Links between Motor Skills and Indicators of School Readiness at Kindergarten Entry in Urban Disadvantaged Children

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Abstract

School readiness represents a kindergarten characteristic which ultimately contributes to academic and personal success. This literature has traditionally focused on cognitive and behavioral characteristics. However, clinicians underscore the critical importance of motor skills to kindergarten preparedness. This study, using data from the Montreal Longitudinal Preschool Study, examines concurrent links between motor skills and other indicators of school readiness in typically developing children attending regular kindergarten classrooms in disadvantaged environments. Participants include a sample of 522 children from the Montreal Longitudinal Preschool Study with individual assessments of receptive vocabulary and number knowledge and teacher ratings of gross, fine, and perceptual-motor skills and classroom behaviors. The link between motor skills and early math skills completely explained any influence attributed to verbal skills. Developing a better understanding of how the distinct key elements of school readiness relate to each other will help teachers devise more comprehensive strategies in helping children become prepared for the first grade transition, especially in urban, disadvantaged settings.

Keywords: Motor skills, Cognitive skills, Behavioral skills, Child, School readiness

1. Introduction

School entry characteristics are important for later academic achievement and attainment (Entwisle, Alexander, & Olson, 2005). To enhance school success with the primary curriculum, children need to begin kindergarten on solid ground with essential precursors for reading, writing, and arithmetic (High & Committee on Early Childhood Adoption, and Dependent Care and Council on School Health, 2008). Thus, characteristics conducive to learning are a functional vocabulary, informal knowledge of the number line and its properties, and adequate behavioral self-control characteristics (La Paro & Pianta, 2000).

Clinicians and researchers working in the area of cognitive development have long known of a critical shift in children's developmental skills between ages five and seven which helps them process information, use logic to

understand mathematical and scientific operations, and allows them to pay closer attention and transact with their environment (Piaget & Inhelder, 1956). These observations are most remarked in Piagetian theory. The addition of enhancements in cortical regions of the brain which manage executive functions (Kerr & Zelazo, 2004) and emotional regulation (Blair, 2002) produces a child that is "school ready."

The need for requisite skills at school entry is dramatic for children living in disadvantaged environments (Pagani et al., 1997; 1999; United Nations Children's Fund, 2005). Young children living in persistent poverty generally score lower on cognitive tests and general academic performance (NICHD Early Child Care Research Network, 2005). Such income gradients can be traced to kindergarten (Entwisle et al., 2005; Pagani et al. 1999; 2001). Children from low-income families experience more at-risk parenting and cognitive environments at home. Parents living in poverty often also report experiencing more stress, family discord and disruption, and less school success themselves (Pagani et al., 1997). They often rate themselves as having less time to read with their children and participate in cognitively stimulating activities at home, which results in a less enriching early childhood environment (Brooks-Gunn, Berlin, & Fuligni, 2000).

School readiness has traditionally defined itself by school entry cognitive and behavioral characteristics which predict later achievement (La Paro & Pianta, 2000; Vitaro, Brendgen, Larose, & Tremblay, 2005). In the first comprehensive approach aimed at estimating the impact of school-entry skills on later academic performance in reading and math, Duncan and colleagues (2007) integrated and analyzed six international longitudinal data sets while holding constant children's preschool cognitive ability, behavior, and other important background characteristics. Their results indicate that early informal math skills, such as knowledge of the number line and ordinality, were the most powerful predictors of later learning. Early language and reading skills also predicted later academic performance, although they were relatively less powerful than early math skills. Finally, of all the behavioral characteristics examined, only attention skills predicted later achievement outcomes.

Much like attention, motor skills have been generally neglected in conceptualizations and investigations of school readiness, despite the link between motor skills and achievement in the clinical literature (Sandler et al., 1992; Sortor & Kulp, 2003). During early childhood, cognitive and motor skills recruit common sensory systems and cortical structures in the brain (Marsh, Gerber, & Peterson, 2008). Brain development occurs through a sequence of major events, beginning with the formation of the neural tube gestation and intense myelination during the first two years of life. Anatomical development typically in sensorimotor areas first, subsequently expanding progressively into dorsal and parietal, superior temporal, and dorsolateral prefrontal cortices. This expansion, driven by a hierarchical principle (in which development proceeds from undifferentiated to increasingly differentiated skills) brings with it more specific cognitive and behavioral skills. For example, less specific infant motricity becomes increasingly defined by its fine, gross, and perceptual motor characteristics by preschool. Cognitive, fine motor, and attention milestones are interdependent, recruiting each other toward higher-order cognitive functions, and are mostly driven by the frontal cortices (Marsh et al., 2008), especially during Piaget's sensorimotor period (Piaget & Inhelder, 1956). In fact, given the well documented overlapping recruitment, one could argue that motor skills fall within the important constellation of cognitive skills. Although it figures most prominently in Piagetian theory, it is also noteworthy that movement plays an important role among the list of preschool key experiences in the Perry Preschool High/Scope Program (Hohmann & Weikart, 2002) and other preschool enrichment programs that favor cognitive control (Diamond, Barnett, Thomas, & Munro, 2007; Lillard & Else-Quest, 2006). The results of a study conducted by Schweinhart and colleagues (1993) indicate that the Perry Preschool Program increased children's later school success and improved the quality of their contributions to society as a whole.

