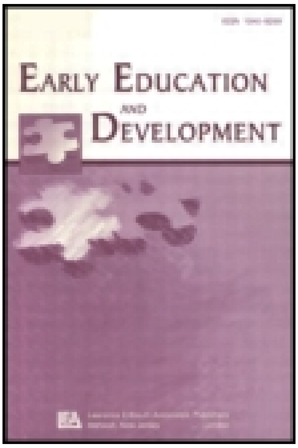

Early Education & Development
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/heed20

Associations Between Low-Income Children's Fine Motor Skills in Preschool and Academic Performance in Second Grade

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Published online: 07 Feb 2013.

Early Education and Development, 24: 138–161

ISSN: 1040-9289 print/1556-6935 online
DOI: 10.1080/10409289.2011.636729

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Research Findings: Given the growing literature pertaining to the importance of fine motor skills for later academic achievement (D. W. Grissmer, K. J. Grimm, S. M. Aiyer, W. M. Murrah, & J. S. Steele, 2010), the current study examines whether the fine motor skills of economically disadvantaged preschool students predict later academic performance in 2nd grade. More specifically, we expand on the current literature and evaluate whether 2 types of fine motor skills—fine motor object manipulation and fine motor writing—predict academic achievement above and beyond the effects of demographic characteristics and early language and cognition skills. Results indicate that performance on both fine motor writing and object manipulation tasks had significant effects on 2nd-grade reading and math achievement, as measured by grades and standardized test scores. Stronger effects were yielded for writing tasks compared to object manipulation tasks. *Practice or Policy:* Implications for researchers and early childhood practitioners are discussed.

Over the past few years, a number of studies have reported significant effects of fine motor skills on later academic achievement (Grissmer, Grimm, Aiyer, Murrah, & Steele, 2010; Son & Meisels, 2006). Many of these studies have reported findings of secondary data analyses from the Early Childhood Longitudinal Study–Kindergarten (ECLS-K), National Longitudinal Study of Youth, and British Cohort Study data sets (Grissmer et al., 2010). As a result, most of the fine motor measures used in these studies are based on a general score of fine motor skills, which has led some to question which specific characteristics of fine motor tasks promote later academic achievement. For example, findings from Grissmer et al. (2010) suggest that copying designs might be particularly influential in promoting achievement compared to other fine motor tasks.

The current study explores the effects of two types of fine motor skills on later academic achievement. The first, fine motor object manipulation, requires children to demonstrate manual dexterity through the manipulation of objects. Tasks associated with manual dexterity include weaving string through holes, stacking blocks, lacing beads on a string, turning the pages of a book, placing pegs on a pegboard, cutting with scissors, manipulating play dough, and folding paper into shapes. The second, fine motor writing, requires children to demonstrate early

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graphomotor skill through the production and often replication (copying) of symbols, numbers, and letters on a piece of paper using a writing utensil.

This study explores these effects among an economically disadvantaged sample of children who received financial subsidies to attend an early education program. Economically disadvantaged children continually have lower academic performance scores during the early elementary school years (Arnold & Doctoroff, 2003; Duncan, Brooks-Gunn, & Klebanov, 1994; McLoyd, 1998; Zhao, Brooks-Gunn, McLanahan, & Singer, 2002) and therefore constitute a large population of children who would benefit from a strong academic beginning. What is interesting is that several studies have also found that children from low-income families score lower on measures of fine motor writing compared to higher income children (Bowman & Wallace, 1990; West, Denton, & Germino-Hausken, 2000). Because of this, it is important to understand how early variations in fine motor skills might positively impact later academic achievement.

FINE MOTOR SKILLS AND ACADEMIC ACHIEVEMENT

Research indicates that fine motor abilities are significant predictors of later academic achievement (Carlton & Winsler, 1999; Grissmer et al., 2010; Luo, Jose, Huntsinger, & Pigott, 2007; Sortor & Kulp, 2003). *Fine motor skills* are defined as small-muscle movements, namely those of the fingers. Researchers examining fine motor ability have historically used various terms (e.g., *visual-motor integration, perceptual-motor ability*) to reflect the fact that successful fine motor performance requires visual perception and discrimination, motoric ability, and the integration of the two (Case-Smith et al., 1998; Sortor & Kulp, 2003). In the classroom, many of the tasks that are used to demonstrate achievement, including assignments submitted for grading, are dependent in large part upon fine motor ability (e.g., Kulp, 1999; Schoemaker & Kalverboer, 1994; Smits-Engelsman, Niemeijer, & van Galen, 2001; Sortor & Kulp, 2003; Tseng & Chow, 2000). McHale and Cermak (1992) found that students in second, fourth, and sixth grade spend 30% to 60% of their time engaged in activities that require fine motor skill, including writing, building, and cutting.

Sortor and Kulp (2003) identified various means by which visual-motor skills can influence academic achievement, including the accurate perception and discrimination of academic symbols (e.g., letters and numbers) and the ability to accurately reproduce the visual form consistently. More recently, Grissmer and his colleagues (2010) reported on a wealth of work suggesting that the link between fine motor ability and academic achievement may be a result of associations with more complex cognitive and behavioral elements. Grissmer et al.'s work highlights current neuroimaging and neuroanatomy research linking motoric development and cognition. Rather than a simple correlation of skills, current evidence suggests that the fine motor/academic performance association is a complex, brain-based phenomenon. In fact, certain motor and cognitive tasks simultaneously activate regions of the brain once thought to be uniquely involved in either motor or cognitive activities (Grissmer et al., 2010).

A number of tasks can be classified as requiring fine motor skill. Some tasks, such as placing a peg in a hole, lacing, and building with blocks, require manual dexterity for their accurate completion. *Manual dexterity* refers to an individual's ability to accurately manipulate objects with the hands (Houwen, Visscher, Lemmink, & Hartman, 2009). Other fine motor skills, particularly those that involve writing, are considered significantly more complex. Researchers have long separated writing from other fine motor skills in both clinical and nonclinical samples (Flapper, Houwen, & Schoemaker, 2006; Jones & Lederman, 2006; Levine, 2002; Mayes, Calhoun, Bixler, & Zimmerman, 2009; Smits-Engelsman et al., 2001; Sugden & Wright, 1998) and have used different tools to measure these skills. For example, the Beery Developmental Test of Visual-Motor Integration (Beery, 1997) is often utilized as a tool to measure fine motor writing, or graphomotor skill (Mayes et al., 2009), whereas the Movement Assessment Battery for Children–2 (Henderson, Sugden, & Barnett, 1992) is often used to measure fine motor manipulation, or manual dexterity (Smits-Engelsman et al., 2001). Similar to receptive and expressive language, fine motor manipulation and fine motor writing may be highly correlated but are considered distinct processes (Levine, 2002; Mayes et al., 2009). In other words, although fine motor manipulation skills are essential to executing the appropriate force and control of the arm, hand, and fingers in order to write (Alston & Taylor, 1987; Thomassen & Teulings, 1983), graphomotor tasks are considered the joint outcome of several cognitive and neuromotor processes (Smits-Engelsman et al., 2001), including visual-spatial perception, visual size discrimination, visual retrieval, and orientation discrimination (Thomassen & Teulings, 1983).

Several studies have examined the effect of fine motor skill on academic achievement as a general construct. For instance, Luo et al. (2007) conducted a secondary analysis using data from the ECLS-K and found that fine motor skill, as measured by the Early Screening Inventory–Revised (Meisels, Marsden, Wiske, & Henderson, 1997), which included building a gate, drawing a person, and copying five simple figures (a circle, cross, square, triangle, and open square and circle), significantly predicted mathematics skills over time and also mediated the relation between ethnicity and mathematics achievement when Asian American kindergartners were compared to their White/Caucasian counterparts. Son and Meisels (2006), also using ECLS-K data, found that fine motor skills, also measured with the Early Screening Inventory–Revised, accounted for a small but unique amount of the variance in math and reading skills at the end of first grade. Together, the research in this area supports a significant and positive association between general fine motor skills and later academic performance but fails to disentangle the effects of fine motor manipulation from fine motor writing.

