raver, 2012). In other words, self-regulation develops differently among children living in highly impoverished environments that might be optimal, at least in the short-term, in that particular environment but may not necessarily be adaptive in the long-term or in other contexts, such as the school environment. Given that behavioral self-regulation is well-established as a protective factor particularly for children at-risk (Sektnan et al., 2010), I was interested in exploring variation in behavioral self-regulation in this sample of kindergarten children from low-income families. As such, this study integrates both variable- and person-centered approaches to more fully understand the positive role that children's self-regulation plays and identify, within this sample of children from high-risk backgrounds, particular subgroups of children based on their developmental progression.

Integrating Analytical Perspective on Behavioral Self-Regulation

Previous work has largely used variable-centered approaches to examine children's self-regulatory abilities. Variable-centered approaches are useful in describing and understanding overall associations between behavioral self-regulation and academic and relational outcomes by quantifying the proportion of variance in these outcomes explained by behavioral self-regulation. Person-centered approaches can extend this research by identifying subgroups of children who display varying patterns of behavioral self-regulation (Bergman & Magnusson, 1997). For instance, variable-centered approaches have shown that there is a strong link between behavioral self-regulation and school-related outcomes, and these associations are assumed to be the same across the population. To obtain more specificity, a person-centered approach can be applied to unmask inherent qualitative differences within individuals in their behavioral self-regulation development and illuminate how these patterns may differentially relate to outcomes (Collins & Lanza, 2010; Garon et al., 2008; McClelland et al., 2007).

Recently, empirical work has used person-centered approaches to examine patterns of growth trajectories of children's behavioral self-regulation across the school transition (Montroy, 2014; Wanless et al., 2016). While these studies highlight the use of person-centered analyses to understand unique patterns of behavioral self-regulation development, they relied on patterns based on summed scores across repeated measures of behavioral self-regulation, which does not provide information about how items function together in an assessment (Embretson, 1983). To date, little is known about variability in children's behavioral self-regulation based on the response patterns of performance across items on a behavioral self-regulation task. A close examination of children's behavioral self-regulation at the item level may convey meaningful differences in performance reflecting distinctions in children's developmental progressions.

Present Study & Hypotheses

Both variable- (i.e., summed score) and person-centered (i.e., group membership based on response patterns) approaches were used to obtain complementary information concerning associations between children's behavioral self-regulation and school adjustment outcomes. More specifically, the variable-centered approach was used to examine how general level of behavioral self-regulation related to achievement and student-teacher relationship quality. Then, a person-centered approach, a latent class analysis (LCA), was purposely conducted to identify distinct subgroups of children based on their response patterns on individual items of a behavioral self-regulation task (Collins & Lanza, 2010; Flaherty & Kiff, 2012; Haertel, 1988; Masyn, 2013). These subgroups were then included to examine whether group membership was differentially related to academic achievement and student-teacher relationship quality.

First, given the high-risk sociodemographic factors associated with the current sample, I expected lower mean scores compared to other samples with more mid-SES children, but also expected considerable variability. Based on theory and prior research, qualitatively different item response patterns on the behavioral self-regulation task were expected. I hypothesized to find groups of children showing differential response patterns reflecting where they are in terms of acquiring behavioral self-regulatory abilities (i.e., beginning versus end of self-control phase and conscious versus integrated self-regulation phase) (Ackerman, 1988; Kopp, 1982; Zimmerman & Kitsantas, 1997). For instance, children in the self-control phase may be more likely to fatigue during the task and show decreases in performance over time. In contrast, children in the self-regulation phase may be able to sustain their attention and integrate their cognitive skills to successfully complete the task.

Second, I expected, in general, that behavioral self-regulation would be related to achievement and relational outcomes. Integrating both variable- and person-centered approaches to examine associations between behavioral self-regulation and school adjustment outcomes is novel and exploratory. Thus, I hypothesized that including response profiles of children to predict outcomes would provide additional nuance that can extend findings from traditional approaches. However, too little is known to make specific predictions as to how these profiles may relate to achievement and relationship quality.

Method

Data for the current study come from the first two cohorts of children recruited for a larger longitudinal randomized control study, which evaluated an after-school social-emotional skills program.

Participants

Participants were 251 kindergarten children (55% female), ranging in age from 4.8 to 6.2 years (*M* = 5.4 years; *SD* = 0.32), with 98 (39%) in the control condition and 153 (61%) in the treatment condition. Over 90% qualified for free or reduced-price lunch, and the majority (90%) of children attended Head Start or formal preschool. Parents reported their ethnicity as: 211 (89%) African American, 18 (8%) Hispanic, and 9 (4%) Caucasian/Other. Self-reported maternal education ranged from eighth grade or less to a master's degree, with 61 (26%) reporting less than a high school diploma and 170 (74%) reporting having a high school degree (or equivalent certificate) or more.

Procedure

Families with children entering kindergarten were recruited to participate between April (at the end of pre-kindergarten) and September (at the beginning of kindergarten), at one of four Title I schools in a southeastern state. All children enrolling in kindergarten were eligible to participate in the study, with the exception of those with severe disabilities that would prevent them from completing any of the assessments, as well as those who relocated prior to beginning kindergarten. Families completed a consent form and demographic questionnaire and were compensated with a $15 gift card. Trained research assistants individually assessed children's behavioral self-regulation, academic achievement, and other cognitive skills in two 45-60 minute sessions in a quiet area of their classroom or school during the summer or fall (beginning of the school year) of the kindergarten year (Time 1) and the first grade year (Time 2). In addition, during the early fall (Sept-Oct; Time 1) and early spring (Mar-Apr; Time 2) of the kindergarten year, teachers were administered questionnaires addressing the quality of their relationship with each study child.

Measures

This study uses data concerning children's behavioral self-regulation, academic and cognitive skills, and student-teacher relationship quality collected at Time 1 and Time 2.

Behavioral self-regulation. Children's behavioral self-regulation was assessed at Time 1 using the Head-Toes-Knees-Shoulders task (HTKS; Cameron Ponitz et al., 2009; McClelland et al., 2014). The HTKS has been well-validated for use with children ages 4-8 years old (e.g., Cameron Ponitz et al., 2009; Lan, Legare, Cameron Ponitz, Li, & Morrison, 2011; McClelland et al., 2007; 2014; Wanless et al., 2013). For each of 30 items, the student receives up to two points: incorrect responses receive zero, self-corrected responses receive one point, and correct responses receive two points. The student must receive at least four points per section in order to continue to the next portion of the task. Scores range from 0 to 60, with higher scores indicating higher levels of behavioral self-regulation. There are three sections on this assessment, with 10 test items per section in addition to four practice items that correspond to each section (for a total of 12 practice items). Prior to the assessment, children respond by following commands as given (e.g., touch their heads when asked to touch their heads) in order to test verbal comprehension of directive. Then, for the practice and test items, they are given the instruction to "do the opposite" (e.g., touch their toes when asked to touch their heads and vice versa). Each of the three test sections involves paired behavioral rules and is more complex than the preceding section.

This study uses only the first 10 items (first section) because all children were given those items, whereas only those who received at least four points on the first section were administered the second or third sections. In the first section, children were asked to remember two paired rules: "touch your head when told to touch your toes" and vice versa.

HTKS requires children to utilize and integrate EFs to direct behavior in a manner that is particularly relevant for the classroom (McClelland & Cameron, 2012). For instance, children need to *pay attention* to the instructions given by the examiner; use their *working memory* to remember the instructions and execute the new rules (performing the opposite of what is being asked), while simultaneously processing the instructions; *inhibit* their natural response to follow the instructions, and instead, respond in the opposite manner, and utilize *cognitive* and *attentional flexibility*, as well as *working memory*, when additional rules are added and then changed (Cameron Ponitz et al., 2009; McClelland et al., 2014; McClelland & Cameron, 2012). Empirical research using teacher and parent reports and direct assessments have supported the idea that HTKS involves the *integration* of the multiple aspects of EF as children self-regulate their gross motor responses (Cameron Ponitz et al., 2009; Fuhs, Farran, & Nesbitt, 2015; Lan et al., 2011; McClelland et al., 2014; Wanless et al., 2013).

The HTKS has strong inter-rater reliability (κ = 0.88-0.90; Cameron Ponitz et al., 2009; McClelland & Cameron, 2012; McClelland et al., 2014) and good test-retest stability (*r* = 0.60-0.74; McClelland et al., 2014), as well as good criterion-related validity. The HTKS corresponds as expected with teacher and parent reports of attention and inhibitory control and components of EF, including working memory, cognitive flexibility, and inhibitory control (Cameron Ponitz, et al., 2009; Lan et al., 2011; McClelland, et al., 2007; 2014; Wanless, et al., 2013). The HTKS also has high internal consistency, with alphas ranging from 0.92 to 0.94, as well as strong predictive validity for academic outcomes in diverse pre-kindergarten and kindergarten samples (McClelland & Cameron, 2012; McClelland et al., 2007; 2014).

Academic outcomes. Children's academic outcomes were assessed at Time 1 and Time 2 using the Letter-Word ID and Applied Problems subtests from the Woodcock-Johnson III Tests of Achievement (WJ-III; Woodcock, McGrew, & Mather, 2001). The WJ-III is widely used and standardized, with strong reliability and validity (McGrew & Woodcock, 2001).

Letter-word ID. The Letter-Word ID subtest assesses children's emergent literacy skills and requires children to identify letters and pronounce words. This subtest has good test-retest reliability of $r = 0.96$ for an interval that is less than one year, and a median split-half reliability of 0.98 for children ages 4-7 years old (McGrew & Woodcock, 2001).

Applied Problems. The Applied Problems subtest assesses children's understanding of quantities, ability to do simple calculations, and solve practical problems using their mathematical skills. This subtest has good test-retest reliability of $r = 0.90$ for an interval that is less than one year, and a median split-half reliability of 0.92 for children ages 4-7 years old (McGrew & Woodcock, 2001).