Interestingly, motor skills are one important aspect of school readiness not examined in the Duncan et al. (2007) consortium study. In recent replications and extensions, fine motor skills in kindergarten were found to make their own unique contribution to reading and math skills and productive classroom learning behavior by the end of second grade (Pagani, Fitzpatrick, Archambault, & Janosz, 2010; Grissmer, Grimm, Aiyer, Murrah, & Steele, 2010). Although these replication studies establish motor skills as an important element of school readiness, neither describes how motor skills relate to other key components of school readiness during kindergarten. In other words, are motor skills independently linked with the key kindergarten elements, such as math, verbal, and attention skills?

A first step in understanding motricity as a school readiness indicator might be to assess its relationship with cognitive and behavioral characteristics which have been traditionally used to estimate school readiness, prior to formal school entry (grade 1). There are good reasons to consider motor skills in the conceptualization and assessment of school readiness. Foremost is the clinically remarked link between learning and motor skill problems (Geuze, Jongmans, Schoemaker, & Smits-Engelsman, 2001; Missiuna, Moll, King, & Law, 2007).

There is also evidence of an overlap between behavioral and motor disorders (Kadesjö & Gillberg, 2001; Kaplan, Wilson, Dewey, & Crawford, 1998; Harvey & Reid, 2003). It is noteworthy than motor deficits are also associated with specific language impairments in school-aged children (Hill, 2001; Webster, Majnemer, Platt, & Shevell, 2005; Gaines & Missiuna, 2006). Previous research has estimated that among children attending regular elementary school classroom, half will exhibit deficits in motor skills (Gubbay, 1975) such as low sporting ability, clumsiness, and poor handwriting. This study found a higher incidence of reading difficulties in children rated as clumsy, which is consistent with more recent clinical studies.

In elementary school, children spend 31% to 60% of their academic day in fine motor activities (McHale & Cermak, 1992) including handwriting tasks and manipulative tasks with school material or tools (e.g., books, rulers, scissors, glue, etc.). A clinical study conducted by Sandler and colleagues (1992) compared two groups of children with developmental and learning problems. One group had writing disorders and another one had no writing problems. Children with writing disorders showed a tendency toward lower mathematics and verbal competence and more attention problems compared to children with no writing problems.

In a sample selected from three elementary schools, Tseng & Murray (1994) reported that perceptual-motor measures of visual motor integration and eye-hand coordination are two significant predictors for handwriting skills. These perceptual-motor skills were measured from standardized tests, including the Developmental Test of Visual-Motor Integration (VMI, which comprises 24 geometric forms for children to copy, Beery, 1989) and the Motor Accuracy Test of the Sensory Integration and Praxis Test (which represents a measure of eye-hand coordination, Ayres, 1989). In addition to gross and fine motor skills (Grissmer et al., 2010; Pagani et al., 2010), visual perceptual skill should be regarded to be among the most significant factors related to math and reading achievement. Sortor and Kulp, 2003 (2003) measured visual perception in 155 children in second through fourth grade classes from primarily white, middle-class, suburban backgrounds. From a subtest of the VMI (Beery & Buktenica, 1997), they asked to children to identify each matching form. Their results suggest that children with poor achievement in math and reading should be tested for deficits in visual perceptual skill.

Motor difficulties are associated to speech and language disorders (Iverson & Thelen, 1999; Gaines & Missiuna, 2006). A recent comprehensive review of the literature of well-designed studies investigating children with specific language impairment found that 40-90% of such children also exhibit motor impairments (Hill, 2001). Webster and colleagues (2005) conducted a 4-year follow up of children initially diagnosed at pre-school age (3-4 years) with developmental language impairment and found a relationship between subsequent motor, language, and cognitive impairments. More specifically, gross and fine motor were highly correlated with communication scores. However, only fine motor scores showed a significant correlation with cognitive scores. Using a convenience sample children who had been identified with speech-language delays as toddlers, Gaines & Missiuna (2006) found that such children may have significant coordination difficulties and are at risk of experiencing more problems by kindergarten.

Given the above findings, we can derive several conclusions. First, motor skills represent easily assessed characteristics of kindergarten readiness. Second, studies showing their association with traditionally assessed indicators of school readiness originate mainly from clinically-based samples of children with motor difficulties. Third, many clinical studies use individual assessments of motor skills, which are more expensive for larger scale studies and real world applications associated with public policy. Studies with larger numbers of students are able to statistically adjust for possible confounds. Finally, very little research has investigated typically developing children in regular kindergarten classrooms.

