AN ABSTRACT OF THE DISSERTATION OF

Amanda Taek Soon Tepfer for the degree of Doctor of Philosophy in Exercise and Sport Science presented on April 23, 2015.

Title: Predicting School Readiness Using Motor Skill Proficiency of At-Risk Preschoolers

Abstract approved:

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Megan MacDonald

Background: Early childhood is filled with incredible growth in all areas of development and offers a critical period for optimal learning (Lerner, 2002). During this critical period both motor skills (Bouffard, Watkinson, Thompson, Causgrove Dunn, & Romanow, 1996; Clark & Metcalfe, 2002; Lubans, Morgan, Cliff, Barnett, & Okely, 2010; Stodden et al., 2008), as well as self-regulation skills develop (Blair, 2002). Recent empirical research suggests active play, during early childhood, may help establish healthy behaviors and play a role in early childhood development through improving cognitive, social, and emotional health (Ginsburg, 2007). Previous research indicates success in the classroom requires strong self-regulation skills, such as attention, memory, and inhibitory control (Blair, 2002). Yet, the role of motor skills amidst other developmental indicators of school readiness is not well documented. Thus, the purpose of this project was to examine the relationship between motor skills and aspects of school readiness in young children between the ages of 3-5 years from at-risk populations.

Methods: This descriptive, cross-sectional study included a sample of 162 children with at least one biological (e.g. disability) or environmental (e.g. low-income) risk factor, per parent report, from two geographical areas in the US. Individual assessments of gross and fine motor skills, behavioral self-regulation, early literacy, and early math skills were used to examine associations between motor skills and early indicators of school readiness.

Results: Results of hierarchical regression analyses demonstrated that preschool gross and fine motor skills significantly predicted indicators of school readiness, specifically behavioral self-regulation and early academic achievement. Further analysis indicated fine motor skills predicted school readiness over gross motor skills, even after controlling for age (in months) and site.

Conclusion: This study found positive relations, with specific aspects of fine motor skills and early indicators of school readiness. These findings have implications for school readiness initiatives focused on improving early developmental trajectories for preschool aged children from at-risk populations.

Predicting School Readiness Using Motor Skill Proficiency of At-Risk Preschoolers

by

Amanda Taek Soon Tepfer

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Dean of the Graduate School

I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Amanda Taek Soon Tepfer, Author

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CHAPTER ONE

Introduction

Characteristics important for school entry have gained attention and are reported to positively contribute to academic success (Blair & Razza, 2007; Duncan et al., 2005; Entwisle, Alexander, & Olson, 2005). School readiness initiatives typically begin in preschool settings and provide learning experiences that foster school readiness skills. These initiatives are rich in curriculum and offer opportunities for pre-reading, writing, and math skills. The amount of children attending early education programs has risen over the past decade. Reports from the Board on Children, Youth, and Families of the National Research Council and the Institute of Medicine, such as *Eager to Learn* (Bowman, Donovan, & Burns, 2001) and *From Neurons to Neighborhoods* (Shonkoff & Phillips, 2000) highlight early childhood as a critical time period for optimal development. In 2012, approximately 41% of 3- year olds, 66% of 4-year olds, and 85% of 5- year olds were enrolled in some type of pre-Kindergarten (pre-K/preschool) program (U.S. Department of Education, 2013). Preschool programs create opportunities for young children that benefit cognitive, motor, and social development. For example, children interact wither other children and teachers to enhance social skills, are introduced to structured activities, and provided opportunities for motor experiences. Programs that offer pre-K services are also on the rise and operate under a variety of sponsors, including but not limited to the federal Head Start Program, publicly funded programs such as local early intervention programs, and privately funded centers. In addition, pre-K programs and early intervention services are mandatory under the Individuals with Disabilities Education Act (IDEA), Part B (U.S. Department of Education, 2011). Thus, children with disabilities or those experiencing developmental delays are eligible to receive special education, specifically designed to meet the educational and developmental needs of the child. Despite the expansion of program enrollment, lower school readiness skills still exist for children from low-income families (Bainbridge et al., 2002), English Language Learners (Galindo& Fuller, 2010; Wanless, McClelland, Tominey, & Acock, 2011), and from other at-risk populations (Gehrmann, Coleman, Weir, Ware, & Boyd, 2014; Gerstein et al., 2011; Pears, Kim, Healey, Yoerger, & Fisher, 2014; Prasad, Corbett, & Prasad, 2014). In order for pre-K programs to increase school readiness skills, curriculum content needs to encompass a variety of meaningful activities, such as exposure to a variety of activities and instruction, regardless of ethnic or income background, gender, or disability. Current curriculum content primarily focuses on solely academic skills and many children are not successfully transitioning from pre-K to kindergarten.