Student-Teacher Relationship Scale. At Time 1 and Time 2, each kindergarten teacher completed the Student-Teacher Relationship Scale-Short Form, an instrument used to assess teachers' perceptions of the level of closeness (7 items) and conflict (8 items) between the teacher and individual students (STRS; Pianta, 2001). The 15-item STRS used a Likert-type format to capture the nature of their relationship with the individual child; the scale ranged from 1 (definitely does not apply) to 5 (definitely applies). Example items within the closeness subscale include, “I share an affectionate, warm relationship with this child” and “It is easy to be in tune with what this student is feeling.” Example items within the conflict subscale include, “This child easily becomes angry at me” and “This child remains angry or is resistant after being disciplined.” This scale has been found in previous studies to have high internal consistency and predictive validity (Birch & Ladd, 1998; Pianta, 2001); in this study, alphas for each subscale were above .80.

Covariates. Research indicates children’s visuomotor integration skills strongly contribute to achievement (Cameron et al., 2015; Carlson, Rowe, & Curby, 2013) and classroom functioning, including teachers’ behavior ratings (Kim et al., 2016); therefore, visuomotor integration was included as a covariate. In addition, similar to prior studies (e.g., Blair et al., 2016), I also controlled for children’s receptive vocabulary skills as a measure of general intelligence.

Visuomotor integration. The 21-item Beery-Buktenica Developmental Test of Visual-Motor Integration, Sixth Edition, Short Format (BEERY VMI; Berry, Buktenica, & Beery, 2010), designed for ages 2-8, was used to assess children’s abilities to integrate their visual and motor skills at Time 1. Children are presented with drawings of geometric figures, such as a vertical line or a circle, that increase in difficulty, and are asked to copy the figures using paper and pencil without any erasing or rotating the booklet in any direction. Children are asked to copy 18 different figures, and a raw score based on the number of correctly copied figures (1 point each) is obtained, for a possible range between 0 and 21. The Beery VMI demonstrates good reliability and validity, with a reliability coefficient alpha between 0.80-0.86 for children ages 4-7 years old and an inter-rater median reliability coefficient of 0.93 (Beery et al., 2010).

Receptive Vocabulary. The Verbal Comprehension subtest of the Differential Ability Scales II (DAS; Elliott, 2007) was used to measure children's receptive language abilities at Time 1. The DAS is designed to assess children ages 2:6 to 17:11 and shows evidence of strong reliability and has been shown to correspond as expected with other well-validated instruments, such as the Wechsler Intelligence Scale for Children-Fourth Edition (WISC-IV; Wechsler, 2003), indicating evidence of convergent and discriminant validity (Elliott, 2007). The 42-item Verbal Comprehension subtest contains five subsections and measures children's receptive language and understanding of oral instruction involving basic language concepts. Children must get fewer than three items incorrect within each section to move onto the subsequent section. In the first section, children are asked to point to different body parts on a picture of a teddy bear. In the second section, children are asked to identify toys placed in front of them (i.e., "Give me the horse"). In the third section, children are asked to manipulate and arrange figures in various ways (i.e., "Put the cat on the box"). In the fourth section, the examiner tells a child a story, and the child must choose one of four pictures that goes best with the story. In the last section, children are asked to use manipulative chips of different colors and shapes in various ways (i.e. "Give me all of the blue chips except the triangle"). This Verbal Comprehension subtest has good internal consistency for ages 5-7 (alpha = 0.84-0.87) and test-retest stability (r = 0.78; Elliott, 2007).

Demographic characteristics. Child's demographic information, including gender, age, and maternal education, was obtained using a parent questionnaire and were included as covariates in the analyses. In addition, the data come from a larger randomized control study; therefore, treatment condition was included as a covariate. However, there were no effects after one year of the program, so there is little concern about study participation affecting this study's results.

Analytic Plan

Statistical analyses were executed in several phases. First, preliminary descriptive analyses were conducted using Stata 14.1 (StataCorp., 2016) to examine the distributions, means, standard deviations, correlations, and the amount of missing data for all variables included in the study (see Table 1). Next, a finite mixture model (i.e., latent class analysis; LCA) was employed, using *Mplus Version 7.1* (Muthén & Muthén, 1998-2012), to identify homogeneous subgroups of children based on their item response patterns on indicators of behavioral self-regulation (i.e., 10 HTKS items). Finally, Stata 14.1 (StataCorp., 2016) was used to examine associations among behavioral self-regulation, student-teacher relationships, and achievement. The analytic strategies are described more fully below.

Missing data. The amount of missing data ranged from 0-16% for all variables included in the analyses (see Table 1). Of the 251 participants, 72% (n = 181) of the sample had complete data for all variables; 7% (n = 18) of the sample were missing only math and reading outcomes at Time 2, and less than 5% (n = 13) were missing data on other variables. Attrition or missing data can lead to data that are not missing at random (MAR), which can bias parameter estimations, especially when traditional methods (e.g., listwise deletion) are used (Enders, 2010). Although there is not a definitive method of testing the MAR assumption, missing data indicator variables were created, and logistic regressions were conducted using all available variables to predict missingness to test for selectivity effects (Schafer & Graham, 2002). Missing data analyses revealed more missing data at Time 2 for children in the treatment group. To account for these differences, treatment status was included as a control variable. Also, full-information maximum likelihood (FIML) estimation method was used to address missing data (Schaefer & Graham, 2002). FIML uses all available information to produce more efficient and less-biased estimates compared to deletion methods (Acock, 2005).

Nesting. In addition, the 251 participants in the current study were nested within 40 classrooms (range: 1-22 children per classroom). Intra-class correlations (ICCs) indicated that there was significant variability at the classroom level for teacher perceptions of student-teacher relationships (conflict ICC at Time 1 and Time 2 = 0.14; closeness ICC at Time 1 and Time 2 = 0.35 and 0.32, respectively). Therefore, standard errors were adjusted using robust standard errors to account for the clustering of children within classrooms.

Latent class analysis. Latent class analysis was conducted to identify different response patterns of performance on the first ten items of the HTKS administered at the beginning of kindergarten. An unconditional measurement model was first conducted, where only the categorical observed indicator variables are included to explain class membership (Masyn, 2013). Two to six-class latent class solutions were estimated in order to determine the optimal number of classes. The following model fit indices were used to compare models of different class solutions: the Akaike information criterion (AIC; Akaike, 1987); Bayesian Information Criterion (BIC; Schwartz, 1978), and sample-size-adjusted BIC (ABIC; Sclove, 1987). There is no criterion for “good fit”, but the model that yielded the smallest overall values on these indices was chosen to be the “better-fitting” model in the current study (Chien et al., 2010). Additionally, entropy approaching 1.0 indicates that groups can be well-distinguished from each other (Celeux & Soromenho, 1996).

Regression analyses. A series of regression analyses were estimated within a structural equation modeling framework using the SEM command in Stata. Specifically, four separate path models were fitted to investigate whether children's behavioral self-regulation at the beginning of kindergarten predicted student-teacher relationships and achievement (math and literacy) at Time 1 (see Tables 5 and 6, models 1 and 2; Figure 1) and at Time 2 (see Tables 5 and 6, models 3 and 4; Figure 2), after controlling for the effects of child demographics (age, gender, and maternal education), treatment status, visuomotor integration and receptive vocabulary. To examine whether behavioral self-regulation was associated with changes in school-related outcomes, initial (i.e., at Time 1) achievement and relationship quality scores were also included to control for their partial effects. All of these analyses were conducted twice, one using the summed score of HTKS (Tables 5 and 6) and the other using group membership based on response patterns identified using LCA in place of the composite score (Tables 7 and 8, see Figure 3), to investigate whether the two representations of HTKS performance yielded differing relations to child outcomes.

Results

In the current study, both variable-centered and person-centered approaches were used to explore associations between children's behavioral self-regulation and school adjustment.

Preliminary Analyses

Descriptive statistics and correlations among all study variables are presented in Tables 1 and 2, respectively. Children's achievement scores improved by about 1.6 standard deviations from the beginning of kindergarten (Time 1) to end of kindergarten (Time 2) on the mathematics assessment, $M = 12.24$ ($SD = 3.55$) to $M = 18.09$ ($SD = 4.08$) and by about 2.3 standard deviations from Time 1 to Time 2 on the literacy assessment, $M = 12.06$ ($SD = 5.20$) to $M = 23.76$ ($SD = 7.94$). Teacher perceptions of both types of relationship quality increased by about 0.14 standard deviations: Conflict increased slightly over the course of the year, $M = 1.80$ ($SD =$

0.84) to *M* = 1.92 (*SD* = 0.93), as did teacher perceptions of closeness, *M* = 4.21 (*SD* = 0.64) to *M* = 4.30 (*SD* = 0.64). Zero-order correlations among predictor and outcome variables were in the expected directions. Specifically, significant gender effects were in favor of girls (i.e., girls outperformed boys) for behavioral self-regulation, teacher-reported closeness, and achievement. Moreover, as expected, significant age effects were found for behavioral self-regulation and achievement outcomes, where older children performed better than younger children, but there were no significant age effects for teacher perceptions of relationship quality. At both Time 1 and 2, behavioral self-regulation was negatively associated with conflict (*r* = -0.07 to -0.19) and positively associated with closeness (*r* = 0.09 to 0.15) and achievement (*r* = 0.30 to 0.45).

Identifying Response Patterns Using Latent Class Analysis

Table 3 displays the fit statistics for the two- through six-class latent class solutions. Based on these fit statistics and theoretical relevance, the four-class model was chosen as the most parsimonious description of the data compared to the other models tested. Figure 4 displays the classes and shows the differing response patterns across the ten items. Descriptively, Class 1 (“Integrated Self-Regulators”; *n* = 92; 37%) was successful on the majority of the items on the assessment, whereas Class 4 (“Poor Regulators”; *n* = 107; 43%) was unsuccessful on all items. Class 2 (“Conscious Self-Regulators”; *n* = 24; 10%) had a U-shaped response pattern, with initial success followed by decreased performance that improved by the end of the assessment. Class 3 (“Effortful Regulators”; *n* = 28; 11%) was similar to Class 2 in that they had initial success on the first couple of items and then decreased in performance; however, unlike Class 2, they continued to do poorly on the items (i.e., did not improve again).