Most of the studies exploring early fine motor skills and later academic achievement have historically focused specifically on fine motor writing skills alone. For example, Keogh and Smith (1967) found that kindergartners' visual-motor integration performance on the Bender-Gestalt (a measure of writing skills) was a significant predictor of performance on standard achievement tests during the latter part of elementary school. Similarly, Kulp (1999) found that kindergartners' performance on the Beery Developmental Test of Visual-Motor Integration (Beery, 1997)—a measure of writing skills—was a significant predictor of various standard measures of concomitant academic achievement, including reading, math, writing, and spelling.

Recent work with the British Cohort Study indicates that kindergartners' ability to copy various shapes using a writing utensil may be a stronger predictor of academic success in middle school than other types of fine motor tasks (Grissmer et al., 2010). Similarly, Mayes and Calhoun (2007) found that fine motor writing explained a significant portion of the variance above and beyond that of IQ in the academic achievement of elementary school students. This finding was supported by Longcamp, Zerbato-Poudou, and Velay's (2005) work, which pointed to fine motor writing as having a unique effect on academic achievement. Four-year-olds who spent time copying letters using a writing utensil made significant gains on a letter recognition assessment compared to 4-year-olds who used a keyboard to type the letters. The authors argued that writing the letters helped the children develop an internal model of the alphabetic character, whereas simply pressing a key on a keyboard (which is arguably different from formal typing) did not. The development of an internal model associated with copying and writing is believed to explain the improved memory for letter recognition that is considered a significant building block for reading (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). Given the growing body of work focused on fine motor ability, and the suggestion that this is a domain in which to target intervention practices (e.g., Grissmer et al., 2010), it is critical to provide evidence of the types of fine motor tasks that will produce the greatest effects.

FINE MOTOR ACTIVITIES IN THE EARLY CHILDHOOD CLASSROOM

The early childhood classroom provides children with opportunities to engage in various fine motor tasks. McHale and Cermak (1992) found that school-age children spent 30% to 60% of their day engaged in fine motor activities. Eighty-five percent of those activities involved paper-and-pencil-type fine motor tasks. In a downward extension of McHale and Cermak's study, Marr, Cermak, Cohn, and Henderson (2003) conducted similar observations of the fine motor engagement of both children in a Head Start classroom and children in a kindergarten classroom. Marr et al. identified two types of fine motor tasks utilized in the early childhood classroom. The first type was identified as nonacademic content, including finger play, art activities, manipulative play (i.e., Legos®, play dough), and play in centers (i.e., blocks, sand table). The second type was characterized as incorporating academic content, included writing letters and numerals, drawing or coloring on a worksheet, and cutting or gluing on a worksheet. Marr and colleagues found that children in Head Start spent an average of 37% of the day engaged in fine motor activities, of which only 10% was spent on paper-and-pencil tasks. They found that by kindergarten children spent 46% of their day engaged in fine motor activities, of which 42% was spent on paper-and-pencil tasks. Although the authors argued that this increase in time spent engaged in more academically focused tasks in kindergarten was developmentally appropriate, they also stated that examining the fine motor skills of children in early childhood programs and their preparedness for later academic demands would be beneficial to occupational therapists and educators alike.

THE CURRENT STUDY

The current study is a secondary data analysis using fine motor data collected through the Miami-Dade School Readiness Project (M-DSRP). The M-DSRP was a large-scale university–community applied research and evaluation project designed to examine the effect of child care on the school readiness of economically disadvantaged children receiving subsidies to attend a community-based preschool program in Miami-Dade, Florida, a multicultural urban community (see Winsler et al., 2008, for a complete description). A substantial group of preschoolers were assessed on their cognitive, language, and fine motor development using the Learning Accomplishment Profile–Diagnostic (LAP-D; Nehring, Nehring, Bruni, & Randolph, 1992). Three years later, children's school performance was assessed by the Miami-Dade County Public School System. The secondary analysis involved merging the preschool data set with the academic records collected by the school system.

The current study focuses on the following research question: Do fine motor skills in preschool, disentangled as two constructs of (a) fine motor manipulation and (b) writing, uniquely predict reading and math achievement in second grade above and beyond the effects of early language and cognition skills? This study intends to expand on the robustness of current findings by examining this phenomenon in a sample of economically disadvantaged and primarily Hispanic preschoolers. Preschoolers were assessed on two fine motor tasks that included (a) the manipulation of objects, such as folding, building towers, and weaving string; and (b) activities involving a writing utensil, such as imitating strokes, copying letters, copying shapes, and drawing simple objects. Academic performance in second grade was evaluated using students' classroom grades in math and reading and the mathematics and reading components of the Stanford Achievement Test, 10th Edition (SAT10; Harcourt Brace, 2003), a standardized achievement test. It was hypothesized that fine motor object manipulation skills in preschool would have a positive association with both math and reading performance in second grade on both classroom grades and the SAT10. Given that paper-and-pencil tasks are more likely to be academic in nature, fine motor *writing* ability in preschool was expected to have a strong positive association with math and reading performance on both classroom grades and SAT10 score in second grade and account for more variance than fine motor object manipulation.

METHOD

Participants

Data used in this study were extracted from the M-DSRP. Children who participated in the M-DSRP received government subsidies to attend a non–Head Start early education program. The M-DSRP data set does not include children enrolled in Head Start programs, as Head Start has its own administrative structure and established school readiness assessment procedure. In accordance with Florida law, the Agency for Workforce Innovation Office of Early Learning requires that children receiving child care subsidies participate in regular assessments to measure school readiness skills prior to kindergarten as well as the quality of educational services provided (Agency for Workforce Innovation, 2007). The preschool assessment process was administered by the Early Learning Coalition of Miami-Dade/Monroe and implemented by Miami-Dade County's Child Development Services. The academic progress of these children during early elementary school was subsequently added to the M-DSRP data set. The academic progress data only included those data from the Miami-Dade County Public Schools. Children who attended private school or school in another district did not have academic progress data in the M-DSRP data set.

The data used in the current study were extracted from the M-DSRP data set. The initial data set from the M-DSRP included children who had both preschool assessment data (2004) and academic progress data in second grade 3 years later (2007; $N = 3{,}903$). The M-DSRP indicated that 25% of eligible children did not participate in preschool assessments because parents did not consent (3%) or because the child was unreachable at the time of assessment (22%). No information was provided for these nonparticipating children. Therefore, it was not possible to determine whether those who participated and those who did not represented different groups.

For the purposes of the current investigation, students identified as having a learning delay/disability in the second grade ($n = 669$) were excluded from the extracted data set. Therefore, all analyses, including the demographic analysis presented here, were conducted on the remaining 3,234 children. These children were enrolled in one of 613 early learning centers in Miami-Dade County in 2004 and 230 schools in the Miami-Dade County Public School System, the fourth largest school district in the United States, in 2007.

Children's average age was 62.5 months ($SD = 3.6$ months) at the time of the initial preschool assessment. Moreover, 47% ($n = 1{,}530$) of the sample was male. Public school records were used to gather the demographic information described here. Thus, the demographic information collected on the participants was limited to the information provided in public school records. According to those records, 57% ($n = 1{,}828$) of the sample was Hispanic/Latino, 35% ($n = 1{,}125$) was Black/African American (including of Caribbean/Haitian origin), and the remaining 8% ($n = 281$) was White/non-Hispanic/Caucasian or other. Children were assessed in either Spanish or English in preschool, depending on their language dominance as determined by teacher report and the assessor. About 80% of the sample was assessed in English ($n = 2{,}587$), and 21% ($n = 646$) was assessed in Spanish. In addition, 77% ($n = 2{,}500$) of the participants were in the free/reduced lunch program in the second grade (an indicator of economic disadvantage; free/reduced lunch, <185% of the federal poverty line). Children's absence from school in second grade ranged from 0 to 66 days, with an average of 6 days ($M = 6.23$, $SD = 6.26$).