Kindergarten is the first full day experience in formal education for many children, and the transition from preschool to kindergarten can be challenging. Furthermore, kindergarten classrooms are becoming more academically focused to ensure children are reaching required achievement standards set by legislations such as No Child Left Behind (U.S. Department of Education, 2010). Future educational trajectories are framed by the way children transition into a more structured classroom (McClelland, Acock, & Morrison, 2006; Ponitz, McClelland, Matthews, & Morrison, 2009). In addition, children who are not prepared socially, emotionally, or cognitively at an early age may not be ready for the academic demands presented in kindergarten (Bulotsky-Shearer & Fantuzzo, 2011; Duncan et al., 2007; Eisenberg et al., 2000; Vitaro, Brendgen, Carose, & Tremblay, 2005). Unfortunately, children who do not transition successfully from pre-K to kindergarten experience poorer academic and social-emotional learning and slower progress in the same academic areas. On the other hand, children who transition successfully adapt to the new setting more easily and engage in learning more positively (Harbin, Rous, Peeler, Schuster, & McCormick, 2007). School readiness is no longer viewed through literacy and mathematics competence alone (Pianta, Cox, & Snow, 2007). Instead, school readiness includes multitude of competencies that emerge during early childhood, including behavioral aspects of self-regulation, appropriate social behaviors, early academic achievement, and the acquisition of motor skills (Bulotsky-Shearer & Fantuzzo, 2011; Duncan et al., 2007; Eisenberg et al., 2000; Pianta, Cox, & Snow, 2007; Vitaro et al., 2005). A national sample of kindergarten teachers indicated very few considered specific skills, such as knowing the alphabet and being able to count to 20 critical for entry into kindergarten. The majority of teachers considered children ready for school if they were able to communicate their needs verbally, showed enthusiasm and curiosity about approaching new activities, could take turns and share with others, and were well-nourished and rested (Heaviside & Farris, 1993). Other studies have reported similar findings, indicating children's behavior, cognition, and emotion towards the classroom environment important to school readiness (Skinner, Kindermann, & Furrer, 2009; Williford, Maier, Downer, Pianta, & Howes, 2013). The increased demands on children's social and self-regulation skills make the transition into a more structured classroom difficult for many children.

More recently, motor skills have been indicated as a contributing factor to school readiness outcomes such as behavioral self-regulation, early academic achievement, and social behaviors (Becker, McClelland, Loprinzi, & Trost, 2014; Cameron et al., 2012; MacDonald et al., in review). Motor skills typically consist of gross motor skills (such as balance, locomotor, and object manipulation skills) and fine motor skills (such as grasping and visual motor integration skills). Becker and colleagues (2014) indicated higher levels of active play, which encompasses the use of motor skills, were associated with better self-regulation skills. Furthermore, higher levels of active play were associated with better self-regulation skills, which were ultimately associated with higher early academic achievement. Similarly, data indicates fine motor skills, specifically visual-motor integration skills, such as design copy (e.g. copying shapes or patterns), predict higher early academic achievement scores (Becker, Miao, Duncan, & McClelland, 2014; Cameron et al., 2012). Although most research focuses on the associations between fine motor skills and school readiness new findings are indicating associations with gross motor skills as well. Children with better gross motor skills, specifically object manipulation skills, such as catching and throwing, demonstrated better classroom social behaviors, per teacher report (MacDonald et al., in review). Early childhood has been identified as a crucial time period for overall growth and development, thus understanding and identifying relations of motor skills and school readiness skills, has the potential to contribute to overall healthy child development.