Class membership characteristics. Table 4 provides descriptive statistics by classes. A comparative analysis of the four-class solution was conducted by examining univariate contrasts across demographic characteristics. Initial chi-square tests revealed that class composition marginally differed by gender in the expected direction (χ^2= 6.46, p = 0.09), such that the percentage of girls in the "Integrated Self-Regulators" (Class 1) group was higher, whereas the percentage of boys was higher in the "Poor Regulators" (Class 4) group. However, after correcting for multiple comparisons, these differences were no longer marginally significant. There were no other demographic differences between classes.

One-way analysis of variance (ANOVA) with Tukey post hoc comparisons were conducted to investigate differences in means by class across all external covariates and outcomes of interest (see Table 4). All four classes significantly differed in their summed behavioral self-regulation scores, with "Integrated Self-Regulators" (Class 1) having a significantly higher average score than "Conscious Regulators" (Class 2), which had a significantly higher score than "Effortful Regulators" (Class 3), which had a significantly higher score than "Poor Regulators" (Class 4). There were no mean differences by class in child members' age or receptive vocabulary. In addition, Classes 1, 2, and 3 did not differ in any of the covariates and outcomes, including visuomotor integration, conflict, and achievement scores at Time 1 and Time 2. However, these three classes, in general, had significantly higher scores in these variables compared to Class 4. The only exception was in teacher-perceived closeness. At Time 1, teachers rated children in Class 3 higher in closeness as compared to the other three groups, whereas at Time 2, children in Class 1 and 3 were both rated significantly higher in closeness compared to those in Class 2 and 4. These class memberships were saved as a variable within the dataset and used in subsequent predictive analyses.

Integrating Variable- and Person-Centered Approaches

Both variable-centered (i.e., using a summed score of HTKS) and person-centered (i.e., using class memberships in place of the summed score) approaches were used to examine concurrent and predictive associations between behavioral self-regulation and school adjustment outcomes (achievement and relationship quality), controlling for age, gender, treatment status, maternal education, receptive vocabulary, and visuomotor integration. For predictive associations, baseline information was also included in the models.

Associations between behavioral self-regulation and academic achievement. A path model was conducted to examine whether behavioral self-regulation was concurrently associated with children's academic achievement at Time 1, controlling for covariates. Another path model examined whether behavioral self-regulation predicted children's achievement at Time 2, controlling for Time 1.

Variable-centered approach. Table 5 presents the results for the path analysis predicting achievement outcomes. Models 1 and 2 examine concurrent associations at Time 1, and Models 3 and 4 examine predictive associations at Time 2. Specifically, Model 1 includes covariates only, Model 2 includes covariates and the summed score of behavioral self-regulation to predict Time 1 achievement scores, Model 3 includes covariates for the predictive models (with baseline variables), and Model 4 includes covariates and summed score of behavioral self-regulation to predict Time 2 achievement scores.

After controlling for the effects of covariates, children's behavioral self-regulation significantly predicted their literacy achievement (Time 1: $\beta = 0.19$, Robust $SE = 0.05$; $p < 0.001$; Time 2: $\beta = 0.10$, Robust $SE = 0.05$; $p < 0.05$) and mathematics achievement (Time 1: $\beta = 0.30$, Robust $SE = 0.04$; $p < 0.001$; Time 2: $\beta = 0.21$, Robust $SE = 0.05$; $p < 0.01$) at Time 1 and Time 2. The covariates and behavioral self-regulation together explained 31% of the variance in literacy achievement at Time 1 and 56% at Time 2, as well as 40% of the variance in mathematics achievement at Time 1 and 46% at Time 2.

Person-centered approach. Dummy coded class membership variables were next included in a new path model to predict achievement outcomes. The model was conducted multiple times, with each class as the reference group, in order to make comparisons between the different classes. Tables 7 and 8 present the results for the final path analysis model predicting achievement outcomes that includes all covariates. At Time 1 (Table 7), the “Integrated Self-Regulators” (Class 1) were significantly higher in literacy achievement than the “Effortful Regulators” (Class 3) and “Poor Regulators” (Class 4); there were no differences in literacy achievement between the “Integrated Self-Regulators” and the “Conscious Regulators” (Classes 1 and 2, respectively). At Time 2 (Table 8), the “Conscious Regulators” (Class 2) improved significantly more over the course of the school year compared to the other three classes, and the “Integrated Self-Regulators” (Class 1) made more improvements than the “Effortful Regulators” (Class 3). There were no other class differences.

For mathematics achievement at Time 1, “Integrated Self-Regulators” (Class 1) and “Conscious Regulators” (Class 2) had significantly higher mathematics scores than “Effortful Regulators” (Class 3) and “Poor Regulators” (Class 4). At Time 2, “Poor Regulators” (Class 4) made significantly fewer improvements across the year compared to the other three classes. There were no other class differences. The covariates and classes together explained 31% of the variance in literacy achievement at Time 1 and 57% at Time 2, and 39% of the variance in mathematics achievement at Time 1 and 70% at Time 2.

Associations between behavioral self-regulation and student-teacher relationships. A path analysis was conducted to examine whether behavioral self-regulation was concurrently associated with teacher perceptions of their quality of relationships at Time 1, controlling for covariates. Another path analysis examined whether behavioral self-regulation predicted relationship quality at Time 2, controlling for Time 1.

Variable-centered approach. Table 6 presents the results for the path analysis predicting teacher perceptions of conflict and closeness in their relationships with students. Models 1 and 2 examine concurrent associations at Time 1, and Models 3 and 4 examine predictive associations at Time 2. Specifically, Model 1 includes covariates only, Model 2 includes covariates and the summed score of behavioral self-regulation to predict Time 1 relationship quality, Model 3 includes covariates for the predictive models (with baseline variables), and Model 4 includes covariates and summed score of behavioral self-regulation to predict Time 2 relationship quality.

After controlling for the effects of covariates, children's behavioral self-regulation marginally predicted teacher-reports of conflict (β = -0.13, Robust *SE* = 0.07; p = 0.07) but not closeness at Time 1. Behavioral self-regulation was not related to conflict or closeness at Time 2. The covariates and behavioral self-regulation together explained 8% of the variance in conflict and 4% of the variance in closeness at Time 1. The covariates and behavioral self-regulation together explained 42% of the variance in conflict and 57% of the variance in closeness at Time 2.

Person-centered approach. Similar to the models with achievement outcomes, dummy coded class membership variables were included to predict relationship outcomes. The model was conducted multiple times, with each class as the reference group, in order to make comparisons between the different classes. Tables 7 and 8 present the results for the final path analysis model predicting student-teacher relationships. For teacher-perceived conflict at Time 1 (Table 7), the "Effortful Regulators" (Class 3) had significantly less conflictual relationships compared to the other three classes. Additionally, the “Integrated Self-Regulators” (Class 1) has less conflict than the “Poor Regulators” (Class 4). There were no other class differences. In terms of teacher-perceived closeness at Time 1, again, the “Effortful Regulators” (Class 3) were significantly higher in closeness as perceived by their teachers compared to the other three classes. There were no other class differences. Interestingly, by Time 2 (Table 8), there were no differences between classes in teacher perceptions of closeness and conflict. The covariates and classes together explained 11% of the variance in conflict and 9% of the variance in closeness at Time 1 and 42% of the variance in conflict and 32% of the variance in closeness at Time 2.

Discussion

This study is the first to use both variable-centered and person-centered approaches to examine the contribution of behavioral self-regulation to academic and relationship quality in a sample of kindergarten children from low-income families. Using complementary approaches can contribute to a more complete understanding of children’s behavioral self-regulation (Bergman & Trost, 2006). Three main findings emerged from this study: 1) there were four distinct response patterns of children’s behavioral self-regulation; 2) behavioral self-regulation was differentially related to concurrent and later achievement and relational outcomes; and 3) incorporating both variable-centered and person-centered approaches offered a different lens on the associations between behavioral self-regulation and school-related outcomes.

Distinct Response Patterns of Children’s Behavioral Self-Regulation

Using a person-centered approach (i.e., LCA), four subgroups were identified based on children’s response patterns on the first ten items of the HTKS (see Figure 4) that may translate to different developmental phases of behavioral self-regulation (Kopp, 1982): an “Integrated Self-Regulators” group, a “Conscious Regulators” group, an “Effortful Regulators” group, and a

“Poor Regulators” group. These four profiles were all significantly different in their summed behavioral self-regulation scores, with “Integrated Self-Regulators” having the highest score and the “Poor Self-Regulators” having the lowest score. While traditional analytic approaches are able to detect these mean differences, examining item performance revealed interesting response patterns that may map onto developmental stages of behavioral self-regulation, which cannot be ascertained from the summed scores. Therefore, the use of person-centered analyses to identify these distinct response patterns may extend our understanding of behavioral self-regulation development in a more holistic and dynamic way.

It is worth mentioning that results from a person-centered approach are derived from the sample, and therefore, shaped by sample characteristics (Masyn, 2013). As such, within this sample of kindergarten children from high-risk backgrounds, the majority of the sample (80%) was either in the “Integrated Self-Regulators” (Class 1) group or “Poor Regulators” (Class 4) group. Given the socio-demographic risk factors associated with this sample, it was not surprising that the largest group was in the lowest “Poor Regulators” group (43%). However, I was pleasantly surprised to find that the next largest group was in the highest “Integrated Self-Regulators” group (37%), who as a group performed comparable to or better than other similar-aged, less risky samples. For instance, the summed score for the “Integrated Self-Regulators” (mean age = 5.5 years) was $M = 17.21$ ($SD = 2.48$), whereas the summed score on the first ten items of the HTKS for a more advantaged sample of children (mean age = 5.5; 76% Caucasian) was $M = 15.15$ ($SD = 5.77$) (Cameron Ponitz et al., 2008). Taken together, this suggests that although the current sample is considered to be high-risk, it is not a monolithic sample. Examining only the sample’s summed score ($M = 8.35$; $SD = 7.93$) would suggest that this sample as a whole has low self-regulatory abilities, which is not the case as evidenced by the person-centered method.