Measures

Fine motor skills in prekindergarten. The LAP-D (Nehring et al., 1992) is a standardized assessment designed to measure children's developmental abilities in the areas of cognition, language, gross motor, and fine motor. In accordance with Florida law, the Agency for Workforce Innovation Office of Early Learning requires that children receiving child care subsidies participate in assessments to determine information about their development and to ensure that these children are receiving quality educational services so that they are ready to learn when they reach kindergarten (Agency for Workforce Innovation, 2007).

As reported in previous work (De Feyter & Winser, 2009; Winsler et al., 2008), the LAP-D was selected by the community's early childhood assessment taskforce to assess school readiness because (a) it is consistent with the state's early learning performance standards (Florida Partnership for School Readiness, 2003); (b) it is a standardized, norm-referenced instrument designed with regard to curriculum-based, authentic assessment (Nehring et al., 1992); (c) it can be administered in either Spanish or English; (d) technology to assist with large-scale data collection and dissemination was available for use; and (e) it reports good internal consistency for both the English-speaking sample ($\alpha = .89$–$.97$; Hardin, Peisner-Feinberg, & Weeks, 2005) and the Spanish-speaking sample ($\alpha = .90$–$.97$; Hardin et al., 2005). The LAP-D technical manual also reports good test–retest reliability for both the English-speaking sample subscales (.88–.96; Hardin et al., 2005) and the Spanish-speaking sample subscales (.86–.94; Hardin et al., 2005). Interrater reliability is also sufficient for both the English-speaking sample subscales (.82–.93; Hardin et al., 2005) and the Spanish-speaking sample subscales (.72–.92; Hardin et al., 2005). Results for construct and criterion validity also indicate that the LAP-D is valid when compared with other established instruments.

The LAP-D assesses development across eight subscales: (a) Fine Motor Manipulation (FM), (b) Fine Motor Writing (FW), (c) Language Naming, (d) Language Comprehension, (e) Cognitive Counting, (f) Cognitive Matching, (g) Gross Motor Body, and (h) Gross Motor Object. Partial correlations controlling for chronological age indicated good construct validity reflecting related but distinct areas of development (Hardin et al., 2005). The current study focuses on the FM and FW subscales of the LAP-D.

The FM subscale of the LAP-D is designed to capture children's manual dexterity and asks children to complete a number of tasks, including building towers, steps, and bridges with blocks; weaving string through holes; lacing beads on a string; turning the pages of a book; placing pegs on a pegboard; cutting with scissors; manipulating play dough; and folding paper into shapes. For all 28 items, assessors are instructed to demonstrate the task and say, ''You do it.'' Items are scored as correct (+) or incorrect (–), and notes are provided to the assessor by the assessment manual when applicable (e.g., the child scores a (–) if he or she laces the outline of a picture, if he/she misses one or more hole). The raw score is the total number of correct items. The FW subscale of the LAP-D is designed to capture children's early graphomotor abilities. All 31 items are conducted using a pencil, and children are asked to imitate strokes; copy letters, numbers, and shapes; and draw simple objects such as people and houses. All items are scored as correct (+) or incorrect (–), and examples of correct and incorrect items are provided to the assessor by the assessment manual when applicable. The raw score is the total number of correct items. The LAP-D reports good internal consistency for both the FM subscale ($\alpha = .81$) and FW subscale ($\alpha = .91$; Hardin et al., 2005).

Academic achievement. Classroom grades and performance scores on the SAT10 were used to assess academic achievement in second grade. Math and reading classroom grades were scored on a 5-point scale, with 4 representing an A and 0 representing an F. Grade point averages (GPAs) were collected at the end of the second-grade academic year and gathered by the local school district. Although classroom grades, as a measure of academic performance, do not hold psychometric properties, they have been shown to be significant predictors of long-term academic success, including retention and dropout rates (Garnier, Stein, & Jacobs, 1997; Jimerson, Egeland, Sroufe, & Carlson, 2000; Lee & Burkam, 2003; Roderick, 1994).

The SAT10 (Harcourt Brace, 2003) is a standardized, nationally recognized assessment of achievement. The SAT10 is administered annually in the spring of the second-grade academic year by the Miami-Dade County Public School System. The assessment is administered by the students' teachers in the children's classrooms. The SAT10 reports good reliability (.88) and validity with other standardized assessments of academic achievement (Harcourt Brace, 2003). The reading section of the assessment evaluates word study skills, reading vocabulary, and reading comprehension. The math portion of the assessment includes problem solving and procedures.

Covariates

Included in the analyses were a series of control variables to examine the extent to which fine motor manipulation and fine motor writing predicted academic achievement above and beyond the effects of other early developmental skills, such as expressive language ability, language comprehension, cognitive matching, and early counting. The Language Naming subscale of the LAP-D is a general measure of expressive language ability. It asks children to repeat words presented by the examiner, spontaneously produce the words presented on a test plate by the examiner, and answer information questions such as ‘‘What makes a car go?’’ and ‘‘What makes the leaves move?’’ The Language Comprehension subscale of the LAP-D, in contrast, is a measure of receptive language ability. The assessment asks children to respond to single- and two-step commands and point to a picture that matches a phrase presented by the examiner, such as ‘‘Point to something we eat with’’ and ‘‘Point to something we wear.’’

Scores on the Cognitive Counting and Cognitive Matching subscales of the LAP-D were also used as control variables in the analyses. On the Cognitive Counting subscale, children are asked to perform tasks generally related to counting, including reciting numbers to 10, counting objects, and understanding differences between quantities. On the Cognitive Matching subscale, children are asked to match pictures of shapes, objects, and animals. Also on the Cognitive Matching subscale, children are asked to copy geometric designs using shape manipulatives and point to letters and numbers on a test plate that are alike.

Missing Data

Complete data were available for 92% of the participants. Multiple imputation using SPSS Version 17.0 created a ‘‘completed’’ data set with the original data enhanced by the imputed data (Hill, Waldfogel, Brooks-Gunn, & Han, 2005). Five sets of imputations were created using all variables in the model. The imputation then aggregated across the five data sets, and data analyses were conducted across all data sets. Given that the results with imputed data were highly congruent (see Table 1), we present the results for a single imputed data set.

TABLE 1
Ranges, Means, and Standard Deviations for Preschool and Second-Grade Performance

Performance	*Range*	*M*	*SD*
Preschool performance			
Control variables (LAP-D raw scores)			
Language Naming	0–30	21.69	4.97
Language Comprehension	2–26	20.14	2.44
Cognitive Counting	0–33	22.85	5.46
Cognitive Matching	0–24	20.65	2.61
Independent variables (LAP-D raw scores)			
Fine Motor Manipulation	13–28	25.77	1.99
Fine Motor Writing	9–31	26.15	4.15
Second-grade performance			
Dependent variables			
Reading GPA	0–4	2.49	0.98
Math GPA	0–4	2.66	0.90
Reading SAT10 score	476–729	597.9	37.58
Math SAT10 score	477–716	578.8	39.30

Note. LAP-D = Learning Accomplishment Profile–Diagnostic; GPA = grade point average; SAT10 = Stanford Achievement Test, 10th Edition.

Procedures

Children's fine motor data were collected using the LAP-D assessment at the end of the preschool year (March–June). All participating children were assessed on the complete LAP-D. Children were administered the assessment individually in their school by one of 82 trained assessors. All assessors participated in comprehensive training on the instrument by a collaborating university and the publisher of the tool. Assessors were bilingual and were able to administer the assessment in either Spanish or English. Language dominance was determined primarily by the child's teacher and confirmed by the assessor upon initial interactions with the child. Students were taken to a separate quiet area of their school where the administration could take place without major disturbance to the child. These early assessment data were then linked with classroom grades and SAT10 scores obtained from the school district.