It would be helpful to teachers and school professionals to better understand how the different key elements of school readiness relate to each other prior to formal school entry. This is especially true for teachers working in urban, disadvantaged settings where children experience cumulative psychosocial risks. Of course, a true examination such relationships must control for any other competing or confounding factors which, if not controlled, could inflate or reduce the concurrent links we wish to examine in kindergarten. For example, cognitive and behavioral characteristics should be controlled when examining the unique association between motor skills and other school readiness characteristics. Moreover, apart from individual child characteristics, family background can represent an important predictor of academic achievement. More specifically, family configuration and income, and parental education and aspirations are all factors that should be considered as potential confounds in studies of children's school readiness and achievement (Al-Yagon, 2003; Pagani et al., 2010; Vitaro et al., 2005). Hence, the objective of this study is to estimate the concurrent links between motor skills and cognitive and behavioral characteristics at kindergarten entry, above and beyond other competing explanations. In light of their common brain recruitment features and overlapping roles in Piagetian theory, we expect significant associations between motor, cognitive, and behavioral skills above and beyond potential

confounding child and family characteristics.

2. Method

2.1 Participants

Participating children were from the first cohort of the Montreal Longitudinal Preschool Study (MLEPS, N = 522) who attended kindergarten during the 1998/99 school year (Duncan et al., 2007; Pagani et al., 2010). Participants were recruited after a multilevel consent process involving school board officials, local school committees, parents, and teachers. Data were collected from multiple sources, including direct individual cognitive (verbal and math) assessments of children, and teachers and parents (child academic/social functioning and family characteristics, respectively).

Seventy-five percent of children in this study lived with both parents. Average total family income was equal or less than 23,600$ CAN (±16,000$ CAN), which represents the poverty line. Less than half of mothers (46.3%) had finished high school or high school level trade school. An important proportion of the mothers (66.5%) hoped that her child would complete university-level studies.

2.2 Measure: Independent Variable

Motor skills. Assessed by teachers at the end of kindergarten, motor skills are divided into three conceptual scales: (1) *Gross Motor* (3 items: is well coordinated; moves without running into or tripping over things; ability to climb stairs, Cronbach alpha = 0.74); (2) *Fine Motor* (2 items: proficiency at holding a pen, crayons, or a brush; and ability to manipulate objects, Cronbach alpha = 0.86); (3) *Perceptual-motor* (8 items: is aware of writing direction (left to right, top to bottom); is interested in copying teacher's print; is interested in writing voluntarily (and not only under the teacher's direction); is able to write his/her own name; is able to write simple words; is able to write simple sentences; is able to sort and classify objects by a common characteristics (e.g., shape, colour, size); and is able to make 1 to 1 correspondence, Cronbach alpha = 0.71). The items were rated by teachers on a Likert scale with response options ranging from 1 (never or not true), 2 (sometimes or somewhat true), to 3 (often or very true). Higher values indicate a higher degree of the factor.

2.3 Measures: Dependent Variables: Cognitive and Behavioral Skills

The *Peabody Picture Vocabulary Test* (PPVT, Forms A and B, French adaptation: Échelle de vocabulaire en images Peabody) was assessed at the end of kindergarten. Administered by trained examiners, the French-version of the PPVT has been standardized by Dunn and colleagues (1993) with a sample of 2,038 French-Canadian children (from ages 2 to 18) using the same images, procedures, and scoring as in the English version. Reliability was established using the split-half method with Spearman-Brown correction for each age group and for both Forms A and B (r = 0.66 and 0.85, respectively). Test-retest reliability of the parallel forms was 0.72 at a one week interval. As with the original version, correlations with other French vocabulary tests and other intelligence tests are high (Dunn et al., 1993).

The *Number Knowledge Test* (NKT, abridged version) was administered at the end of kindergarten. From ages 4 through 6, the NKT represents an individually administered assessment of children's informal knowledge of numbers and conceptual prerequisites of arithmetic operations (Okamoto & Case, 1996). Administered by trained examiners, the test for the 5-year-old children measures the following conceptual prerequisites: (1) knowledge of the number sequence from one to ten; (2) knowledge of the one to one correspondence in which a sequence is mapped onto objects being counted; (3) understanding the cardinal value of each number; (4) understanding the generative rule which relates adjacent cardinal values; and (5) understanding that each successive number represents a set which contains more objects. In a recent psychometric study, the test was shown to have a higher mathematics factor loading than other available preschool tests (Robinson et al., 1996). The kindergarten version comprises 19 items that assess more advanced informal number knowledge regarding knowledge of shapes, colors, counting, and basic concept of addition.