In general, the “Integrated Self-Regulators” (Class 1) exhibited high behavioral self-regulation and were able to successfully complete the items on the first part of HTKS. This group may have successfully and seamlessly integrated the cognitive and behavioral aspects that underlie self-regulation to quickly and accurately adapt their behaviors based on the expectations of the task. Thus, they were able to correctly follow the rule (“do the opposite”) with little attentional demands for the entire length of the task. On the other hand, the “Poor Regulators” (Class 4) exhibited low behavioral self-regulation and were unsuccessful on all items of the task. This group may be in the self-control phase; they can comply only with the stated commands of the HTKS (e.g., “Touch your head”) but can’t remember the instructions. In other words, at this beginning phase, children are focusing much of their attention to the commands and are not able to adapt their behaviors to meet new demands to “do the opposite.”

Two smaller subgroups, combined to be roughly 20% of the sample, were identified, extending our knowledge of behavioral self-regulation development. The “Effortful Regulators” (Class 3; 11% of the sample) had initial success on the first couple of items but then decreased in performance. This group may have been able to recall a rule to “do the opposite” and successfully follow it at first. However, because much of their attention is on the conscious effort to inhibit the natural tendency to do what is stated, rather than the opposite, performance may have been limited by their attentional capacity. Consequently, after a couple of items, this group had difficulty continuing to remember to do the opposite, and instead, followed what was stated. Interestingly, the ”Conscious Regulators” (Class 2; 10% of the sample) had initial success on items followed by decreased performance, which then improved (i.e., U-shaped curve). This group may be in the conscious self-regulation phase. In other words, they are in the process of learning and increasing their self-regulatory abilities. They are able to modify their behavior to accommodate the request (“do the opposite”), as well as remember multiple rules. Yet, children in this group have not fully integrated the regulatory skills; as such, their behaviors still require conscious effort. This point is further evidenced by the specific item response patterns for this group (Figure 4). Items 3 and 7 repeat the previous command (i.e., Items 2 and 3 are both “Touch your toes”; Items 6 and 7 are both “Touch your head”). When the command for item 3 was presented, the “Conscious Regulators”, for the most part, failed to do the opposite by touching their heads, perhaps indicating difficulties in cognitive or attentional flexibility; and, for the next three items, this group struggled to “get back on track”. But, by item 7, another repeated item, they were able to modify their behavior once again to follow the request to “do the opposite” and successfully perform on the rest of the items. Although more research is needed to confirm whether these profiles are generalizable across multiple samples, findings from this study provide unique information concerning the multiple, distinct patterns of behavioral self-regulation development in kindergarten children from high-risk environments.

Child characteristics and patterns of behavioral self-regulation. Overall, child age, gender, ethnicity, maternal education, and initial cognitive skills (i.e., receptive vocabulary, visuomotor integration, and achievement) were not indicative of children’s distinct response patterns on the behavioral self-regulation task. This is somewhat in line with a previous study that also found no differences in behavioral regulation development by demographic characteristics (e.g., Wanless et al., 2016). Despite prior research that suggests differences in behavioral self-regulation by age, gender, maternal education, or early cognitive skills (e.g., Bronson, 2000; McClelland et al., 2014), the lack of significant differences by demographic characteristics in the present study could be due to the relative homogeneity in the current sample. Almost 90% of the children were African American and qualified for free/reduced lunch status. In addition, 74% of the mothers reported having at least a high school diploma. The limited variability in sociodemographic variables may have contributed to the lack of significant differences between profiles. The fact that these demographic factors did not differentiate the groups also suggests that the method of relying on age, gender, and maternal education to group children may not necessarily be the most informative in terms of children's self-regulatory abilities. Rather, children's developmental progression captured by their response patterns may be an informative way of grouping children.

Links Between Behavioral Self-Regulation and School-Related Outcomes

For academic outcomes, both traditional and person-centered approaches provided largely the same results, although examining differences based on response patterns revealed some nuance in these associations. Interestingly, these two approaches offered different information on the link between behavioral self-regulation and student-teacher specific associations. These findings are discussed in greater detail below.

Behavioral self-regulation and academic outcomes. In accordance with previous research demonstrating that early behavioral self-regulation is robustly associated with achievement (e.g., McClelland et al., 2007; Sektnan et al., 2010; Welsh et al., 2010), the current study also shows positive links between children's behavioral self-regulation and mathematics and literacy achievement. When initial achievement scores were included in the model, children's behavioral self-regulation continued to be positively associated with changes in achievement over the kindergarten year. In other words, children with greater behavioral self-regulation at the beginning of kindergarten, on average, made greater improvement in achievement scores from the start to the end of kindergarten. These findings were robust, given that this general pattern of results was evident regardless of the approach I used. The person-centered approach, though, further decomposed these results and provided greater detail about how the different response patterns were related to achievement.

In general, at both Time 1 and Time 2, “Integrated Self-Regulators” and “Conscious Regulators” were significantly higher in mathematics and literacy achievement, whereas the “Poor Regulators”, and to a certain extent, the “Effortful Regulators” were significantly lower than the other two groups. Both “Integrated Self-Regulators” and “Conscious Regulators” may be better able to meet the classroom expectations on their own without an overpowering demand on their cognitive system (Kopp, 1982; Zimmerman & Kitsantas, 1997), and therefore, have the cognitive resources available to learn new academic material. On the other hand, “Poor Regulators” and “Effortful Regulators” may have difficulties meeting the demands of the classroom, including remembering and following the rules, switching from one task to another, and completing tasks in a timely manner. These groups may need more reminders from their teachers to function in the classroom and much of their effort may be directed towards regulating their behavior, taking away the limited resources necessary for academic learning. In sum, combining both approaches allowed us to not only corroborate the positive association between behavioral self-regulation and achievement, but also take this one step further and identify and compare particular groups of children based on their behavioral self-regulation development.

Behavioral self-regulation and student-teacher relationship quality. The variable-centered approach indicated that overall behavioral self-regulation (i.e., summed score) was marginally related to teacher perceptions of conflict but not related to closeness at the beginning of kindergarten. Also, children’s behavioral self-regulation did not predict improvements in conflict or closeness at the end of the kindergarten year. This is somewhat inconsistent with previous research suggesting certain aspects of behavioral self-regulation, including regulating behavior and attention, are linked to the development and maintenance of relationships with their teachers (Eisenberg et al., 2010). One possible explanation may be that the HTKS behavioral self-regulation task taps more into children’s abilities to integrate their cognitive regulatory processes and is not designed to capture the emotional processes that may be important for building relationships (Eisenberg et al., 2010). Being able to modulate one’s emotions is a critical aspect for developing positive relationships. For instance, children who can control their behavior and emotions, such as using their words rather than hitting another child, are likely to interact in socially appropriate ways with their teachers (Eisenberg, Sadovsky, & Spinrad, 2005) and exhibit less problematic behaviors (Eisenberg et al., 2010). Therefore, future research should include measures of self-regulation that include an emotional regulation component.

Findings from the person-centered approach seem to suggest another possible explanation for the lack of association between behavioral self-regulation and relationship quality. Where children are in terms of the developmental phases of behavioral self-regulation may be particularly important for student-teacher relationships, at least for the beginning of kindergarten. Specifically, teachers perceived having the closest and the least conflictual relationship with the “Effortful Regulators” (Class 3), the group with the second-lowest behavioral self-regulation score, as compared to all the other groups, including the “Integrated Self-Regulators.” At first glance, this finding was surprising, given that past variable-centered research would have led me to expect that higher behavioral self-regulation should be related to higher relationship quality (Eisenberg et al., 2010).

Yet, the "Effortful Regulators" may be the group of children who are in that transitional process of co-regulation in the acquisition of self-regulation (Hadwin & Oshige, 2011). Co-regulation requires engagement, positive interactions, and mutual relationships between the teacher and student (McCaslin, 2009). These children may be aware that they are not yet able to regulate their behaviors on their own but may seek out help and rely on their teachers to "share" in their regulation. The response pattern of the "Effortful Regulators" indicates that they were able to successfully follow the rule (i.e., "do the opposite") for a short period of time before forgetting the rule and unsuccessfully performing the appropriate behavior. But, even though they were no longer following the rule to do the opposite, they were still paying attention to the commands and following them (i.e., touching their heads when asked to touch their heads). Therefore, these children may have the desire to comply with instructions in the classroom, but the cognitive demands of completing tasks or guiding behaviors may require external supports from the teacher (Hadwin & Oshige, 2011). This process of co-regulation may result in closer and less conflictual relationships between teachers and these children, due to more opportunities to interact and children's willingness to comply with teacher guidance.

Children who are relatively more competent in their regulatory abilities (i.e., Integrated Self-Regulators or Conscious Regulators) may interact in a positive manner with their teachers; however, they may not need to rely on their teachers as much in the classroom. Instead, these children may be forming positive relationships with their peers (Jerome et al., 2009) and finishing their tasks earlier than other children with less assistance from the teacher. Therefore, teachers may not necessarily interact favorably or positively with these children, who may be more autonomous. Also, children who are poor regulators may be disruptive and initiate difficult student-teacher interactions. Teachers may perceive these children to be more conflictual and may isolate and neglect these children (Howes, Phillipsen, & Peisner-Feinberg, 2000).

By the end of kindergarten, both variable- and person-centered approaches revealed similar findings: no differences between any of the groups in terms of conflict or closeness after accounting for conflict and closeness at the beginning of kindergarten. In other words, overall behavioral self-regulation did not relate to changes in teacher perceptions of their relationship quality, nor did these changes differ across the distinct profiles of behavioral self-regulation. This is in line with previous research indicating the stability in teacher perceptions of conflict and closeness in the early childhood years (Howes et al., 2000). Teachers appear to have expectations for how children should behave and form impressions of children based on their behaviors in the classroom. The teachers then act in accordance with these impressions, and at the same time, children generally interact in a manner that is consistent with their working model of relationships, which likely leads to stable co-constructed relationships (Howes et al., 2000; Myers & Pianta, 2008).