Children who are “at-risk” due to a developmental delay or disability demonstrate lower school readiness skills than typical developing peers (Pugello et al., 2010; Robbins, Stagman, & Smith, 2012; Wanless et al., 2012). Children with developmental delays have demonstrated cognitive deficits in executive skills necessary for self-regulatory functions, and demonstrate less effective regulation methods than typically developing peers (Bekman, 2009; Cmic, Hoffman, Gaze, & Edelbrock, 2004; Gerstein et al., 2011; Konstantareas & Steward, 2006). It is suggested that children with developmental delays use regulation strategies differently than typical peers. Boys with developmental delays demonstrated different regulatory patterns, including using less gaze aversion, less use of new strategies, and more return to solitary play after social failure compared to typically developing peers. Previous research reported preschool children with epilepsy scored lower in a variety of self-regulatory skills, such as auditory attention, short-term memory, rapid word retrieval, and slower processing in comparison to peers (Seassie, Viggedal, Olsson, & Jennische, 2008). Young children with Autism Spectrum Disorder (ASD) exhibited more maladaptive regulatory strategies when given a frustrating situation (removal of an attractive toy) compared to peers (Konstantareas & Stewart, 2006). Thus, understanding potential mechanisms underlying behavioral self-regulation may inform early childhood programming. Children with developmental delays are more likely to remain on a negative developmental trajectory leading to social isolation and later adjustment difficulties, thus suggesting the importance of appropriate early interventions (Guralnick, 1999; Kopp, Baker, & Brown, 1992).

Understanding how motor skills, in children from at-risk populations, affect other developmental constructs in early childhood should provide insight into the role of motor skill development in school readiness skills. The purpose of this project was to examine the relationships between motor skills and aspects of school readiness, specifically behavioral self-regulation and early academic achievement in children between the ages of 3-5 years from at-risk populations. The first manuscript examines the relations of motor skills with behavioral self-regulation in a large and diverse sample of children between the ages of 3-5 years from two geographical region in the United States. The second manuscript examines relations of motor skills with early indicators of academic achievement, specifically early literacy and early math skills. It was hypothesized that children with higher motor skills would demonstrate higher levels of behavioral self-regulation and higher scores in early academic achievement, based on previous research (Becker et al, 2014; Cameron et al., 2012; MacDonald et al., in review; Westendorp et al., 2011).

Research Aims and Approaches:

Manuscript 1 Aim: To assess and examine gross motor, fine motor, and behavioral self-regulation skills of children between the ages of 3- to 5- years, identified at-risk through parent report. To examine relationships between motor skills and behavioral self-regulation.

Manuscript 2 Aim: To assess and examine gross motor, fine motor, early literacy, and early math skills of children between the ages of 3- to 5- years, identified at-risk through parent report. To examine relationships between motor skills and early academic achievement.

Approach: Assessments were conducted in children's homes and/or preschool classrooms in the fall of the preschool year.

Assumptions:

1) It was assumed that all participants would put forth their best effort in each assessment.
2) It was assumed that the preschools involved were representative of other community-based preschools.
3) It was assumed that the participants understood the directions of each assessment.

Limitations:

1) The participants were from two specific geographic locations and thus do not represent a random, generalizable population.
2) Participants were assessed in classrooms, hallways, and other work spaces within the schools with potential distractions.
3) Assessments ranged in time from 5-min to 45-minutes in length and some participants may have tired or lost interest in participation.

Delimitations: The study is delimited to the following:

1) Participants with at least one biological and/or environmental risk factor within the age of 3-5, including both males and females.

2) Participants attending a community-based or Head-Start preschool program, including half-day and full-day programming.

Operational definitions:

At-risk: Term used to describe a number of different categories of children, refers to infants and young children who are physically, medically, or psychologically in danger of failing to thrive and also includes children who are affected by diverse economic, environmental, and geographical factors.

Biological risk: Refers to medical conditions and anomalies that invariably result in disability or developmental delay (often related to genetic and chromosomal problems) and children with a history of developmental events such as premature and low birth weight, thus placing them in an at-risk category.

Environmental risk: Conditions that occur when a child is biologically normal but does not develop age-appropriate behavior at the typical rate. Refers to children who have characteristics, live in environment, or have experiences that make them more prone to develop some form of a disabling condition and/or more likely to fail in school. Physical risk factors include chemical, biological, and physical influences such as prenatal drug exposure (e.g. alcohol and tobacco) and exposure to pollutants (e.g. air, water, noise, radiation). Social risk factors include low socio-economic status, family composition and size, parental mental health, parental substance abuse, and community demographics.

Chapter 2

Motor Skill Mechanisms Underlying Behavioral Self-Regulation in At-Risk Preschoolers

Motor Skill Mechanisms Underlying Behavioral Self-Regulation in At-Risk Preschoolers

KEYWORDS: motor skill proficiency, early childhood, at-risk populations, disability, behavioral self-regulation

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Abstract

Purpose: The present study examined the gross and fine motor skills of 3- to 5- year-old at-risk children using the Peabody Developmental Motor Scales -2. Additionally, associations of fine and gross motor skills with behavioral self-regulation, a known indicator of school-readiness, were examined.