The *Social Behavior Questionnaire* (SBQ, Pagani et al., 1997; 2001) was completed by teachers at the end of kindergarten. This measure assesses children's behavioral adjustment. The items on the questionnaire can be divided into the following conceptual scales: *Hyperactive-inattentive* (7 items: seems agitated and has difficulty staying in one place; keeps moving; seems impulsive; has difficulty waiting his/her turn; difficulty staying calm; inattentive; does not listen attentively, Cronbach alpha = 0.91); *Physical Aggression* (7 items: physical fight at least once a day; threatens others; bullies or is cruel toward others; bites, kicks, and hits; gets into many fights; if accidentally hurt, assumes it was intentional; physically attacks people, Cronbach alpha = 0.72); *Emotional distress* (5 items: seems unhappy, sad, or depressed; cries a lot; seems worried or fearful; seems anxious; is nervous or tense, Cronbach alpha = 0.81); *Prosocial behavior* (9 items: shows sympathy toward others; tries to

help someone who is hurt; offers to help clean up somebody else's accidental mess; tries to make peace if there is a conflict; offers to help someone perceived as weaker or less able; consoles a crying or upset peer; helps spontaneously to clean or pick things up; invites others to take part in play; comes to the aid of others, Cronbach alpha = 0.92); and *Classroom Engagement* (8 items: plays and works cooperatively with other children at the level appropriate for age; demonstrates self-control; shows self-confidence; follows directions; completes work on time; works independently; is capable of making decisions; follows rules and instructions, Cronbach alpha = 0.80). Hyperactive-inattentive and physical aggression represent two kinds of externalized behavior, emotional distress represents an internalized behavior, and prosocial behavior and classroom engagement represent two positive behaviors. The SBQ is a good predictor of later psycho-social adjustment and academic failure (Dobkin et al., 1995). National Longitudinal Study of Children and Youth norms are available from early childhood through age 12. All SBQ items were rated on a Likert scale with response options ranging from 1 (never or not true), 2 (sometimes or somewhat true), to 3 (often or very true). Higher values indicate a higher degree of the factor.

2.4 Measures: Control Variables

Family Characteristics. (1) Maternal education (mothers not finishing high school versus completion, mother reports); (2) Family configuration (early childhood single-parent family status versus intact, mother reports); (3) Total family income (sections of 5000 on 13 levels); and (4) Parents'aspirations regarding the child's future level of academic attainment.

Child characteristics. Academic and behavioral difficulties are more often observed in boys. Sex, cognitive characteristics were controlled when examining behavioral outcomes, and behavioral characteristics were controlled when examining children's cognitive outcomes. Additionally, children's other behavioral characteristics were controlled when looking at a specific behavioral outcome.

2.5 Procedure: Data Analytic Strategy

A series of multiple regressions were computed to examine the relationship between kindergarten motor skills and concurrently measured cognitive/behavioral skills and modelled as follows:

$$COG/BEH_{iK} = a_1 + ß_1\ MOT_{iK} + \gamma_1\ FAM_i + \gamma_2\ CHILD_i + e_{it.}$$

In this estimation equation, COG/BEH_{iK} represents performance on the PPVT and NKT individual assessments and teacher-rated behavior for the individual child during kindergarten. MOT_{iK} refers to kindergarten teacher-rated motor indices for each child at kindergarten; FAM_i and $CHILD_i$ are sets of family background and child characteristics that, if left uncontrolled, are likely to exert enduring influences on children's characteristics up to and beyond the end of the kindergarten school year; a_1 and e_{it} represent the constant and stochastic (patterns resulting from random effects) error term, respectively.

Our objective is to reliably estimate the relationship between kindergarten motor skills and other concurrently measured school readiness skills. For an unbiased estimation of our predictor (MOT_{iK}), we adopt and estimate an equation that includes measures of FAM and CHILD for the individual$_i$ that could theoretically have a direct or indirect influence on motor skills. We have chosen maternal education, family configuration, total family income, and parents' aspirations of their children's school success as family level control variables. Child level control variables include sex and concurrent behavior and cognitive skills that might influence estimates of $ß_1$.

3. Results

Table 1 reports descriptive statistics of children's characteristics which serve as independent and dependent variables in this study. A correlation matrix of the relationship of cognitive/behavior characteristics and motor skills is reported in Table 2. All Pearson correlation coefficients were significant yet below to 0.70, indicating less concern for multicolinearity between variables. Although the results addressing cognitive skills and behavioral skills as dependent variables are reported in stepwise detail, Tables 3 and 4 only report the results for the fully controlled model, respectively.

3.1 Cognitive Variables

Verbal Competence and Motor Skills. In the initial (uncontrolled) model, gross motor ($\beta = .12$, $p < .05$) and perceptual-motor ($\beta = .16$, $p \leq .01$) factors were significantly related to verbal competence, as measured by PPVT. When family controls were added, family configuration and income also were significantly associated with verbal competence (family configuration: $\beta = -.21$, $p \leq .001$; family income: $\beta = .31$, $p \leq .001$). Adding the family controls did not alter the relationship between verbal and motor skills. However, in the fully controlled model, reported in Table 3, where child factors are added, the relationship between motor skills and verbal

competence becomes mediated by child characteristics, especially by number knowledge, as measured by NKT [β =.38, t(13,446) = 8.45; p ≤ .001] and to a lesser extent, by prosocial behavior [β =.11, t(13,446) = 2.30; p < .05]. The fully controlled model explained 26% of the variance in the verbal competence [F(13, 446) = 12.09; p ≤ .001], compared with 4% and 13% with the uncontrolled and family controlled model, respectively.