Limitations and Future Directions

A number of limitations should be considered when interpreting the results of this study. First, the majority of the sample included African American children from low-income families; therefore, the results may not generalize to other more socially and economically advantaged samples. Future research would benefit from samples with more diverse demographic and socioeconomic backgrounds. Second, I recognize the complexity of children's self-regulatory processes and the many different conceptualizations and measures designed to capture self-regulation. However, this study used a single measure of children's behavioral self-regulation. This measure was chosen intentionally, as it was a direct assessment designed to capture children's abilities to *integrate* the cognitive processes underlying behavioral self-regulation (Cameron Ponitz et al., 2009). Nevertheless, future work might include a broader array of tasks that capture the different components or combinations of components underlying behavioral self-regulation, as well as multiple types of assessments, such as teacher-reports of children's behavioral self-regulation. Additionally, student-teacher relationship quality was measured using a teacher-report. Although teacher perceptions are important and have implications for children's experiences in the classroom (Hughes & Kwok, 2007), future research should include direct or observational measures of relationship quality or teacher-student interactions.

Third, many aspects of children's functioning are interrelated with the development of self-regulation, such as motivation and social processes (Bronson, 2000). Future studies are needed to replicate and extend these findings by including additional proximal and distal factors related to behavioral regulation to obtain a more complete understanding of children's behavioral self-regulation development in early childhood. Finally, the current study examined children's response patterns at the beginning of kindergarten. However, children's behavioral self-regulation develops rapidly during this period; and therefore, future studies should examine whether children's response profiles change over the course of the year and what may predict change from one profile to another.

Implications and Conclusion

Because self-regulation can either facilitate or hinder children's abilities to function successfully and appropriately in school environments, understanding and improving children's regulatory abilities has become a major focus of intervention research (Bierman, Nix, Greenberg, Blair, & Domitrovich, 2008; Raver et al., 2011). Integrating both traditional and person-centered methods enhances the validity and depth of existing research findings, adds nuance to conventional views and understandings, and further enriches our knowledge of children's behavioral self-regulation development. Findings from this study have implications for addressing the major challenge of how and when to support the development of self-regulation.

Typically, interventions that target children's self-regulation are designed in such a way that all children in the treatment group receive the same intervention without considering the individuals' needs. Yet, children come to school with varying self-regulatory abilities. This study suggests that how children respond on a task can reveal important information about where they are in the developmental progression of behavioral self-regulation. In conjunction with classroom-level interventions, an individualized approach based on where children are in the developmental process of acquiring behavioral self-regulation may be effective in supporting their development (Ackerman, 1988; Kopp, 1982). For example, for "Poor Regulators", teachers can provide instructions where children are asked to do the opposite, which may help them develop the cognitive processes underlying self-regulation. For "Effortful Regulators", teachers may want to play a more active role as co-regulator and provide reminders throughout the activity to help ease the cognitive demands on these children. Finally, for the "Conscious Regulators", teachers may want to provide additional opportunities to practice their behavioral self-regulation in the classroom context.

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Table 1.

Descriptive Statistics

	n	%	*% Missing*	*M*	*SD*	*Min.*	*Max.*
Demographic Variables							
Child age in years at Time 1	250		0%	5.41	0.32	4.75	6.17
Gender	251		0%				
Male = 1	113	45%					
Female = 0	138	55%					
Ethnicity	238		5%				
African American/Black	211	89%					
Hispanic/Latino	18	8%					
Caucasian/White/Other	9	4%					
Maternal Education	231		8%				
High School or more = 1	170	74%					
Less than high school = 0	61	26%					
Treatment Condition	251		0%				
Treatment=1	153	61%					
Control=0	98	39%					
Other Variables							
Receptive vocabulary at Time 1	246		2%	16.09	3.37	6	20
Visuomotor integration at Time 1	249		1%	12.99	2.3	3	18
Behavioral self-regulation at Time 1	251		0%	8.35	7.93	0	20
Teacher-reported Conflict at Time 1	227		10%	1.8	0.84	1	4.25
Teacher-reported Conflict at Time 2	232		8%	1.92	0.93	1	4.88
Teacher-reported Closeness at Time 1	227		10%	4.21	0.64	2.29	5
Teacher-reported Closeness at Time 2	232		8%	4.3	0.64	2	5
Mathematics Achievement at Time 1	249		1%	12.24	3.55	0	23
Mathematics Achievement at Time 2	214		15%	18.09	4.08	6	36
Literacy Achievement at Time 1	249		1%	12.06	5.2	1	39
Literacy Achievement at Time 2	213		15%	23.76	7.94	7	56

Note. Time 1 = Beginning of kindergarten; Time 2 = End of kindergarten

Table 2.

Correlations

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Age	-														
2. Gender	-0.12	-													
3. Maternal Education	0.01	0.04	-												
4. Treatment	-0.07	0.002	-0.08	-											
5. Receptive Vocabulary	0.07	-0.01	0.02	0.08	-										
6. Visuomotor Integration	0.21**	0.02	-0.04	-0.06	0.04	-									
7. Behavioral Self-Regulation	0.15*	-0.14*	-0.11	-0.10	0.02	0.23***	-								
8. Conflict Time 1	-0.03	0.13	0.14*	0.04	-0.06	-0.14*	-0.19**	-							
9. Conflict Time 2	-0.03	0.12	0.10	0.02	-0.16*	-0.07	-0.07	0.63***	-						
10. Closeness Time 1	-0.005	-0.17*	-0.05	-0.03	0.06	0.04	0.09	-0.34***	-0.22**	-					
11. Closeness Time 2	0.04	-0.24***	-0.04	-0.10	0.05	0.07	0.15*	-0.30***	-0.38***	0.51***	-				
12. Mathematics Time 1	0.29***	-0.15*	-0.09	-0.06	0.06	0.51***	0.43***	-0.17*	-0.04	0.17**	0.15*	-			
13. Mathematics Time 2	0.15*	-0.11	-0.09	-0.14*	0.02	0.47***	0.45***	-0.19**	-0.13	0.17*	0.18**	0.63***	-		
14. Literacy Time 1	0.14*	-0.09	-0.06	0.02	0.02	0.51***	0.30***	-0.14*	-0.01	0.17**	0.10	0.58***	0.44***	-	
15. Literacy Time 2	0.15*	-0.16*	-0.11	0.03	0.09	0.52***	0.35***	-0.18**	-0.12	0.11	0.22**	0.57***	0.61***	0.70***	-

Note. Time 1 = Beginning of kindergarten; Time 2 = End of kindergarten; Gender (Male = 1; Female = 0); Maternal education (High School or more = 1; Less than high school = 0); Treatment (Treatment = 1; Control = 0); $^{*}p<.05$; $^{**}p<.01$; $^{***}p<.001$.

Table 3.

Class Enumeration Fit Statistics

# of Classes	Log likelihood	# of free parameters	AIC	BIC	ABIC	Entropy
2	-1352.08	41	2786.16	2931.03	2801.05	1.00
3	-1285.93	62	2695.86	2914.93	2718.38	0.96
4	-1225.93	83	2617.85	2911.12	2648.00	0.98
5	-1174.79	104	2557.58	2925.05	2595.35	0.97
6	-1140.61	125	2531.22	2972.89	2576.62	0.97

Note. AIC = Akaike Information Criterion; BIC = Bayesian information criterion; ABIC = sample-size adjusted BIC.

Table 4.

Descriptive Statistics by Distinct Response Profiles on the Head-Toes-Knees-Shoulders Items.