Students' raw scores on two subscales of the LAP-D, FM and FW, were used as measures of the independent variables. Raw scores on four other subscales of the LAP-D (Cognitive Counting, Cognitive Matching, Language Naming, and Language Comprehension) were used as control variables. Several control variables were also created from the demographic information. These included gender (male = 1, female = 0); age at assessment (LAP-D age); days absent in first grade (absence); free/reduced lunch as an indicator of low socioeconomic status (free/reduced lunch; free/reduced lunch, <185% of the federal poverty line = 1, no free/reduced lunch, >185% of the federal poverty line = 0); and ethnicity, coded as White (yes = 1, no = 0) and Black (yes = 1, no = 0), with Hispanic as the reference group.

RESULTS

Descriptive statistics on preschool and second-grade performance were conducted and are presented in Table 1. Intercorrelations among the main variables used in the study are presented in Table 2. Given the large sample size, only a correlation coefficient of .50 or larger was

TABLE 2
Intercorrelations Among the Main Variables

Variable	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1. Language Naming	—									
2. Language Comprehension	.63*	—								
3. Cognitive Counting	.53*	.59*	—							
4. Cognitive Matching	.49	.46	.43	—						
5. Fine Motor Manipulation	.36	.34	.32	.46	—					
6. Fine Motor Writing	.47	.46	.46	.53*	.50*	—				
7. SAT10 math	.30	.29	.38	.33	.22	.33	—			
8. SAT10 reading	.32	.32	.35	.25	.15	.30	.65*	—		
9. Math GPA	.23	.25	.25	.29	.21	.31	.62*	.56*	—	
10. Reading GPA	.24	.30	.34	.25	.15	.28	.55*	.64*	.70*	—

Note. SAT10 = Stanford Achievement Test, 10th Edition; GPA = grade point average.

*Given the large sample size, Cohen's (1988) conventions were used to interpret the effect size. Only a correlation coefficient of .50 or larger was considered a strong or large correlation.

considered a strong or large coefficient (Cohen, 1988). Language Comprehension was strongly correlated with Language Naming, Cognitive Counting was associated with Language Naming and Language Comprehension, and FW was associated with Cognitive Matching and FM. Moreover, all academic achievement scores (SAT10 math, SAT10 reading, math GPA, and reading GPA) were all associated.

Preliminary analyses were conducted to examine whether any of the independent or dependent variables varied by the participants' demographic information. Means and standard deviations of scores by child characteristics are listed in Table 3. Scores on the FM and FW subscales of the LAP-D were examined for differences in gender and race/ethnicity. Results from two one-way analyses of variance indicated a significant effect of gender on FM, $F(1, 2973) = 168.02$, $p < .001$; and FW, $F(1, 2973) = 76.01$, $p < .001$; such that girls performed significantly better on both FM and FW tasks than boys. Results also indicated a significant effect of race/ethnicity on FW, $F(4, 2970) = 6.77$, $p < .001$; and FW, $F(4, 2970) = 10.82$, $p < .001$. Scores on the academic achievement outcome variables were also examined for differences in gender and race/ethnicity as well as second-grade participant characteristics, including free/re-reduced lunch status and number of absences from school. Results from four one-way analyses of variance (one for each of the four academic achievement variables) indicated that math GPA varied significantly by gender, $F(1, 2973) = 9.81$, $p < .01$; race/ethnicity, $F(3, 2971) = 33.68$, $p < .001$; free/reduced lunch status, $F(1, 2973) = 142.89$, $p < .001$; and number of absences from school, $F(1, 2973) = 52.41$, $p < .001$. Reading GPA also varied significantly by gender, $F(1, 2973) = 55.20$, $p < .001$; race/ethnicity, $F(3, 2971) = 10.62$, $p < .001$; free/reduced lunch status, $F(1, 2973) = 141.22$, $p < .001$; and number of absences from school, $F(1, 2973) = 37.99$, $p < .001$. Math SAT10 scores varied significantly by gender, $F(1, 2973) = 7.40$, $p < .01$; race/ethnicity, $F(3, 2971) = 68.93$, $p < .001$; free/reduced lunch status, $F(1, 2973) = 176.5$,

TABLE 3
Differences Among Groups on Preschool and Second-Grade Measures

	Fine Motor Manipulation		*Fine Motor Writing*		*Math GPA*		*Reading GPA*		*Math SAT10*		*Reading SAT10*	
Child Characteristic	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Gender												
Male	25.4	2.0	25.6	4.5	2.6	0.93	2.4	1.0	580.9***	40.7	594.2	37.3
Female	26.2***	1.9	27.0***	3.7	2.7**	0.85	2.6***	0.93	577.1	37.4	601.8**	37.4
Race/ethnicity												
White (non-Hispanic)[a]	25.7	1.8	26.4[c]	4.2	3.0[b,c]	0.77	2.7[b,c]	0.95	596.0[b,c]	39.6	612.9[b,c]	39.2
Hispanic[b]	25.8	1.9	26.5[c]	4.0	2.7[c,d]	0.86	2.5[c]	0.96	584.2[c,d]	38.5	601.6[c]	37.1
Black (non-Hispanic)[c]	25.9	2.2	25.5[d]	4.3	2.5[d]	0.92	2.4[d]	0.97	566.0[d]	36.2	589.1[d]	35.9
Other[d]	25.7	2.0	27.3	3.7	3.2	0.77	2.8	1.0	595.6	34.0	611.2	38.0
Free/reduced lunch												
Yes					3.1***	0.77	3.0***	0.86	599.3***	39.8	619.9***	36.7
No					2.6	0.89	2.4	0.96	574.7	37.5	593.7	36.2

Note. GPA = grade point average; SAT10 = Stanford Achievement Test, 10th Edition.
[a,b,c,d]Indicates a significant difference between the labeled groups down the columns.
** $p < .01$. *** $p < .001$.

$p < .001$; and number of absences from school, $F(1, 2793) = 25.64$, $p < .001$. Finally, reading SAT10 also varied significantly by gender, $F(1, 2973) = 30.26$, $p < .001$; race/ethnicity, $F(3, 2971) = 38.64$, $p < .001$; free/reduced lunch status, $F(1, 3167) = 218.75$, $p < .001$; and number of absences from school, $F(1, 2973) = 8.60$, $p < .01$.

Multilevel Analyses

Four multilevel regressions (one for each academic achievement variable) were conducted to examine the effects of fine motor skills on the long-term academic performance of children from low-income families. Given that there was some degree of nesting in the data, four unconditional models were fit to compute intraclass correlation coefficients. The intraclass correlation coefficients provided an indication of the variance in the predictor variables accounted for between child care centers versus within child care centers. The unconditional model yielded modest intraclass correlation coefficients for math GPA (.10), math SAT10 scores (.17), reading GPA (.07), and reading SAT10 scores (.13). A multilevel model allowed us to separate the variance between two levels: (a) within child care center variance (Level 1) and (b) between child care center variance (Level 2). Given the significant findings from the preliminary analyses, gender, race/ethnicity, free/reduced lunch status, and number of absences from school were used as control factors and entered into the regression equation in Model 1. Scores from the Cognitive Matching, Cognitive Counting, Language Naming, and Language Comprehension subscales of the LAP-D were added as independent measures in Model 2 of each regression. Model 3 of each regression examined the unique effect of fine motor manipulation scores above and beyond the effects of the controls variables on achievement, and Model 4 examined the unique effect of fine motor writing scores above and beyond the effects of control variables on achievement. Math GPA was entered as the dependent variable in the first regression analysis (see Table 4). Math SAT10 was entered as the dependent variable in the second regression analysis (see Table 5). Reading GPA was entered as the dependent variable in the third regression analysis (see Table 6), and Reading SAT10 was entered as the dependent variable in the fourth regression analysis (see Table 7).