Number Knowledge and Motor Skills. The initial model revealed that fine motor (β = 0.17, p ≤ .01) and perceptual-motor (β = .22, p ≤ .001) factors were significantly associated with number knowledge, as measured by NKT. When family controls were added, maternal education, family configuration and income also were significantly related to number knowledge (maternal education: β = .11, p ≤.01; family configuration: β = -.09, p < .05; family income: β = .24, p ≤.001). Adding family characteristics as controls did not alter the relationship between number knowledge and motor skills. In the fully controlled model, the relationship between motor skills and number knowledge remained significant once child characteristics were added to the equation (Table 3) [fine motor: β = .16, t(13,446) = -2.85; p ≤ .01 and perceptual-motor: β = .14, t(13,446) = -3.09; p ≤ .01]. Verbal competence was significantly related to number knowledge [β = .36, t(13,446) = 8.45; p≤ .001]. Hyperactive-inattentive behavior [β = -.16, t(13,446) = 2.81; p ≤ .01] also was significantly associated with number knowledge; however, to a lesser extent. The fully controlled model explained 31% of the variance in the number knowledge [F(13, 446) = 15.49; p ≤ .001], compared with 12% and 19% for the uncontrolled) and family controlled models, respectively.

3.2 Behavioral Variables

Hyperactive-Inattentive Behavior and Motor Skills. The uncontrolled model revealed that fine motor (β = -.34, p ≤ .001) and perceptual-motor skills (β = -.19, p < .001) were each associated with hyperactive-inattentive behavior, as measured by SBQ. Then, adding family controls did not alter the relationship between motor skills and hyperactive-inattentive behavior. However, only fine motor remained a significantly associated once child characteristics were added to the equation [β = -.23, t(13,446) = 4.76; p ≤ .001] in the fully controlled model which includes child controls, reported in Table 4,. Specifically, physical aggression, as measured by SBQ, explained the link between perceptual-motor skills and hyperactive-inattentive behavior [physical aggression: β = -.42; t(13,446) = 11.48; p ≤ .001]. The other child characteristics, with the exception of verbal competence, also significantly influenced hyperactive-inattentive behavior; however, to a lesser extent [emotional distress: β =.12, t(13,446) = 3.32; p ≤ .001; number knowledge: β = -.11, t(13,446) = -2.81; p ≤ .01; sex: β = .11, t(13,446) = -3.00; p ≤ .01; prosocial behavior: β = -.08, t(13,446) = -2.15; p < .05;]. The fully controlled model explained 50% of the variance in the hyperactive-inattentive behavior [F(13, 446) = 34.71; p < .001], compared with 22% and 23% for the uncontrolled and family controlled models, respectively.

Physical Aggression and Motor Skills. Initial results revealed that perceptual-motor (β = -.12, p < .05) was significantly associated with physical aggression behavior, as measured by SBQ. Next, adding family characteristics as controls did not alter the relationship between motor skills and physical aggression, even though family configuration also was significantly linked with physical aggression (β = -.10, p < .05). However, in the fully controlled model, three child characteristics mediated the relationship between physical aggression and perceptual-motor skills. Hyperactive-inattentive made the largest unique contribution in the link between physical aggression and perceptual-motor skills [β = .54, t(13,446) =11.48; p ≤ .001]. Specifically, prosocial [β = -.15, t(13,446) =-3.35; p ≤ .001] and emotional distress [β = .08, t(13,446) =1.99; p < .05] were significantly associated with physical aggression. The fully controlled model explained 37% of the variance in the physical aggression [F(13, 446) = 19.94; p ≤ .001], compared with 4% and 6% for the uncontrolled and family controlled models, respectively.

Emotional Distress and Motor Skills. Gross motor skills were significantly associated (β = -.21, p ≤ .001) with emotional distress in the initial uncontrolled model. Next, parental aspirations also were significantly related to emotional distress (β = .18, p ≤ .001). Adding family characteristics as controls did not alter the relationship between gross motor and child emotional distress. The relationship between gross motor skills and emotional distress remained significant after adding child characteristics in the fully controlled model [β = -.16, t(13,446) = 2.86; p ≤ .01]. Hyperactive-inattentive, prosocial, and physical aggression also were significantly linked with emotional distress [hyperactive-inattentive: β = .20, t(13,446) = 3.32; p ≤ .001; prosocial: β = -.13, t(13,446) = -2.71; p ≤ .01; physical aggression: β =.11, t(13,446) = 1.99; p < .05]. The fully controlled model explained 22% of the variance in the emotional distress behavior [F(13, 446) = 9.41; p ≤ .001], compared with 8% and 12% for the uncontrolled and family controlled models, respectively.