	Class 1	**Class 2**	**Class 3**	**Class 4**	**Overall**	**χ^2/F test**
n (%)	92 (37%)	24 (10%)	28 (11%)	107 (43%)	251	
Age: M (SD)	5.46 (.30)^{a}	5.44 (.36)^{a}	5.50 (.29)^{a}	5.34 (.32)^{a}	5.41 (.32)	$F(3,246) = 3.15^{*}$
Gender						$\chi^2_{(3)} = 6.46^{+}$; N = 251
Male	37%	46%	39%	54%	45%	
Female	63%	54%	61%	46%	54%	
Ethnicity						$\chi^2_{(6)} = 10.06$; N = 243
Black	92%	74%	84%	89%	88%	
White/Other	3%	13%	4%	2%	4%	
Latino	4%	13%	12%	9%	8%	
Maternal Education						$\chi^2_{(3)} = 5.35$; N = 236
Less than HS	19%	39%	25%	30%	26%	
HS or More	81%	61%	75%	70%	74%	
Treatment	57%	67%	50%	66%	61%	$\chi^2_{(3)} = 3.79$; N = 256
HTKS ITEMS: M(SD)						F(3,247)
HTKS 1	1.48 (.70)^{a}	1.58 (.72)^{a}	1.64 (.62)^{a}	.06 (.30)^{b}	.90 (.92)	143.10^{**}
HTKS 2	1.67 (.71)^{a}	1.83 (.56)^{a}	1.82 (.55)^{a}	0 (0)b	.99 (.99)	246.13^{**}
HTKS 3	1.54 (.62)^{a}	.67 (.96)^{b}	.61 (.83)^{b}	.08 (.39)^{c}	.73 (.89)	95.85^{**}
HTKS 4	1.91 (.28)^{a}	.79 (.98)^{b}	.64 (.95)^{b}	.02 (.14)^{c}	.86 (.97)	265.08^{**}
HTKS 5	1.96 (.21)^{a}	.54 (.88)^{b}	.54 (.88)^{b}	.02 (.14)^{c}	.84 (.97)	338.3^{**}
HTKS 6	1.86 (.41)^{a}	.83 (1.01)^{b}	.64 (.95)^{b}	.02 (.14)^{c}	.84 (.97)	214.11^{**}
HTKS 7	1.47 (.72)^{a}	1.33 (.96)^{a}	.21 (.57)^{b}	.07 (.38)^{b}	.72 (.90)	99.96^{**}
HTKS 8	1.76 (.56)^{a}	1.92 (.28)^{a}	0 (0)^{b}	0 (0)^{b}	.83 (.96)	541.47^{**}
HTKS 9	1.72 (.58)^{a}	1.5 (.88)^{a}	.04 (.19)^{b}	.03 (.21)^{b}	.79 (.95)	260.52^{**}
HTKS 10	1.83 (.50)^{a}	1.75 (.53)^{a}	0 (0)^{b}	0 (0)^{b}	.84 (.97)	566.81^{**}
HTKS Total	17.21 (2.48)^{a}	12.83 (2.06)^{b}	6.14 (2.99)^{c}	.30 (.72)^{d}	8.35 (7.93)	1277.07^{**}
OTHER VARIABLES:						
Receptive Vocabulary	16.25 (3.71)^{a}	16.13 (3.48)^{a}	15.78 (3.70)^{a}	16.02 (2.99)^{a}	16.09 (3.37)	$F(3,242) = 0.16$
Visuomotor Integration	13.41 (2.36)^{ab}	13.88 (2.15)^{a}	13.43 (1.91)^{ab}	12.29 (2.19)^{b}	12.99 (2.30)	$F(3,245) = 6.34^{**}$
Closeness Time 1	4.30 (.60)^{ab}	3.97 (.59)^{a}	4.54 (.54)^{b}	4.10 (.66)^{a}	4.21 (.64)	$F(3,223) = 5.03^{**}$
Closeness Time 2	4.43 (0.51)^{a}	4.02 (0.85)^{b}	4.57 (0.50)^{a}	4.16 (0.68)^{b}	4.30 (0.64)	$F(3,228) = 5.85^{**}$
Conflict Time 1	1.66 (.76)^{a}	1.88 (.75)^{ab}	1.38 (.58)^{a}	2.04 (.91)^{b}	1.80 (.84)	$F(3,223) = 5.80^{**}$
Conflict Time 2	1.89 (0.90)^{ab}	1.99 (0.84)^{ab}	1.46 (0.75)^{a}	2.06 (0.99)^{b}	1.92 (0.93)	$F(3,228) = 3.04^{*}$
Mathematics Time 1	13.7 (3.28)^{a}	14.04 (3.57)^{a}	12.46 (3.16)^{a}	10.56 (3.12)^{b}	12.24 (3.55)	$F(3,245) = 18.34^{**}$
Mathematics Time 2	19.71 (3.51)^{a}	20.95 (4.25)^{a}	18.25 (3.14)^{a}	15.94 (3.70)^{b}	18.09 (4.08)	$F(3,210) = 19.81^{**}$
Literacy Time 1	13.8 (5.9)^{a}	13 (5.54)^{ab}	11.18 (3.46)^{ab}	10.62 (4.37)^{b}	12.06 (5.20)	$F(3,245) = 7.14^{**}$
Literacy Time 2	26.43 (7.83)^{a}	28.67 (8.30)^{a}	21.33 (6.03)^{b}	20.96 (7.19)^{b}	23.76 (7.94)	$F(3,209) = 11.25^{**}$

Note. Means in the same row that share superscripts do not differ at $p < .05$ according to Tukey post hoc comparisons. Class 1 = "Integrated Self-Regulators"; Class 2 = "Conscious Regulators"; Class 3 = "Effortful Regulators"; and Class 4 = "Poor Regulators"

Table 5.

Path analysis results predicting achievement outcomes from summed score of behavioral self-regulation

		Concurrent Associations (Time 1)						Predictive Associations (Time 2)					
		Model 1 (Covariates Only)			Model 2 (Covariates + Behavioral Self-regulation)			Model 3 (Covariates Only)			Model 4 (Time 2)		
Outcome	Predictors	*β*	*SE*	*z*	*β*	*SE*	*z*	*β*	*SE*	*z*	*β*	*SE*	*z*
Literacy													
	Age	0.03	0.05	0.61	0.02	0.05	0.38	-0.01	0.05	-0.12	-0.003	0.05	-0.05
	Male	-0.09	0.04	-2.11*	-0.07	0.04	-1.49	-0.09	0.05	-1.72†	-0.09	0.06	-1.55
	Treatment	0.05	0.06	0.88	0.07	0.05	1.22	0.04	0.04	1.06	0.05	0.04	1.35
	High School or More	-0.03	0.04	-0.78	-0.01	0.04	-0.29	-0.04	0.03	-1.14	-0.04	0.04	-0.89
	Receptive Vocabulary	-0.01	0.05	-0.23	-0.01	0.04	-0.3	0.05	0.03	1.54	0.05	0.04	1.39
	Visuomotor Integration	0.51	0.06	8.43***	0.47	0.06	7.72***	0.15	0.04	2.92***	0.16	0.05	3.02***
	Literacy Time 1							0.5	0.04	13.05***	0.51	0.04	12.75***
	Math Time 1							0.18	0.05	3.78***	0.12	0.06	2.16*
	Behavioral Self-Regulation				0.19	0.05	4.02***				0.10	0.05	2.10*
	R-square		0.28			0.31			0.55			0.56	
Math													
	Age	0.18	0.04	4.07***	0.16	0.04	3.77***	-0.05	0.04	-1.08	-0.04	0.04	-1.00
	Male	-0.14	0.07	-2.09	-0.1	0.07	-1.49	-0.05	0.06	-0.78	-0.04	0.06	-0.57
	Treatment	-0.03	0.04	-0.71	-0.01	0.04	-0.15	-0.1	0.05	-2.06*	-0.08	0.05	-1.78†
	High School or More	-0.07	0.05	-1.44	-0.04	0.04	-0.9	-0.06	0.04	-1.38	-0.04	0.04	-0.88
	Receptive Vocabulary	0.03	0.08	0.33	0.02	0.06	0.34	-0.01	0.04	-0.25	-0.02	0.04	-0.51
	Visuomotor Integration	0.47	0.05	9.38***	0.41	0.05	8.15***	0.17	0.05	3.14***	0.18	0.06	3.16***
	Literacy Time 1							0.05	0.09	0.55	0.07	0.10	0.72
	Math Time 1							0.51	0.06	8.79***	0.39	0.06	6.10***
	Behavioral Self-Regulation				0.30	0.04	7.10***				0.21	0.06	3.61***
	R-square		0.32			0.40			0.44			0.46	
	Overall R-square		0.40			0.47			0.66			0.68	

Note. SE = Robust Standard Error; Male = 1, Female = 0; Treatment = 1, Control = 0; High School or more = 1, Less than High School = 0.

Table 6.

Path analysis results predicting student-teacher relationships from summed score of behavioral self-regulation

		Concurrent Associations						Predictive Associations					
		Model 1 (Covariates only)			Model 2 (Time 1)			Model 3 (Covariates Only)			Model 4 (Time 2)		
Outcome	Predictors	*β*	*SE*	*z*	*β*	*SE*	*z*	*β*	*SE*	*z*	*β*	*SE*	*z*
Conflict													
	Age	0.02	0.05	0.35	0.02	0.04	0.54	-0.01	0.06	-0.12	-0.01	0.05	-0.19
	Male	0.13	0.07	1.78†	0.11	0.07	1.56	0.02	0.03	0.75	0.03	0.03	0.89
	Treatment	0.05	0.07	0.74	0.04	0.07	0.59	0.01	0.03	0.4	0.02	0.03	0.59
	High School or More	0.14	0.07	1.90†	0.12	0.07	1.72†	0.02	0.03	0.47	0.02	0.03	0.63
	Receptive Vocabulary	-0.07	0.05	-1.54	-0.07	0.05	-1.45	-0.12	0.08	-1.54	-0.12	0.07	-1.56
	Visuomotor Integration	-0.14	0.09	-1.73†	-0.12	0.08	-1.44	0.04	0.04	0.99	0.03	0.04	0.7
	Conflict Time 1							0.62	0.06	10.85***	0.63	0.06	11.22***
	Closeness Time 1							0.00	0.06	-0.01	-0.002	0.06	-0.04
	Behavioral Self-Regulation				-0.13	0.07	-1.82†				0.06	0.06	1.1
	R-square		0.06			0.08			0.42			0.42	
Closeness													
	Age	0.04	0.04	-0.89	-0.04	0.05	-0.94	0.01	0.06	0.2	0.01	0.06	0.14
	Male	-0.17	0.08	-2.30*	-0.17	0.08	-2.16†	-0.15	0.04	-3.49***	-0.14	0.04	-3.26**
	Treatment	-0.03	0.05	-0.62	-0.03	0.06	-0.5	-0.07	0.05	-1.47	-0.07	0.05	-1.44
	High School or More	-0.04	0.08	-0.57	-0.04	0.08	-0.51	-0.01	0.07	-0.13	-0.01	0.07	-0.08
	Receptive Vocabulary	0.06	0.05	1.24†	0.06	0.05	1.24	0.02	0.05	0.29	0.02	0.05	0.3
	Visuomotor Integration	0.05	0.06	0.88	0.04	0.06	0.68	0.02	0.05	0.44	0.01	0.05	0.28
	Conflict Time 1							-0.12	0.06	-2.19*	-0.12	0.05	-2.17*
	Closeness Time 1							0.44	0.08	5.39***	0.44	0.08	5.49***
	Behavioral Self-Regulation				0.05	0.07	0.81				0.05	0.04	1.16
	R-square		0.04			0.04			0.30			0.31	
	Overall R-square		0.08			0.10			0.56			0.57	

Note. SE = Robust Standard Error; Male = 1, Female = 0; Treatment = 1, Control = 0; High School or more = 1, Less than High School = 0.

Table 7.