Methods: Children (*n* = 162) from two geographical areas in the U.S. were recruited for this study. Participants were identified as at-risk if at least one biological (e.g. disability) or environmental (e.g. low-income, single parent) risk factor was reported by the parent or primary caregiver. Motor skills were compared to standardized norms and age equivalent scores of the PDMS-2. This descriptive, cross-sectional study used hierarchical multiple regressions to examine relationships between gross and fine motor skills and behavioral self-regulation.

Results: Children at-risk scored lower on both gross and fine motor skills compared to standardized norms. Children with biological risk factors (n = 75) scored poorer on gross and fine motor subscales than children (n = 87) with environmental risk factors. Gross motor skills ($\beta = .22$, $p = .03$) and fine motor skills ($\beta = .35$, $p = .001$) had significant associations with behavioral self-regulation after controlling for covariates, explaining 41% of variance in the model. Further analysis indicated visual-motor integration skills ($\beta = .30$, $p = .01$) and stationary skills ($\beta = .18$, $p = .04$) had significant associations with behavioral self-regulation after controlling for age, ethnicity, and site.

Conclusion: This study found positive relations, with aspects of motor skills and school readiness skills, specifically behavioral self-regulation. These positive associations offer potential implications for school readiness initiatives for children in at-risk populations.

Introduction

Kindergarten is the first full day experience in formal education for many children, and the transition from preschool to kindergarten can be challenging for both the parent and child. Kindergarten classrooms are becoming more academically focused to ensure children are reaching required achievement standards set by legislations such as No Child Left Behind (U.S. Department of Education, 2010). Evidence suggest that future educational trajectories are framed by the way children transition into kindergarten (McClelland, Acock, & Morrison, 2006; Ponitz, McClelland, Matthews, & Morrison, 2009). Children who are not prepared socially, emotionally, or cognitively may not be ready for the demands of a more structured school environment (Bulotsky-Shearer & Fantuzzo, 2011; Duncan et al., 2007; Eisenberg et al., 2000; Vitaro, Brendgen, Carose, & Tremblay, 2005). Children with disabilities and children from other at-risk populations exhibit difficulties with behavioral aspects of self-regulation thus entering kindergarten less successfully (Howse, Lange, Farran & Boyles, 2003; McClelland, Morrison, & Holmes, 2000). Furthermore, children who do not transition successfully from preschool to kindergarten experience poorer academic and social-emotional learning and slower progress in these areas, whereas children who transition successfully adapt to the new setting more easily and engage in learning more positively (Harbin, Rous, Peeler, Schuster, & McCormick, 2007). Although school-readiness is well-studied, few studies have examined school readiness skills in children with disabilities, thus the current study targets children from at-risk populations, including children with disabilities in examining the role of motor skills in known school-readiness outcomes.

Preschool programs are designed to expose children to pre-academic material, such as math, language, and science skills, to further enhance academic skills and social-behavioral competence (Barnett, Hustedt, Robin, & Schulman, 2005; Clifford et al., 2005). The National Governors Association (NGA) Task Force on School Readiness describes school readiness as demonstrated in five areas: health and motor skill development (e.g. gross and fine motor skills), socio-emotion al development (e.g. self-regulation), motivation to learn (e.g. persistence to tasks), language and early literacy skills (e.g. listening, story comprehension, print concepts), and conceptual knowledge and application (e.g. reasoning and problem solving) (2005). Although these domains are distinctly different, they all work together to enhance a child's ability to succeed in school. Extensive research indicates relationships between each of the above mentioned domains except for motor skill development. Research involving motor skills typically refers to fine motor skills, including visual-motor integration (VMI) skills (Becker et al., 2014; Cameron et al., 2012; Grissmer et al., 2010; Son & Meisels, 2006). VMI skills include skills requiring hand-eye coordination and integrate grasping skills and visual-spatial abilities (visual information processing skills), which is often captured with pencil-paper tasks, such as copying and drawing. Fine motor skills that encompass integration of fine motor and visual-spatial abilities are reported to have stronger associations with school readiness compared to fine motor skills that do not integrate VMI (Cameron et al., 2012; Carlson, Rowe, & Curby, 2013; Grissmer et al., 2010). The current study examines both gross motor and fine motor skills, as measured by the Peabody Developmental Motor Scales, 2nd Ed. Moreover, specific aspects of motor skills are examined and mechanisms underlying gross and fine motor are examined. For example, the gross motor subscale can be broken down further into stationary, locomotor, and object-manipulation skills. The fine motor subscale can be broken down into grasping and visual motor integration (VMI) skills. VMI skills incorporate hand-eye coordination in tasks such as copying shapes, replicating block towers, stringing beads, and cutting out shapes. Utilizing a comprehensive motor skills assessment allows examination of specific aspects motor skills and their contributions to school readiness indicators.