Prosocial Behavior and Motor Skills. Initially, gross motor (β = .18, p ≤ .001) and perceptual-motor (β = .25, p ≤ .001) were significantly associated with prosocial behavior. Then, adding family characteristics did not alter

the relationship between motor skills and prosocial behavior. Once child characteristics were added to the equation in the fully controlled model, the relationship between prosocial behavior and motor skills remained significant [gross motor: (β = .19, t(13,446) = -3.49; $p \leq .001$); perceptual-motor: (β = .16, t(13,446) = -3.36; $p \leq .001$)]. Many child characteristics were significantly related to prosocial behavior, including: verbal competence (β = .11, t(13,446) = 2.30; $p < .05$); sex (β = -.18, t(13,446) = 4.00; $p \leq .001$); physical aggression (β = -.17, t(13,446) = -3.35; $p \leq .001$); emotional distress (β = -.12, t(13,446) = -2.71; $p \leq .01$); and hyperactive-inattentive behavior (β = -.12, t(13,446) = -2.15; $p < .05$). The fully controlled model explained 27% of the variance in the equation addressing the prosocial variable [$F(13, 446) = 12.22$; $p \leq .001$], compared with 12% for uncontrooled and family control models.

Classroom Engagement and Motor Skills. All motor variables (gross motor: β = .15, $p \leq .01$; fine motor: β = .29, $p \leq .001$; perceptual-motor: β = .22, $p \leq .001$) were initially significantly associated with the SBQ classroom engagement scale. Next, family characteristics were not significant as controls and thus did not alter the relationship between motor skills and classroom engagement. In the fully controlled model, many child characteristics were significantly related to classroom engagement, including hyperactive-inattentive (β = -.49, t(14,445) = -12.91; $p \leq .001$), emotional distress (β = -.20, t(14,445) = -6.65; $p \leq .001$), physical aggression (β = -.15, t(14,445) = -4.57; $p \leq .001$), and prosocial behavior (β = .08, t(14,445) = 2.57; $p \leq .01$). The relationship between classroom engagement behavior and motor skills remained significant once child characteristics were added to the equation [gross motor: (β = .07, t(14,445) = -2.08; $p < .05$), fine motor: (β = .10, t(14,445) = -2.56; $p \leq .01$), and perceptual-motor: (β = .08, t(14,445) = -2.54; $p \leq .01$)]. The fully controlled model explained 68% of the variance of the classroom engagement [$F(14, 445) = 67.92$; $p \leq .001$], compared with 27% and 28% for the uncontrolled and family controlled models, respectively.

4. Discussion

Children enter kindergarten with skills and characteristics that either facilitate or hinder learning. The last forty years have focused on cognitive and behavioral indicators of school readiness. Well controlled, empirical studies tell us that cognitive characteristics, especially early math, reading, and attention skills, are especially important (Duncan et al., 2007). Practitioners in the field suggest that being cooperative and able to sit still are also pertinent (Hohmann & Weikart, 2002; Entwisle et al., 2005). Nevertheless, many requisite skills for first formal learning of reading, writing, and arithmetic involve specific motor abilities (Henderson & Pehosk, 1995). This study sought to examine and describe the concurrent relationship between kindergarten motor skills and such cognitive and behavioral characteristics.

With respect to cognitive school readiness indicators, early math skills were strongly related to both fine motor and perceptual-motor abilities. The relationship with fine motor ability is likely influenced by the fact that early informal knowledge of numbers is generated by manipulating objects and exploring their properties. This overlap is likely attributable to the fact that much of early and informal knowledge of mathematics involves rules that require perceptual-motor knowledge in terms of spatial relations (Okamoto & Case, 1996; Cirino, 2011) such as: (1) relative magnitude; (2) incrementing and decrementing tasks, as when addition or subtraction of one element to a set alters the number of elements in a set by one unit up or down on the number line; (3) knowledge of relative position on the number line, which is useful for determining the relative quantities in real world situations; and (4) the features of objects such as shape, color, dimension, and other perceptual features for selective grouping, matching, and classification tasks. The perceptual-motor skills evaluated in this study include being able to sort and classify objects by a common characteristics (e g., shape, colour, size) and understanding one-to-one object correspondence both overlap with early number knowledge. Moreover, other perceptual-motor skills measured such as being able to write his/her own name and being able to write simple words require spatial knowledge and directional orientation (Henderson & Pehoski, 1995). These represent mathemathical reasoning and knowledge (Cirino, 2011; Newcombe & Huttenlocher, 2000).