Path analysis results predicting academic and relationship outcomes at Time 1 from patterns of behavioral self-regulation

		Class 4 is the reference			Class 3 is the reference			Class 2 is the reference			Class 1 is the reference		
Outcome	Predictors	*β*	*SE*	*z*	*β*	*SE*	*z*	*β*	*SE*	*z*	*β*	*SE*	*z*
Literacy Time 1													
	Age	0.03	0.05	0.55									
	Male	-0.07	0.04	-1.63									
	Treatment	0.05	0.06	0.98									
	High School or More	-0.01	0.04	-0.35									
	Receptive Vocabulary	-0.02	0.04	-0.39									
	Visuomotor Integration	0.49	0.06	7.80***									
	Class 1	0.17	0.05	3.55***	0.24	0.08	2.95**	0.12	0.10	1.22			
	Class 2	0.03	0.06	0.46	0.07	0.08	0.96				-0.07	0.06	-1.23
	Class 3	-0.05	0.05	-0.91				-0.08	0.08	-0.96	-0.16	0.05	-3.12**
	Class 4				0.08	0.08	0.91	-0.05	0.1	-0.46	-0.17	0.05	-3.61***
	R-square						0.31						
Math Time 1	Age	0.16	0.04	3.74***									
	Male	-0.1	0.07	-1.5									
	Treatment	-0.02	0.04	-0.5									
	High School or More	-0.06	0.05	-1.22									
	Receptive Vocabulary	0.02	0.06	0.31									
	Visuomotor Integration	0.41	0.05	7.89***									
	Class 1	0.28	0.05	5.61***	0.17	0.07	2.38*	-0.03	0.06	-0.48			
	Class 2	0.19	0.04	4.61***	0.12	0.04	2.76**				0.02	0.04	0.48
	Class 3	0.07	0.06	1.25				-0.13	0.05	-2.93**	-0.11	0.05	-2.50*
	Class 4				-0.11	0.08	-1.29	-0.32	0.07	-4.48***	-0.29	0.05	-5.73***
	R-square						0.39						
	Overall R-square						0.47						
Conflict Time 1													
	Age	0.03	0.04	0.74									
	Male	0.1	0.06	1.53									
	Treatment	0.03	0.06	0.47									
	High School or More	0.12	0.07	1.77†									
	Receptive Vocabulary	-0.07	0.04	-1.57									
	Visuomotor Integration	-0.1	0.07	-1.35									
	Class 1	-0.16	0.08	-2.14*	0.17	0.09	1.92†	-0.09	0.1	-0.96			
	Class 2	-0.04	0.07	-0.57	0.16	0.07	2.36*				0.06	0.06	0.95
	Class 3	-0.22	0.05	-4.18***				-0.18	0.08	-2.18*	-0.11	0.06	-1.89†
	Class 4				0.34	0.08	4.39***	0.07	0.12	0.57	0.16	0.08	2.12*
	R-square						0.11						
Closeness Time 1													

Age	-0.05	0.05	-1.14									
Male	-0.15	0.08	-1.87†									
Treatment	-0.01	0.05	-0.19									
High School or More	-0.02	0.08	-0.29									
Receptive Vocabulary	0.06	0.05	1.13									
Visuomotor Integration	0.04	0.06	0.64									
Class 1	0.12	0.07	1.59	-0.2	0.10	-1.97*	0.23	0.15	1.5			
Class 2	-0.07	0.09	-0.76	-0.26	0.09	-2.90**				-0.14	0.09	-1.47
Class 3	0.2	0.07	3.13***				0.27	0.11	2.57*	0.13	0.07	1.97*
Class 4				-0.32	0.10	-3.35**	0.11	0.15	0.77	-0.12	0.08	-1.57
R-square						0.09						
Overall R-square						0.16						

Note. SE = Robust Standard Error; Male = 1, Female = 0; Treatment = 1, Control = 0; High School or more = 1, Less than High School = 0. Class 1 = "Integrated Self-Regulators"; Class 2 = "Conscious Regulators"; Class 3 = "Effortful Regulators"; and Class 4 = "Poor Regulators"

Table 8.

Path analysis results predicting academic and relationship outcomes at Time 2 from patterns of behavioral self-regulation

		Class 4 is the reference			Class 3 is the reference			Class 2 is the reference			Class 1 is the reference		
Outcome	Predictors	*β*	*SE*	*z*	*β*	*SE*	*z*	*β*	*SE*	*z*	*β*	*SE*	*z*
Literacy Time 2													
	Age	-0.004	0.04	-0.09									
	Male	-0.09	0.05	-1.76†									
	Treatment	0.04	0.03	1.25									
	High School or More	-0.05	0.04	-1.15									
	Receptive Vocabulary	0.05	0.03	1.57									
	Visuomotor Integration	0.15	0.05	3.00**									
	Literacy Time 1	0.51	0.04	12.06***									
	Math Time 1	0.12	0.05	2.37*									
	Class 1	0.08	0.06	1.51	0.13	0.05	2.56*	-0.15	0.08	-1.84†			
	Class 2	0.15	0.06	2.56*	0.18	0.05	3.85***				0.09	0.05	1.79†
	Class 3	-0.03	0.04	-0.85				-0.19	0.05	-3.90***	-0.09	0.03	-2.61**
	Class 4				0.05	0.06	0.87	-0.24	0.09	-2.75**	-0.09	0.06	-1.50
	R-square							0.57					
Math Time 2													
	Age	-0.05	0.04	-1.36									
	Male	-0.03	0.06	-0.53									
	Treatment	-0.09	0.04	-2.13*									
	High School or More	-0.05	0.05	-1.04									
	Receptive Vocabulary	-0.01	0.04	-0.15									
	Visuomotor Integration	0.15	0.05	2.79**									
	Literacy Time 1	0.06	0.08	0.72									
	Math Time 1	0.42	0.05	7.62***									
	Class 1	0.20	0.06	3.23**	0.05	0.06	0.91	-0.12	0.10	-1.22			
	Class 2	0.19	0.06	3.05**	0.10	0.07	1.59				0.07	0.06	1.19
	Class 3	0.10	0.05	1.86†				-0.11	0.07	-1.67†	-0.03	0.04	-0.93
	Class 4				-0.15	0.08	-1.93†	-0.33	0.09	-3.46**	-0.21	0.06	-3.28**
	R-square							0.48					
	Overall R-square						0.70						
Conflict Time 2													
	Age	-0.004	0.06	-0.07									
	Male	0.03	0.04	0.83									
	Treatment	0.01	0.03	0.46									
	High School or More	0.02	0.03	0.65									
	Receptive Vocabulary	-0.12	0.07	-1.65									
	Visuomotor Integration	0.03	0.04	0.88									
	Conflict Time 1	0.62	0.06	10.84***									

	Closeness Time 1	0.004	0.05	0.08									
	Class 1	0.05	0.06	0.91	0.14	0.08	1.74†	0.03	0.09	0.31			
	Class 2	0.02	0.05	0.32	0.07	0.06	1.21				-0.02	0.05	-0.31
	Class 3	-0.06	0.04	-1.36				-0.08	0.06	-1.20	-0.09	0.05	-1.73†
	Class 4				0.09	0.07	1.37	-0.03	0.09	-0.31	-0.06	0.06	-0.90
	R-square							0.42					
Closeness Time 2													
	Age	0.004	0.06	0.06									
	Male	-0.14	0.04	-3.22**									
	Treatment	-0.07	0.05	-1.45									
	High School or More	0.003	0.07	0.04									
	Receptive Vocabulary	0.02	0.05	0.34									
	Visuomotor Integration	0.02	0.05	0.39									
	Conflict Time 1	-0.11	0.06	-1.96†									
	Closeness Time 1	0.41	0.09	4.68***									
	Class 1	0.07	0.05	1.51	-0.03	0.08	-0.32	0.17	0.14	1.27			
	Class 2	-0.06	0.08	-0.74	-0.12	0.1	-1.26				-0.11	0.08	-1.29
	Class 3	0.07	0.07	0.97				0.13	0.11	1.25	0.02	0.05	0.31
	Class 4				-0.10	0.10	-1.00	0.10	0.14	0.73	-0.08	0.05	-1.49
	R-square							0.32					
	Overall R-square						0.58						

Note. SE = Robust Standard Error; Male = 1, Female = 0; Treatment = 1, Control = 0; High School or more = 1, Less than High School = 0. Class 1 = "Integrated Self-Regulators"; Class 2 = "Conscious Regulators"; Class 3 = "Effortful Regulators"; and Class 4 = "Poor Regulators"

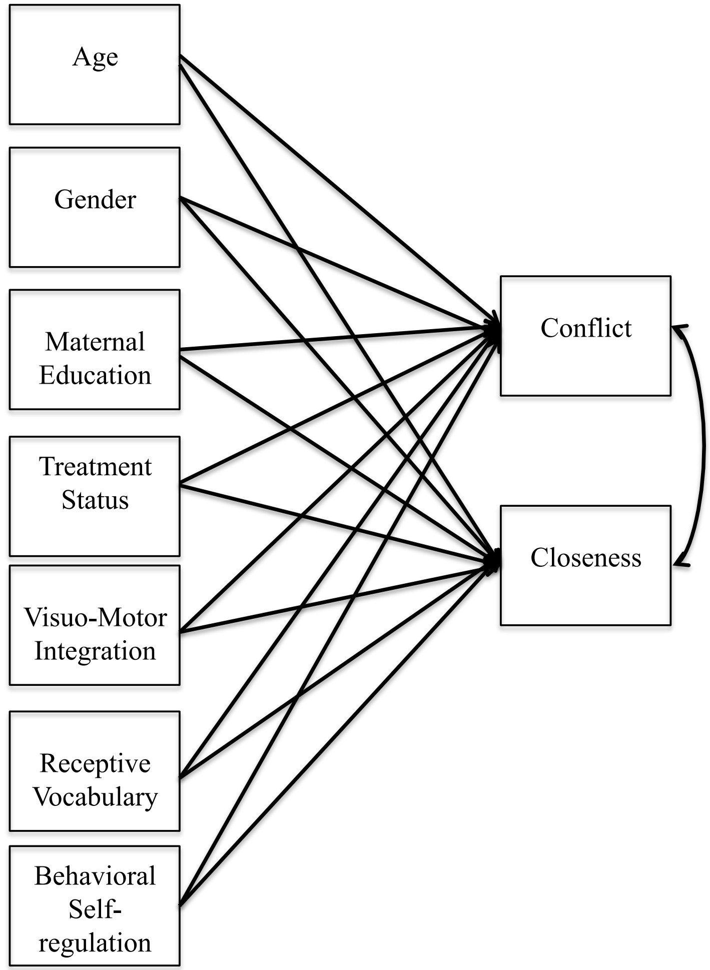


Figure 1. Concurrent associations examining the contribution of behavioral self-regulation (sum score) at the beginning of kindergarten (Time 1) to teacher perceptions of closeness and conflict at Time 1, controlling for age, gender (male = 1), maternal education (0 = less than high school; 1 = high school or more), treatment status (0 = control; 1 = treatment), visuomotor integration, and receptive vocabulary. This model was also conducted using achievement scores (math and literacy at Time 1) as outcomes. All predictors were correlated with each other.