Generally speaking, the concept of school readiness refers to a child's attainment of skills, including self-regulation. Self-regulation, which develops rapidly in early childhood, refers to the capability of controlling one's attention, thoughts, emotions, and actions (Blair & Razza, 2007). Better self-regulation establishes positive classroom behaviors and predicts academic outcome in preschool and elementary school (Blair & Razza, 2007; Liew, McTigue, Barrois, & Hughes, 2008; McClelland, Acock, & Morrison, 2006; McClelland, Cameron, Connor, Farris, Jewkes, & Morrison, 2007; McClelland et al., 2000; Valienate, Lemery-Chalfant, & Castro, 2007). In addition, strong behavioral self-regulation has been found to positively predict long-term academic success, including high school and college graduation (Breslau, Miller, Breslau, Bohnert, Lucia, & Schweitzer, 2009; McClelland, Acock, Piccinin, Rhea, & Stallings, 2013; Morrison, Ponitz, & McClelland, 2010; Vitaro et al., 2005). School readiness is no longer viewed through literacy and mathematical competencies alone, but rather through a multitude of competencies that emerge during early childhood, such as behavioral aspects of self-regulation, (Bulotsky-Shearer & Fantuzzo, 2011; Duncan et al., 2007; Eisenberg et al., 2000; Pianta, Cox, & Snow, 2007; Vitaro et al., 2005).

One avenue that has been less studied, but has more recently gained attention is the role of motor skills within school readiness. In addition to school readiness initiatives, the importance of motor skill development is noted by the National Association for the Education of Young Children (NAEYC), indicating motor experiences and motor skill acquisition are fundamental to cognitive development during early childhood (Henninger, 2009; Pica, 2004). Motor skills have been identified as a contributing factor to school readiness outcomes such as self-regulation and early academic achievement (Becker, Miao, Duncan, McClelland, 2014; Cameron et al., 2012; MacDonald, McClelland, Lipscomb, Duncan, & Becker, in review; Westendorp, Hartman, Houwen, Smith, & Visscher, 2011). Becker and colleagues (2014) indicated higher levels of active play, which involves aspects of motor skills, were associated with better self-regulation skills. In addition, children with better gross motor skills, specifically object manipulation skills, demonstrated better classroom social behaviors, per teacher report (MacDonald et al., in review). Previous studies including at-risk populations tend to focus on children from ethnic or low-socioeconomic backgrounds, however, few have included children with disabilities or other biological risk factors. Jeon and colleagues (2011) examined school readiness at kindergarten of low-income children with disability indicators identified before age three; indicating children with suspected developmental delays had lower academic skill scores compared to children with no disability indicators. Children born very preterm (≤32 weeks' gestation) are at a higher risk to demonstrate significant educational delays in literacy, math or both compared with full-term children (Pritchard, Bora, Austin, Levin, & Woodward, 2014). Preschool aged children with cerebral palsy perform significantly below their peers in school readiness skills including mobility, self-care, and communication abilities (Gehrmann, Coleman, Weir, Ware, & Boyd, 2014).

School readiness initiatives acknowledge the importance of a multitude of domains, including physical well-being and motor skill development (NGA Task Force on School Readiness, 2005; National School Readiness Indicators Initiative, 2005), yet they do not address how motor skills contribute to school readiness or solely focus on fine motor skills. The National School Readiness Indicators Initiative (2005) identifies and describes a multitude of indicators important for success in school. This initiative identifies includes motor skills as an important indicator, but only indicates fine motor skills as being important. Gross and fine motor skills are separate and distinct, however they interact and reinforce each other. For example, children acquire large muscle (gross motor) movements prior to smaller muscle (fine motor) movements. It is plausible to suggest gross motor skills contribute to school readiness skills as they precede fine motor skill acquisition. Research aimed at examining predictors of school readiness is rapidly growing. The current study uses a comprehensive measure to assess gross motor (stationary, locomotor, and object-manipulation skills) and fine motor (grasping and visual motor) skills.