Math GPA. As expected, all covariates entered into Model 1 were significant, including female ($B = -0.10$, $p < .001$), Black ($B = -0.24$, $p < .001$), White ($B = 0.14$, $p < .05$), age at assessment ($B = -0.02$, $p < .001$), free/reduced lunch ($B = -0.37$, $p < .001$), and absence in second grade ($B = -0.02$, $p < .001$). Model 2 included the early assessment controls, indicating significant effects of cognitive counting ($B = 0.04$, $p < .001$) and cognitive matching ($B = 0.05$, $p < .001$) as well as a small but significant effect of language comprehension ($B = 0.02$, $p < .05$). Model 3 examined the effect of fine motor manipulation skills on second-grade math GPA above and beyond the effects of the control variables. Model 3 indicated a unique effect of fine motor manipulation skills in preschool ($B = 0.03$, $p < .001$) on second-grade math GPA, with a modest effect size (Cohen's $d = 0.14$). Model 4 explored the effect of fine motor writing skills above and beyond the effect of the demographic and early language and cognition measures. The model indicated a unique ($B = 0.03$, $p < .001$) effect of fine motor writing skills in preschool on second-grade math GPA. The magnitude of the effect of fine motor writing (Cohen's $d = 0.21$) was greater than that of fine motor manipulation on second-grade GPA. These effect

TABLE 4
Summary of Random Coefficients Regression Model on the Effects of Fine Motor Ability on Second-Grade Math Grade Point Average

Fixed Effects	*Model 1 Estimate (SE)*	*ES*	*Model 2 Estimate (SE)*	*ES*	*Model 3 Estimate (SE)*	*ES*	*Model 4 Estimate (SE)*	*ES*
Intercept (constant)	1.78 (0.26)***	0.24	1.33 (0.28)***	0.17	0.77 (0.29)**	0.09	1.31 (0.26)***	0.18
Control variables								
Gender								
Male (reference)								
Female	–0.10 (0.03)***	0.12	–0.030 (0.00)*	0.09	–0.05 (0.03)	0.06	–0.04 (0.03)	0.05
Ethnicity								
Hispanic (reference)								
Black	–0.24 (0.04)***	0.47	–0.40 (0.06)***	0.60	–0.31 (0.03)***	0.60	–0.27 (0.03)***	0.50
White/other	0.14 (0.06)*	0.09	0.171 (0.14)	0.04	0.07 (0.05)	0.05	0.08 (0.05)	0.05
LAP-D age at assessment	0.02 (0.00)***	0.19	–0.01 (0.00)*	0.06	–0.01 (0.00)*	0.07	–0.01 (0.00)**	0.10
Free/reduced lunch								
No (reference)								
Yes	–0.37 (0.04)***	0.44	–0.12 (0.06)***	0.27	–0.23 (0.04)***	0.27	–0.22 (0.04)***	0.26
Absence (second grade)	–0.02 (0.00)***	0.36	–0.02 (0.00)***	0.36	–0.02 (0.00)***	0.36	–0.02 (0.00)***	0.35
Preschool control variables								
Cognitive Counting			0.04 (0.00)***	0.46	0.04 (0.00)***	0.45	0.04 (0.00)***	0.41
Cognitive Matching			0.05 (0.01)***	0.23	0.03 (0.00)***	0.17	0.03 (0.01)***	0.16
Language Naming			0.00 (0.00)	0.03	0.00 (0.00)	0.01	0.00 (0.00)	0.00
Language Comprehension			0.02 (0.01)*	0.09	0.02 (0.01)*	0.08	0.01 (0.01)	0.06
Preschool independent variables								
Fine Motor Manipulation (Model 3)					0.03 (0.001)***	0.14		
Fine Motor Writing (Model 4)							0.03 (0.00)***	0.21
Estimates of random parameters								
Level 2 intercept (between child care variance)	0.03 (0.01)*		0.02 (0.01)*		0.02 (0.01)**		0.03 (0.01)**	
Level 1 intercept (within child care variance)	0.69 (0.02)***		0.60 (0.02)***		0.60 (0.02)***		0.59 (0.02)***	
−2 log likelihood	8,131.05		7,716.38		7,709.16		7,692.38	
Change in model fit (χ^2) from prior model (*df*)			–414.67 (*4*)***		–7.22 (*1*)**		–24.00 (*1*)***	

Note. ES = effect size, expressed as Cohen's $d = 2t/\sqrt{(df)}$; LAP-D = Learning Accomplishment Profile–Diagnostic.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

TABLE 5
Summary of Random Coefficients Regression Model on the Effects of Fine Motor Ability on Math SAT10 Scores

Fixed Effects	*Model 1 Estimate (SE)*	*ES*	*Model 2 Estimate (SE)*	*ES*	*Model 3 Estimate (SE)*	*ES*	*Model 4 Estimate (SE)*	*ES*
Intercept (constant)	530.14 (11.34)***		507.69 (10.99)***		481.12 (12.14)***		509.51 (10.92)***	
Control variables								
Gender								
Male (reference)								
Female	3.87 (1.28)**	0.05	5.72 (1.16)***	0.09	6.84 (1.12)***	0.10	6.99 (1.17)***	0.11
Ethnicity								
Hispanic (reference)								
Black	–15.09 (1.57)***	0.27	–18.35 (1.48)***	0.30	–18.49 (1.48)***	0.30	–16.81 (1.50)***	0.27
White/other	7.83 (2.52)**	0.05	3.32 (2.29)	0.03	3.68 (2.28)	0.03	3.99 (2.27)	0.03
LAP-D age at assessment	1.08 (0.08)***	0.11	–0.62 (0.17)***	0.06	–0.71 (0.17)***	0.07	–0.84 (0.18)***	0.08
Free/reduced lunch								
No (reference)								
Yes	–15.64 (1.68)***	0.18	–7.62 (1.56)***	0.09	–7.96 (1.56)***	0.09	–7.51 (1.56)***	0.09
Absence (second grade)	–0.70 (0.10)***	0.12	–0.65 (0.09)***	0.12	–0.63 (0.09)***	0.12	–0.61 (0.09)***	0.11
Preschool control variables								
Cognitive Counting			1.96 (0.14)***	0.24	1.91 (0.14)***	0.23	1.81 (0.14)***	0.22
Cognitive Matching			2.00 (0.28)***	0.13	1.58 (0.29)***	0.10	1.51 (0.29)***	0.09
Language Naming			0.72 (0.17)***	0.08	0.65 (0.17)***	0.07	0.60 (0.17)***	0.06
Language Comprehension			1.09 (0.34)**	0.06	1.01 (0.34)**	0.05	0.87 (0.34)*	0.04
Preschool independent variables								
Fine Motor Manipulation (Model 3)					1.75 (0.35)***	0.09		
Fine Motor Writing (Model 4)							1.20 (0.19)***	0.11
Estimates of random parameters								
Level 2 intercept (between child care variance)	83.42 (18.53)***		99.77 (17.95)***		104.56 (18.32)***		109.61 (26.72)***	
Level 1 intercept (within child care variance)	1,233.12 (33.68)***		1,012.53 (27.14)***		1,001.89 (28.89)***		994.25 (18.76)***	
−2 log likelihood	32,428.68		31,769.35		31,744.49		31,730.81	
Change in model fit, χ^2 (*df*)			–659.33 (*4*)***		–24.86[a] (*1*)***		–38.54 (*1*)***	

Note. SAT10 = Stanford Achievement Test, 10th Edition; ES = effect size, expressed as Cohen's $d = 2t/\sqrt{(df)}$; LAP-D = Learning Accomplishment Profile–Diagnostic.

[a]Change in model fit from Model 2.