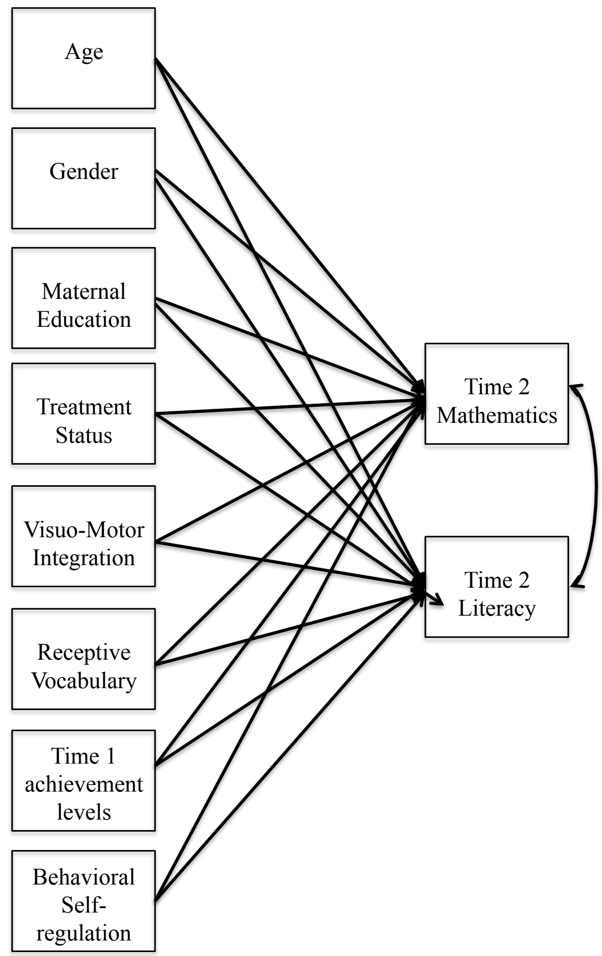


Figure 2. Associations examining the contribution of behavioral self-regulation (sum score) at the beginning of kindergarten (Time 1) to mathematics and literacy achievement at the end of kindergarten (Time 2), controlling for age, gender (male = 1), maternal education (0 = less than high school; 1 = high school or more), treatment status (0 = control; 1 = treatment), visuomotor integration, receptive vocabulary, and initial levels (Time 1) of mathematics and literacy. This model was also conducted using relationship quality scores (conflict and closeness at Time 2) as outcomes. All predictors were correlated with each other

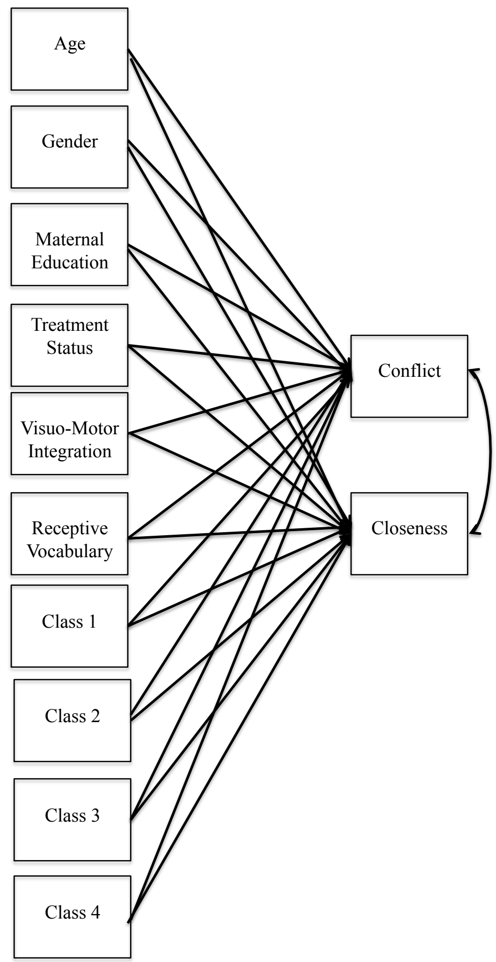
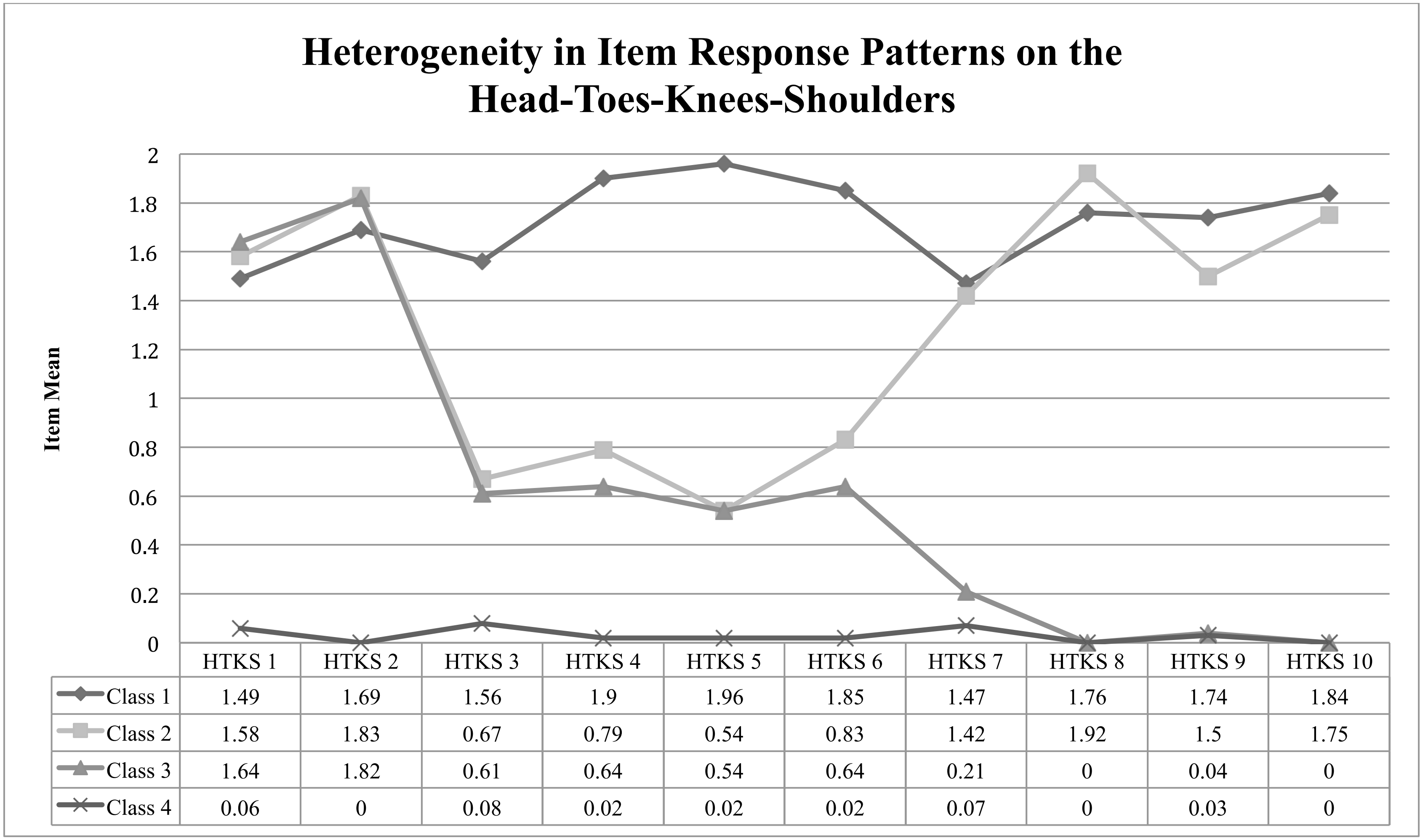


Figure 3. Associations between distinct response profiles of behavioral self-regulation at the beginning of kindergarten (Time 1) to relationship quality at Time 1, controlling for age, gender (male = 1), maternal education (0 = less than high school; 1 = high school or more), treatment status (0 = control; 1 = treatment), visuomotor integration, and receptive vocabulary. This model shows four classes as a visual; however, the actual model included three dummy coded classes with the fourth being the reference group. This model was also conducted using achievement scores (math and literacy at Time 1) as outcomes, as well as relationship quality and achievement scores at Time 2, controlling for initial scores at Time 1. Class 1 = "Integrated Self-Regulators"; Class 2 = "Conscious Regulators"; Class 3 = "Effortful Regulators"; and Class 4 = "Poor Regulators". All predictors were correlated with each other



	HTKS 1	HTKS 2	HTKS 3	HTKS 4	HTKS 5	HTKS 6	HTKS 7	HTKS 8	HTKS 9	HTKS 10
Class 1	1.49	1.69	1.56	1.9	1.96	1.85	1.47	1.76	1.74	1.84
Class 2	1.58	1.83	0.67	0.79	0.54	0.83	1.42	1.92	1.5	1.75
Class 3	1.64	1.82	0.61	0.64	0.54	0.64	0.21	0	0.04	0
Class 4	0.06	0	0.08	0.02	0.02	0.02	0.07	0	0.03	0

Figure 4. Distinct item response patterns on the Head-Toes-Knees-Shoulders (HTKS; Cameron Ponitz et al., 2009) task. Class 1 = "Integrated Self-Regulators"; Class 2 = "Conscious Regulators"; Class 3 = "Effortful Regulators"; and Class 4 = "Poor Regulators".