Children at-risk

The term "at-risk" can encompass many possible characteristics and conditions. The Centers for Disease Control and Prevention (CDC) identifies "at-risk" as any vulnerable population as defined by age, ethnicity, socioeconomic status, or disability, at risk for health disparities (CDC, 2014). In education the term "at-risk" describes children who are considered to have a higher probability of academic failure or dropping out of school. Children at-risk can encompass a broad range of specific biological and environmental (physical and social) characteristics. Biological risk factors include disability, genetic disorders, low birth weight, and premature births (Ettinger, 2004). Environmental risk factors include children who are affected by diverse economic, environmental, and geographical factors (Winter et al., 2007). Physical risk factors include chemical, biological, and physical influences such as prenatal drug exposure (e.g. alcohol and tobacco) and exposure to pollutants (e.g. air, water, noise, radiation) (Ettinger, 2004). Social risk factors include low socio-economic status, family composition and size, parental mental health, parental substance abuse, and community demographics (Ettinger, 2004).

Children with environmental risk factors are at higher risk for poor outcomes in such areas as school performance, health, and mental health due to family or life circumstances (Robbins, Stagman, & Smith, 2012). Research suggests children identified as at-risk, especially those experiencing multiple risk factors such as poverty and English language learners perform worse than more advantaged peers on a variety of school readiness indicators like behavioral self-regulation and early academic achievement (Dearing et al., 2006; Halle et al., 2009; Schlee, Mullis, & Shriner, 2008). Wanless and colleagues reported children with an accumulation of risk factors (e.g. low parental education, low income, and English language learners) were at a higher risk of entering preschool with low levels of behavioral self-regulation and the lower levels of behavioral self-regulation persisted into kindergarten (Wanless et al., 2011). Similarly, it was reported that children exposed to three or more risk factors are at greater risk to experience school failure and maladaptive behaviors (Pungello et al., 2010). Federal programs, such as Head Start, have been created to decrease the gap in school readiness skills. Head Start is a federally funded program of the US Department of Health and Human Services designed to provide comprehensive childhood education services to low-income children and families (USDHHS, YEAR).

Biological risk factors include identified disabilities as well as developmental delays. Over the past 12 years the prevalence of developmental disabilities, in the United States, has increased 17% (Boyle et al., 2011). A disability survey in 18 low- and middle-income countries reported that 23% of children aged 2-9 years had or were at risk for disability (Walker et al., 2011). Unfortunately well-defined literature on school readiness for young children with disabilities is limited and is primarily descriptive (Carlson, Jenkins, Bitterman, & Keller, 2011; Hebbeler et al., 2007). For example, results from the Preschool Early Education Longitudinal Study (PEELS) indicated children with disabilities were functioning well below the population mean in motor skills, social behaviors, and early academic achievement (Carlson et al., 2011). Individual educational plans (IEP's) are federally mandated written document under the Individuals with Disabilities Education Act (IDEA), which define programming and educational needs of children with disabilities. Although IEP's are specific to the unique needs of each child they are often geared towards communication and educational needs. Motor needs, under physical therapy or occupational therapy typically focuses on activities of daily living. Data from the National Early Intervention Longitudinal study reported children with an IEP entered kindergarten with poorer behavior and social skills, and difficulty with communication. Specifically, 4 out of 5 children with disabilities were reported to become easily distracted and two-thirds were reported to act impulsively (Hebbeler et al., 2007). Research indicates cumulative exposure to developmental risks, such as disability, poor prenatal care and nutrition, widens disparities and negative trajectories become more firmly established in children from at-risk populations. Research involving children from diverse, at-risk populations is emerging; however, most research is aimed at examining environmental risk factors. Studies including children with disabilities and other biological risk factors are mostly comparative studies, highlighting the differences in children with disabilities with typically developing children. The sample in the current study includes children with both biological and environmental risk factors.