$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

TABLE 6
Summary of Random Coefficients Regression Model on the Effects of Fine Motor Ability on Second-Grade Reading Grade Point Average

Fixed Effects	*Model 1 Estimate (SE)*	*ES*	*Model 2 Estimate (SE)*	*ES*	*Model 3 Estimate (SE)*	*ES*	*Model 4 Estimate (SE)*	*ES*
Intercept (constant)	1.95 (0.29)***		1.31 (0.29)***		1.38 (0.32)***		1.31 (0.26)***	
Control variables								
Gender								
Male (reference)								
Female	–0.26 (0.03)***	0.28	–0.22 (0.03)***	0.25	–0.22 (0.03)***	0.25	–0.20 (0.03)***	0.26
Ethnicity								
Hispanic (reference)								
Black	–0.10 (0.04)*	0.18	–0.19 (0.04)***	0.32	–0.19 (0.04)***	0.32	–0.16 (0.04)***	0.26
White/other	0.12 (0.06)	0.07	0.03 (0.06)	0.02	0.03 (0.06)	0.02	0.04 (0.06)	0.03
LAP-D age at assessment	0.02 (0.00)***	0.14	–0.01 (0.00)**	0.10	–0.01 (0.00)**	0.10	–0.02 (0.00)***	0.13
Free/reduced lunch								
No (reference)								
Yes	–0.43 (0.04)***	0.48	–0.26 (0.04)***	0.27	–0.26 (0.04)***	0.13	–0.26 (0.04)***	0.26
Absence (second grade)	–0.02 (0.00)***	0.31	–0.02 (0.00)***	0.31	–0.02 (0.00)***	0.18	–0.02 (0.00)***	0.31
Preschool control variables								
Cognitive Counting			0.04 (0.00)***	0.40	0.04 (0.00)***	0.40	0.04 (0.00)***	0.36
Cognitive Matching			0.02 (0.01)**	0.11	0.02 (0.01)**	0.11	0.01 (0.01)	0.06
Language Naming			0.01 (0.00)	0.04	0.01 (0.00)	0.05	0.00 (0.00)	0.02
Language Comprehension			0.05 (0.01)***	0.19	0.05 (0.01)***	0.19	0.04 (0.01)***	0.17
Preschool independent variables								
Fine Motor Manipulation (Model 3)					–0.00 (0.01)	0.02		
Fine Motor Writing (Model 4)							0.02 (0.00)***	0.17
Estimates of random parameters								
Level 2 intercept (between child care variance)	0.02 (0.01)*		0.03 (0.01)**		0.03 (0.01)**		0.03 (0.01)**	
Level 1 intercept (within child care variance)	0.84 (0.02)***		0.74 (0.02)***		0.74 (0.02)***		0.73 (0.02)***	
−2 log likelihood	8,737.69		8,361.75		8,369.07		8,348.89	
Change in model fit (χ^2) from prior model (*df*)			–375.94 (*4*)***		7.32 (*1*)**		–12.96 (*1*)***	

Note. ES = effect size, expressed as Cohen's $d = 2t/\sqrt{(df)}$; LAP-D = Learning Accomplishment Profile–Diagnostic.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

TABLE 7
Summary of Random Coefficients Regression Model on the Effects of Fine Motor Ability on Reading SAT10 Scores

Fixed Effects	*Model 1 Estimate (SE)*	*ES*	*Model 2 Estimate (SE)*	*ES*	*Model 3 Estimate (SE)*	*ES*	*Model 4 Estimate (SE)*	*ES*
Intercept (constant)	565.9 (11.0)***		552.0 (11.3)***		556.5 (12.0)***		553.1 (10.81)***	
Control variables								
Gender								
Male (reference)								
Female	–7.56 (1.24)**	0.22	–6.01 (1.14)**	0.19	–6.20 (1.16)***	0.19	–5.22 (1.16)***	0.16
Ethnicity								
Hispanic (reference)								
Black	–10.02 (1.51)***	0.40	14.30 (1.45)***	0.53	–14.3 (1.46)***	0.53	–13.37 (1.47)***	0.47
White/other	5.50 (2.44)*	0.08	1.13 (2.25)	0.02	1.07 (2.26)	0.02	1.54 (2.25)	0.02
LAP-D age at assessment	0.87 (0.17)***	0.19	–0.60 (0.17)**	0.12	–0.58 (0.17)**	0.12	0.73 (0.17)***	0.15
Free/reduced lunch								
No (reference)								
Yes	–17.50 (1.63)***	0.44	–10.08 (1.54)***	0.25	–10.0 (1.54)***	0.25	–10.04 (1.54)***	0.25
Absence (second grade)	–0.46 (0.10)***	0.16	–0.46 (0.09)***	0.18	–0.46 (0.09)***	0.18	–0.44 (0.09)***	0.17
Preschool control variables								
Cognitive Counting			1.52 (0.14)***	0.38	1.53 (0.14)***	0.39	1.43 (0.14)***	0.36
Cognitive Matching			0.42 (0.27)	0.05	0.50 (0.28)	0.06	0.11 (0.28)	0.01
Language Naming			1.11 (0.16)***	0.24	1.12 (0.17)***	0.24	1.03 (0.17)***	0.22
Language Comprehension			1.70 (0.34)***	0.18	1.72 (0.34)***	0.18	1.56 (0.34)***	0.16
Preschool independent variables								
Fine Motor Manipulation (Model 3)					–0.30 (0.35)	0.03		
Fine Motor Writing (Model 4)							0.75 (0.19)***	0.14
Estimates of random parameters								
Level 2 intercept (between child care variance)	75.3 (18.6)***		90.2 (17.7)***		89.9 (18.3)***		109.6 (26.72)***	
Level 1 intercept (within child care variance)	1,185.9 (37.2)***		988.91 (26.7)***		989.2 (26.7)***		994.25 (18.8)***	
−2 log likelihood	32,212.70		31,680.53		31,680.07		31,665.87	
Change in model fit, χ^2 (*df*)			–532.17 (*4*)***		–0.46 (*1*)		–14.7 (*1*)***	

Note. SAT10 = Stanford Achievement Test, 10th Edition; ES = effect size, expressed as Cohen's $d = 2t/\sqrt{(df)}$; LAP-D = Learning Accomplishment Profile–Diagnostic.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

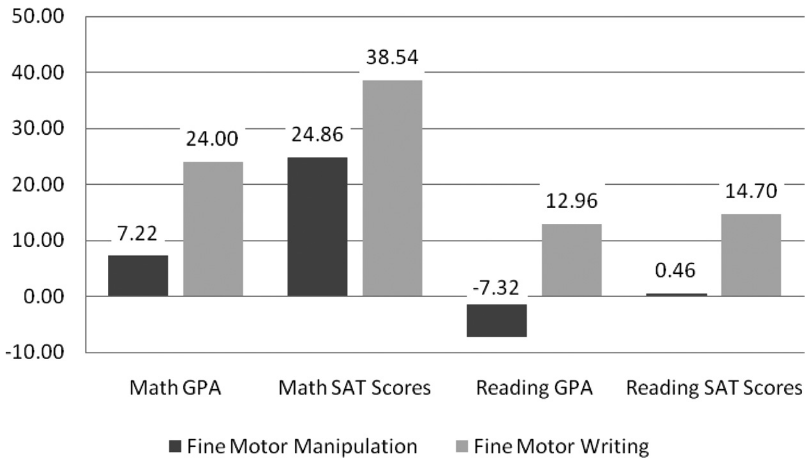

FIGURE 1 Amount of decrease in −2 log likelihood when fine motor scores were added to the model. Fine motor writing had significant decreases for all outcome measures (math GPA, math SAT scores, reading GPA, reading SAT scores). Fine motor manipulation had significant decreases for math outcome measures, a nonsignificant decrease for reading SAT scores, and a significant increase (indicating that the model had worse fit) for reading GPA. For all outcome measures, the improvement in model fit was much greater for fine motor writing compared to fine motor manipulation. GPA = grade point average; SAT = Stanford Achievement Test, 10th Edition.

sizes were similar or equal to the effect sizes reported by other secondary data analyses (Grissmer et al., 2010). It is also important to note the decrease in the −2 log likelihood when fine motor manipulation and fine motor writing were added to the models (see Figure 1). In both Models 3 and 4, the change in model fit was significant for both fine motor manipulation, $\chi^2(1) = -7.22$, $p < .01$; and fine motor writing, $\chi^2(1) = -24.00$, $p < .001$.