The relationship between early math skills and motor skills was so strong that it completely explained the relationship between motor skills and verbal competence. Its power is not surprising, given that there is much overlap in brain recruitment of areas responsible for motor, math, and attention skills (Grissmer et al. 2011, Cirino, 2011). On some significant level, even if the effect size is modest, motor skills develop in tandem with other school readiness skills that are honed between birth and school entry. If a child falls behind on one essential skill, it is likely to have a negative influence on other related skills, thus calling for comprehensive intervention strategies.

This study examined relationship between three different categories of behaviors and motor skills. These correspond to externalizing, internalizing, and positive classroom behaviors. Some clinical studies suggest a

relationship (Kaplan et al., 1998; Kadesjö & Gillberg, 2001; Harvey & Reid, 2003). However, these results, using very controlled models, break new ground by informing us about the relationship between motor and psychosocial characteristics in typically developing children.

With respect to externalizing behaviors, only hyperactive-inattentive behavior was significantly related to fine motor skills. Specifically, children showing greater levels of hyperactive-inattentive behavior were more likely to show deficits with fine motor skills. In fact, this unique association completely accounted for relationship between fine motor skills and physical aggression. It is noteworthy that previous work suggests that strength and weakness in attention represent the only behavioral factors that influence later achievement outcomes (Duncan et al., 2007; Pagani et al., 2011). This link, which reflects the overlap between executive function and motor circuitry in the brain during early childhood development, suggests the mutual importance of attention to fine motor skills and assessing both skills when one deficit is noted in a young child. The other deficit may be present or may become more evident over time. Consequently, focused intervention strategies can be made to circumvent the co-occurring deficits.

The only result that highlighted gross motor skills is in its association with emotional distress. Children showing depressed, worried, or anxious classroom behavior showed a greater propensity toward difficulty with gross motor skills. A study with overweight children reported an inverse association between depressive symptoms and physical activity in children, reminding us that fatigue and loss of energy represent robust symptoms of dysphoria across human development (Gray et al., 2008).

All three motor skills were associated with positive classroom behaviors represented by prosocial behavior and classroom engagement. Helping others and remaining oriented to classroom activities and exhibiting productive classroom behavior not only involves good cognitive control skills which are governed by executive functions, they also involve some level of self-regulation in overall motor abilities. Our main conclusion here is that good motor abilities co-occur with better social skills and task-oriented behaviors in class. It is not unexpected that both gross motor movement (Hohmann & Weikart, 2002) and fine and perceptual-motor movement (Diamond et al., 2006; Lillard et al., 2008) figure prominently among the list of key early childhood experiences in enrichment programs that favour positive development and school readiness.

Surprisingly, our results found more associations between motor skills and positive behaviors, compared to negative behaviors. Most problem behaviors which involve aggression and oppositional behavior are strongly associated with inattentive-hyperactive behavior (Dobkin et al., 1995). We controlled for these symptoms when examining the relationships between behavior and motor skills in this study. The results are quite compelling because the relationships remained significant despite the adjustments made for family and child factors that could have confounded this relationship. The most remarkable feature of the results is the robustness of positive social skills and task oriented behaviors (represented by the prosocial and classroom engagement variables, respectively). It could also be said that, much like all three specific motor skills examined in this study, positive behaviors require more effortful control than negative behaviors (Blair & Diamond, 2008) and most learning tasks and activities involve some degree of effort in motor abilities.

Several observations are worthy of note: Child characteristics such as sex and behavioral skills showed no influence on the relationship between motor and cognitive skills. However, it seemed important to control for family characteristics. A possible explanation is that cognitive skills and their correlates, fine motor and perceptual-motor skills, are often linked with family characteristics. In other words, family characteristics can be viewed as a support mechanism for learning, especially in low-income settings (Pagani et al., 2001). This is much in line with findings that parents who provide a stimulating home environment (La Paro & Pianta, 2000) and participate in children's learning (Entwisle et al., 2005) tend to promote school success.

Inversely, we noted that, in general, family characteristics do not play a significant role in the relationship between the motor and behavioral skills, as measured in this study. Yet, child characteristics such as verbal competence, sex, and behavioral skills must be controlled when examining this relationship. Motor skills might be inherent to child behavior. This could explain why it is important to control for child characteristics in its relationship with behavioral more than cognitive characteristics.

We can conclude that, generally, kindergarten entry motor skills are independently related with a number of important psychosocial characteristics. Both are expected to have an impact on later learning (Entwisle, 2005). Self-regulation of effortful control (measured by attention in this study), regulated by executive functions, overlaps with learning fine motor skills, and together provide the prerequisites for later learning. Because impaired gross motor skills are often accompanied by emotional distress, it likely affects one's overall physical disposition toward learning.