Behavioral Self-regulation

Behavioral self-regulation, regulated by executive function, is a multi-dimensional construct encompassing attentional flexibility, working memory, and inhibitory control (Cameron-Ponitz, McClelland, Jewkes, Connor, Farris, & Morrison, 2008; McClelland, Cameron, Connor et al., 2007; McClelland, Cameron, Wanless, & Murray, 2007; Morrison et al., 2010). Attention or cognitive flexibility is the ability to maintain focus and adapt to changing goals or stimuli (Rothbart & Posner, 2005; Rueda, Posner, & Rothbart, 2005). Children demonstrate attentional flexibility by voluntarily focusing and sustaining attention on a task while ignoring distractions.

Working memory is the ability to remember and apply information while simultaneously encountering and processing new information (Gathercole, Pickering, Knight, & Stegmann, 2004). Children demonstrate working memory as they remember classroom rules while playing a game, or recalling the steps of a favorite recipe. Inhibitory control consists of controlling an inappropriate dominant response and choosing a more adaptive behavior (Dowsett & Livesey, 2000). For example, children display inhibitory control in the classroom by resisting the inclination to shout out the answer when a teacher poses a question to another child or being able to wait ones turn or raise one's hand.

Children who demonstrate poor self-regulatory skills, such as difficulty following directions, clearly communicating wants, needs and thoughts verbally, are at an increased risk for low academic achievement and peer rejection (Blair, 2002; McClelland et al., 2000; Rimm-Kaufman, Pianta, & Cox, 2000). Clear deficits in school readiness are demonstrated by children at-risk, and this has negative implications for future academic success (Dearing, Berry, & Zaslow, 2006; Evans & Rosenbaum, 2008; Howse et al., 2003; Wanless, McClelland, Tominey, & Acock, 2011). Children exposed to social and biological risk factors are at greater risk for demonstrating weaker self-regulatory skills, thus putting them at further risk for poor school performance (Sameroff & Fiese, 2000). The importance of self-regulation skills, specifically for children at-risk, suggests the early years as a critical point for potential interventions or initiatives to improve school readiness. The development of behavioral aspects of self-regulation are paralleled by significant changes in motor abilities, yet how the mechanisms of school readiness relate to other aspects of development, like motor skills is relatively unknown. The present study includes children from at-risk populations and used a comprehensive motor assessment to examine the specific aspects of motor skills associated with behavioral self-regulation.

Links between motor skills and school readiness

Extensive research has linked motor skills and school readiness indicators. Foremost, neurological evidence suggests cognitive and motor skills employ common sensory systems and structures in the brain (Diamond, 2000; Marsh, Gerber, & Peterson, 2008). There is also a significant amount of literature linking learning and motor skill difficulties as well as links between behavioral and motor disorders (Gueze, Jongmans, Schoemaker, & Smits-Engelsman, 2001; Harvey & Reid, 2003; Kadesjö & Gillberg, 20001; Kaplan, Wilson, Dewey, & Crawford, 1998; Missiuna, Moll, King, & Law, 2007; Westendorp et al., 2011). Motor difficulties have been documented in a variety of disabilities including autism, attention-deficit-hyperactivity disorder, learning disabilities, and externalizing behavior disorders, thus suggesting a a co-occurrence of impairment in cognitive and motor processes (Livesey, Keen, Rouse, & White, 2006; Sugden, Kirby, & Dunford, 2008; Westendorp et al., 2011; Williams, Whiten, & Singh, 2004r Fine motor skills have been reported, not only as strong predictors of school readiness skills but have been reported to be one of the strongest predictors of special education referral (Roth, McCaul, & Barnes, 1993). This may be due to the time spent in fine motor activities, as approximately 37% to 46% of class time in kindergarten is spent in some type of fine motor skills activity (Marr, Cermak, Cohn, & Henderson, 2003).

Fine motor skills have been reported as strong predictors of school readiness, in addition to behavioral aspects of self-regulation (Becker, Miao, Duncan & McClelland, 2014; Cameron et al., 2012; Grissmer, Grimm, Aiyer, Murrah, & Steele, 2010; MacDonald et al., in review; Son & Meisels, 2006). For example, fine motor skills positively predict math and reading achievement and higher fine motor skills were also reported to predict higher achievement on multiple subtests at kindergarten entry (Cameron et al., 2012; Grissmer et al., 2010). Fewer studies examine the relationships between gross motor skills and behavioral self-regulation. MacDonald and colleagues (in review) reported children with better object-manipulation skills demonstrated more self-control, more cooperation, and less hyperactivity over the pre-K year. It is unknown how the constructs of motor development and behavioral self-regulation develop and interact in children from at-risk populations including children with disabilities. Children from at-risk populations are more likely to experience chronic physical, developmental, behavioral, or emotional conditions and delays in development that limit their school readiness (Newacheck et al., 1998; Perrin et al., 1993; Stein, Bauman, Westbrook, Coupey, & Ireys, 1993; Westendorp et al., 2011). The current study goes beyond examining the broad constructs of gross and fine motor skills and examines specific aspects of motor skills. The motor assessment used in the current study breaks down each motor construct into specific sub-groups. Gross motor skills are broken down into stationary, locomotor, and object-manipulation skills while fine motor skills are divided into grasping and visual-motor skills. Examining relations between these developmental constructs, specifically the underlying mechanisms within each construct, in at-risk and diverse populations is an initial step towards understanding the role of motor skills in school readiness for at-risk children. In addition, these relationships may provide evidence informing essential services focused on improving early developmental trajectories and decreasing disparities in at risk children.