Math SAT10 scores. For math SAT10 scores, all covariates entered into Model 1 were significant, including female ($B = 3.87$, $p < .001$), Black ($B = -15.09$, $p < .001$), White ($B = 7.83$, $p < .01$), age at assessment ($B = 1.08$, $p < .001$), free/reduced lunch ($B = -15.64$, $p < .001$), and absence in second grade ($B = -0.70$, $p < .001$). Once again, Model 2 included the early assessment controls and yielded significant effects for cognitive counting ($B = 1.96$, $p < .001$), cognitive matching ($B = 2.00$, $p < .001$), language naming ($B = 0.72$, $p < .001$), and language comprehension ($B = 1.09$, $p < .01$) on second-grade math SAT10 scores. Model 3 examined the effect of fine motor manipulation skills on second-grade math GPA above and beyond the effects of the control variables. Model 3 indicated a small, unique effect of fine motor manipulation skills ($B = 1.75$, $p < .001$; Cohen's $d = 0.09$). Model 4 explored the effect of fine motor writing skills above and beyond the effect of the demographic and early language and cognition measures. The model indicated a unique effect of fine motor writing ($B = 1.20$, $p < .001$) on second-grade math SAT10 scores. Similar to the effect on math GPA, the magnitude of the effect of fine motor writing (Cohen's $d = 0.11$) was greater than that of fine motor manipulation on second-grade SAT10 scores. These effect sizes were similar or equal to the effect sizes reported by other secondary data analyses (Grissmer et al., 2010). Change in model fit was significant for both Models 3 and 4 when fine motor manipulation, $\chi^2(1) = -24.86$,

$p < .001$; and fine motor writing, $\chi^2(1) = -38.54$, $p < .001$; were added to the models, respectively (see Figure 1).

Reading GPA. Similar to the findings for math achievement, female ($B = -0.26$, $p < .001$), Black ($B = -0.10$, $p < .05$), age at assessment ($B = -0.02$, $p < .001$), free/reduced lunch ($B = -0.43$, $p < .001$), and absence in second grade ($B = -0.02$, $p < .001$) were all significant predictors of reading GPA. Model 2 included early assessment control variables in order to examine the unique effect of fine motor skills on reading achievement. Model 2 indicated significant effects of cognitive counting ($B = 0.04$, $p < .001$), cognitive matching ($B = 0.02$, $p < .01$), and language comprehension ($B = 0.05$, $p < .001$) on second-grade reading GPA. Model 3 explored the effects of fine motor manipulation on second-grade reading GPA and indicated no significant effect. Model 4 explored the effect of fine motor writing skills above and beyond the effect of the demographic and early language and cognition measures. The model indicated a unique effect of fine motor writing skills in preschool on second-grade reading GPA ($B = 0.03$, $p < .001$), with a modest effect size (Cohen's $d = 0.11$). These effect sizes were similar or equal to the effect sizes reported by other secondary data analyses (Grissmer et al., 2010). It is important to note that there was no decrease in model fit when fine motor manipulation was added to the model (see Figure 1). There was, however, a significant improvement in model fit when fine motor writing was added to the model, $\chi^2(1) = -12.96$, $p < .001$.

Reading SAT10 scores. All covariates entered into Model 1 were significant, including female ($B = -7.56$, $p < .01$), Black ($B = -10.02$, $p < .001$), White ($B = 5.50$, $p < .05$), age at assessment ($B = 0.87$, $p < .001$), free/reduced lunch ($B = -17.50$, $p < .001$), and absence in second grade ($B = -0.46$, $p < .001$). Model 2 indicated significant effects of cognitive counting ($B = 1.52$, $p < .001$), language naming ($B = 1.11$, $p < .001$), and language comprehension ($B = 1.70$, $p < .001$) on second-grade reading SAT10 scores. Model 3 explored the effects of fine motor manipulation in preschool on reading SAT10 scores in second grade, and the results indicated no unique effect. Model 4 examined the unique effect of fine motor writing in preschool on second-grade reading SAT10 scores. Results indicated a unique effect of fine motor writing on second-grade reading SAT10 scores ($B = 0.75$, $p < .001$), with a modest effect size (Cohen's $d = 0.11$). Again, these effect sizes were similar or equal to the effect sizes reported by other secondary data analyses (Grissmer et al., 2010). Of note is that there was no decrease in model fit when fine motor manipulation was added to the model (see Figure 1). There was, however, a significant improvement in model fit when fine motor writing was added to the model, $\chi^2(1) = -14.7$, $p < .001$.

DISCUSSION

Multilevel modeling was used to directly examine the unique effects of preschoolers' fine motor skills on second-grade achievement. Overall, the results indicate that fine motor skills in preschool are important predictors of later academic achievement, particularly fine motor skills that involve the use of a writing utensil. This finding is consistent with current work by Grissmer and his colleagues (2010), who have demonstrated the importance of fine motor skills on later academic achievement using other secondary data sets, including the ECLS-K, the National Longitudinal Study of Youth, and the British Cohort Study. Although many of these data sets utilize few tasks to assess fine motor skills and provide composite scores that do not allow researchers to disentangle the effects of specific fine motor abilities on later academic achievement, the current study was able to explore specific effects of fine motor skills by including two fine motor assessments, one that focused on writing and copying and the other that focused on the manipulation of objects.

The results from the current study suggest that fine motor writing ability in preschool is a stronger predictor of reading and math achievement in second grade than fine motor manipulation skill. There are several plausible explanations for why early writing, or early graphomotor skill, relates more consistently to later academic achievement. One possibility is that writing provides children with the opportunity to create internal models for the symbol system necessary to succeed in academic disciplines. Longcamp et al. (2005) randomly assigned 4-year-old children to one of two word-writing groups. In both groups, children were asked to write small-syllable words. In the first group, the children were asked to write the same words using a writing utensil (e.g., a crayon) on a piece of paper. The second group was asked to write the words using the keys on a QWERTY keyboard. The authors argued that if children were able to identify the letters in the words by simply seeing them over and over, then both groups would perform equally well on a letter recognition task. However, if children formed a better internal model for letters by writing them, then children in the writing group would be expected to outperform the children in the typing group. The results supported the latter position, suggesting that writing letters helped children develop an internal model of the alphabetic character, whereas simply pressing a key on a keyboard did not. Given these findings, it is possible that in the current study, children with stronger graphomotor skill in preschool had higher academic achievement in second grade because they had already formed or were more likely to form internal models of the symbol systems that provide the foundation for academic disciplines.

Another possibility for why early fine motor skills relate to higher academic performance in elementary school may be due to the association between self-regulation and fine motor skills. The link between self-regulation and academic performance has been well established in the literature (McClelland & Cameron, 2011). This is particularly true of the cognitive elements of self-regulation, including attentional flexibility, impulse control, and working memory (McClelland & Cameron, 2011). Fine motor activities, particularly copying letters and symbols, require that children either have or at least exercise the cognitive elements of self-regulation. Certainly, fine motor activity is said to stimulate the prefrontal cortex, an area of the brain critical to self-regulation and other elements of executive functioning (Diamond, 2000). It can also be argued that children use fine motor writing to *learn how to learn* (Adolph, 2008)—that is, to develop self-regulated learning skills. Thus, it is possible that in the current study children with stronger fine motor skill in preschool may have had higher academic achievement in second grade because they were demonstrating or were more likely to be exercising self-regulation skills that ultimately result in higher academic achievement during elementary school (McClelland, Morrison, & Holmes, 2000).

Grissmer et al. (2010) also provided an important framework by which fine motor skill and later academic achievement may be linked. Evidence from work in neuroscience suggests that fine motor skills and cognition may be neurologically linked. Adolph (2005, 2008; Adolph & Berger, 2006) suggested that researchers have long overlooked infants' ability to solve complex problems within an ever-changing motoric system. Neurologically speaking, these activities involve the interplay of the prefrontal cortex, the cerebellum, and the basal ganglia. On a more functional note, children are said to use fine motor skills in order to learn how to learn (Adolph, 2008). More specifically, Ito (2005) argued that certain motor and cognitive-learning tasks share the need for internal neural representations. Perhaps it is this intersect that drives the fine motor/cognitive association.