This study is not without limitations. First, we cannot be certain of the true validity of our teacher-rated motor assessment. For purposes of secondary analysis of already existing longitudinal data, this scale was created by a clinical content expert from occupational therapy department at the University of Montreal. Its construct and predictive validity has been established through a principal components analysis which suggests a very good fit between its items and factors (Pagani et al., 2010). Second, although our work establishes link between motor skills and cognitive and behavioral characteristics have been traditionally used to estimate school readiness, we cannot know if motor skills in kindergarten predict later cognitive and behavioral characteristics later. A longitudinal study would be required to assess the impact of motor development on school readiness. While we offer a cost-effective alternative for assessing motor skills by using teacher reports, this approach is not as profound a measure as would be derived using observational data and more rigorous testing of motor skills. Screening instruments using teacher reports of motor and behavioral skills can flag the need for more in-depth assessment for children showing atypical development.

These results offer a better understanding of how cognitive and behavioral development co-occur with motor skills. Preventive intervention treatment of children who show less preparedness in cognitive skills may also require enrichment of motor skills and vice-versa. Developing a better understanding of how the distinct key elements of school readiness relate to each other prior to formal school entry will help teachers and school professionals devise more comprehensive strategies in helping children become prepared for the first grade transition, especially in urban, disadvantaged settings.

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Table 1. Descriptive statistics of the child characteristics which represent the independent and dependent variables in the study

	N	Minimum	Maximum	Mean (sd)
Cognitive skills				
Verbal competence (PPVT)	471	3	133	63.15 (23.2)
Number Knowledge (NKT)	463	0	19	13.07 (4.0)
Behavioral skills				
Hyperactive-inattentive	470	9	27	13.25 (4.7)
Physical aggression	470	7	21	8.24 (2.7)
Emotional Distress	468	5	15	6.44 (1.9)
Prosocial behavior	471	9	27	19.80 (5.1)
Classroom engagement	471	12	23	20.67 (2.7)
Motor skills				
Gross motor	471	-0.69	2.35	0.08 (0.88)
Fine motor	471	0.71	2.55	1.15 (0.49)
Perceptual motor	471	0.71	2.92	1.21 (0.50)

Table 2. Correlation matrix depicting the relationship between motor skills and cognitive and behavioural characteristics in kindergarten

Variables	VC	NK	ME	FC	FI	PA	Sex	HI	PAG	ED	PRO	CE	GM	FM
Gross motor	0.12**	0.20***	0.008	-0.09	0.09	0.11**	0.05	-0.28***	-0.09	-0.26***	0.25***	0.38***		
Fine motor	0.08	0.29***	0.04	-0.05	0.04	0.06	-0.28***	-0.44***	-0.16***	-0.22***	0.22***	0.47***	0.60***	
Perceptual motor	0.16***	0.31***	0.05	-0.07	0.11*	0.006	-0.29***	-0.35***	-0.16***	-0.16***	0.30***	0.38***	0.27***	0.45***

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Table 3. Relationship between motor skills and cognitive skills

Fully controlled model	Verbal competence	Number knowledge
Independent variable: Motor skills		
Gross motor	0.09	0.002
Fine motor	0.10	0.16**
Perceptual motor	0.05	0.14**
Control variables: family characteristics		
Maternal education	0.02	0.10**
Family configuration (single-parent)	-0.16***	-0.03
Family income	0.22***	0.12**
Parents' aspirations	0.02	-0.003
Control variables: child characteristics		
Number knowledge	0.38***	
Verbal competence		0.36***
Sex (boys)	0.03	0.03
Hyperactive-inattentive	-0.08	-0.16**
Physical aggression	-0.02	-0.05
Prosocial behavior	0.11*	0.06
Emotional distress	-0.04	-0.04

Note. $*p < 0.05$; $**p \leq 0.01$; $***p \leq 0.001$

Table 4. Relationship between motor skills and behavioral skills

Fully controlled model	Hyperactive inattentive	Physical aggression	Emotional distress	Prosocial behaviour	Classroom engagement
Independent variable: Motor skills					
Gross motor	0.01	-0.07	-0.16**	0.19***	0.07*
Fine motor	-0.23***	-0.07	0.002	0.10	0.10**
Perceptual motor	0.07	0.03	0.01	0.16***	0.08**
Control variables: family characteristics					
Maternal education	-0.001	-0.05	-0.03	0.02	0.004
Family configuration (single-parent)	-0.03	-0.05	-0.03	-0.04	-0.01
Family income	-0.02	-0.05	-0.03	-0.04	0.004
Parents' aspirations	0.01	-0.02	0.18***	0.04	-0.01
Control variables: child characteristics					
Verbal competence	0.05	0.02	0.04	0.11*	-0.01
Number knowledge	-0.11**	0.05	0.05	-0.06	-0.01
Sex (boys)	0.11**	0.005	0.01	-0.18***	-0.04
Hyperactive-inattentive		0.54***	0.20***	-0.12*	-0.49***
Physical aggression	0.42***		0.11*	-0.17***	-0.15***
Prosocial behavior	-0.08*	-0.15***	-0.13**		0.08**
Emotional distress	0.12***	0.08*		-0.12**	-0.20***

Note. $*p < 0.05$; $**p \leq 0.01$; $***p \leq 0.001$