Of course, early fine motor writing skills may be related to later academic achievement as a result of more environmental factors. One could argue, for instance, that parents who work with their children during preschool to develop fine motor writing skills may also work with their children in early elementary school to excel academically. This would suggest that the relation between fine motor writing and academic skills may exist because both are dependent on home enrichment. However, if there is a consistent unmeasured factor causing variance in the model on the child's academic development, then the correlation between fine motor skill and academic achievement would also be zero when other early academic variables are controlled. In other words, one would have to believe that parents spent their enrichment time on writing during preschool but not math or reading and then switched over to spending their enrichment time on math and reading once the child entered elementary school. The control for preschool achievement (cognitive counting and receptive/expressive language) essentially acts as a proxy for *all* factors associated with early math and reading skills, including parental influence. On might also argue that teacher bias could also be a factor influencing outcome, as good penmanship may positively influence teacher perceptions of a child's intellect. Such teacher bias would likely result in inflated classroom grades but not standardized test scores (because the teacher has no direct influence on these scores). The current study found a significant impact of early fine motor writing on standardized tests (in which penmanship is not a factor) as well as classroom grades, suggesting that teacher perceptions (based on penmanship) are not likely to be the reason early fine motor writing skills relate to later academic achievement.

The Unique Contributions of the Current Study

In addition to the fact that it extends and replicates research that demonstrates the unique effect of fine motor skills on later academic achievement (Grissmer et al., 2010), the current study is unique in three ways: (a) It examines the effect of early fine motor skills on later math and reading achievement above and beyond a variety of other critical factors, (b) it disentangles the effects of fine motor writing (graphomotor skills) from fine motor skills related only to the manipulation of objects, and (c) it emphasizes the universal effect of fine motor skills on later academic achievement by exploring this relation with children from a predominantly Hispanic and low-income sample. Each of these unique features is discussed in turn here.

Effects of fine motor skills on later math and reading, controlling for other critical factors. One of the unique contributions of the current study is that a variety of early preacademic skills as well as demographic factors were controlled when the effects of early fine motor skills on later academic achievement were examined. These skills and factors included sex, age, ethnicity/race, socioeconomic status (free/reduced lunch status), days absent from school, school attended, early counting skills, early cognitive manipulation skills, early language naming skills, and early language comprehension skills. Because fine motor skills, and fine motor writing in particular, were significantly related to later academic achievement in math and reading after these factors were controlled, the conclusion that early fine motor skills are uniquely related to later academic achievement is a robust finding. If fine motor skills were merely a proxy for early language skills or early math skills, the addition of the fine motor variables into the model would not have produced significant changes in model fit. As shown in Figure 1, fine motor writing explained significant variance above and beyond all of the previously mentioned factors on all second-grade academic outcome measures and did so to a greater extent than the measure of other fine motor manipulation skills.

Disentangling the effects of fine motor skills on later academic achievement. The early childhood classroom provides children with various opportunities to engage in fine motor activities because it is believed that having these skills are important for later learning. Fine motor activities include the regular manipulation of objects and opportunities to use writing utensils (Marr et al., 2003), but the distinction between which type of fine motor skill relates more to later academic achievement has not been explored in research prior to the current study. Making this distinction is important for two reasons. First, identifying the skills that predict greater academic success may provide a deeper understanding of the cognitive processes underlying the link between fine motor ability and long-term academic achievement. Second, given that fine motor skills significantly predict later academic achievement, promoting fine motor writing skills in preschool may provide a method to reduce the achievement gap prevalent between children in kindergarten.

Grissmer et al. (2010) reported that the *copying eight designs* task of the British Cohort Study was a stronger predictor of outcome than other fine motor tasks. This is consistent with our findings, which suggest that fine motor writing was a significant predictor of both reading and math achievement in second grade. The fine motor writing tasks included in the current study are representative of early graphomotor skills that typically require the coordination of several cognitive and neuromotor processes (Smits-Engelsman et al., 2001). In comparison, fine motor manipulation was found to have a significant effect on math ability—both second-grade math GPA and second-grade math SAT10 scores. Fine motor manipulation in the current study required children to engage in tasks of manual dexterity, such as folding paper, building with blocks, and weaving string. Compared to fine motor writing, the majority of the fine motor manipulation tasks could be viewed as nonacademic in nature. However, given their significant association with math achievement, the fine motor manipulation tasks may have provided a window into children's early experiences and abilities with spatial understanding. It is also possible that strong manipulation skills allow children greater opportunity to accurately use manipulatives for mathematics-related activities. Future research should consider item-by-item analyses of very specific fine motor activities that further highlight the link between fine motor skills and achievement.

The extent to which early childhood classrooms vary with respect to fine motor experiences has not yet been determined, and a discussion of this is outside the scope of the current study. Yet the current findings could have significant educational implications. Grissmer et al. (2010) argued that early childhood education interventions should shift the focus from direct math and reading instructional practices to more on building foundational skills of attention and fine motor actions. This may be particularly true for disadvantaged populations, for whom the achievement gap persists despite increased standards-based accountability systems that have consistently promoted math and reading performance (Grissmer et al., 2010). The few studies that have examined fine motor intervention models have reported improved cognition scores, but these scores have not yet been linked to academic performance (Schellenberg, 2004). Future research should continue to examine this link, particularly once a clearer association between fine motor skills and academic performance is established.

Fine motor skills predict achievement in a predominantly Hispanic and low-income sample. There is growing evidence that fine motor skills have a significant effect on later academic achievement (Grissmer et al., 2010; Son & Meisels, 2006), and the current study adds to the robustness of these findings. Much of the research has focused on the effects of fine motor skills through secondary data sets such as the ECLS-K, National Longitudinal Study of Youth, and British Cohort Study data sets. The participants typically include a nationally representative sample of children from mostly middle-income and White families. The current study expands on these findings by examining the extent to which fine motor skills predict academic achievement among a diverse group of children from economically disadvantaged homes. Current estimates from the National Center for Education Statistics indicate that in the 500 largest school districts, minority students already represent the majority: a total of 56% of the total population of students (Hoffman & Sable, 2006). In urban communities, minority children, including Hispanics, disproportionately represent children from low-income populations (Proctor & Dalaker, 2002). The Latino population in particular is growing and is estimated to triple over the next half century. Thus, understanding factors that may diminish the academic gap may be critical to this population.

The results of the present study, which used a predominantly Hispanic low-income sample, were very similar to those from nationally representative samples. Although there were no direct comparisons made between these different sample characteristics, it seems justified to suggest that early fine motor skills are important for all children attending a modern formal school system, regardless of cultural background. It seems that the use of writing utensils in early education settings will likely have a similarly positive effect on later academic achievement for all children. It is important to note that the current study did not include children with disabilities, children who did not attend public school after preschool, or children who did not have second-grade data after preschool (i.e., retention). To expand on the robustness of the current findings, studies should continue to examine the effect of fine motor skills on later academic achievement in these populations. The collective results from data sets representative of the United States and United Kingdom along with the results from the current study (from a predominantly Hispanic U.S. sample) suggest that fine motor skills, particularly fine motor writing, should be included in universal early education curriculum and standards.

Overall, the current study suggests that fine motor skills, particularly fine motor writing, should be considered a valuable indicator of school readiness (Grissmer et al., 2010). In addition to extending the literature showing a link between early fine motor skills and later academic achievement, the current study lays the groundwork for future research to explore how fine motor skills impact learning and other skills important for academic success. The use of early education curricula that include fine motor writing and copying might prove to be an effective method for improving learning during the early school years. Future research should explore the naturally varying amounts of fine motor skills taught in early childhood classrooms to determine the extent to which copying and writing is included and the extent to which the inclusion of copying and writing impacts young children's fine motor writing skills. It is unclear whether early childhood teachers understand the value of fine motor skills and have means by which to instruct, evaluate, and provide early intervention services for children with limited fine motor ability. Future research should also determine how effective teaching teachers about the importance of fine motor skills will be on improving their students' fine motor skills. Thus, it is important to continue to disentangle the effects of fine motor skills, examine the underlying processes that result in stronger academic achievement, and determine the effectiveness of adding these skills to early education curricula. These findings will be central to educational policy and practice in the early childhood classroom.

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