The aims of the present study were twofold. The first aim was to examine and describe gross and fine motor skills of at-risk preschoolers. The second aim examined associations between motor skills and behavioral self-regulation in at-risk preschoolers, specifically the gross and fine motor mechanisms underlying behavioral self-regulation. Based on previous research, which indicates better motor skills are positively related to better behavioral self-regulation in typical peers (Böhm, Lundquist, & Smedler, 2010; Decker, Englund, Carboni, & Brooks, 2011; Pagani & Messier, 2012), it is expected that children with better motor skills will demonstrate higher levels of behavioral self-regulation, in an at-risk sample of children.

Methods

Participants

One hundred sixty-two children identified as at-risk were recruited for this study from local preschool programs in two geographic locations in the Pacific Northwest (N=50) and one geographic area in the Midwest (N=112). Participants were 100 boys and 62 girls between the ages of 36- 71 months (M = 51.15 months, SD = 8.43). The sample was comprised of 71.3% Caucasian and 28.7% non-white (16.8% African American, 6% Latino, 1.8% Middle Eastern, 1.2% Asian, and 2.9% bi-racial or other). Thirty-one percent (n = 51) of participants were enrolled in Head Start, a federally funded program promoting comprehensive early childhood education services to low-income children and families, and 69% (n = 111) attended community-based preschool centers. Forty-six percent (n = 75) of participants were identified with a disability, as indicated on the child's individualized education plan (IEP), and 54% (n = 87) were identified as at-risk with at least one parent-reported environmental risk factor (e.g. low-income, single parent, English language learner, residential mobility). Maternal education consisted of: 19.7% (n = 32) High school/GED, 16% (n = 26) Associate's, 22.2% (n = 36) Baccalaureate, 18.5% (n = 30) Master, 6.2% (n = 10) Doctorate (PhD, MD, JD), 3.7% (n = 6) no degree, and 13.6% (n = 17) missing.

Recruitment flyers and parental consent forms were sent home through preschool classrooms via backpack mailing. Written informed consent was obtained from the parent and/or legal guardian for all participants. Child assent, as indicated verbally or by their engagement with materials was obtained from each child prior to assessments. Trained research assistants conducted each assessment in accordance with each test manual. The Institutional Review Board approved all methods and procedures. Data collected from the Pacific Northwest site(s) was a part of a larger study. Data collection occurred in the child's home and school, while data collected from the Midwest location occurred in the child's school.

Measures

Demographic questionnaire. A demographic questionnaire was sent home and completed by the primary caregiver. The questionnaire consisted of questions about the participant and family background. Participant questions included child's age, gender, ethnicity, native language, and disability diagnosis (if applicable).

Parent questions included relationship to child, age, educational level, employment level, marital status, income, residential mobility, and amount of public assistance information (if applicable).

Motor skill assessment. The Peabody Developmental Motor Scales 2nd Ed (PDMS-2) is a normed and standardized motor assessment of gross and fine motor skills in children age birth to 5 years (Folio & Fewell, 2000). The PDMS-2 is composed of two distinct scales of motor skills: gross and fine motor skills. The gross motor subscale consists of reflexes, stationary, locomotor, and object manipulation skills. The reflexes subscale was not used in this study, as it is only administered to children birth to 11 months. The fine motor subscale consists of grasping and visual-motor integration skills. Scores from each subscale contribute to either the gross motor quotient (GMQ) or the fine motor quotient (FMQ) score. The GMQ measures the ability to utilize the large muscle systems to move from place to place, assume a stable posture, react to environmental changes, and catch/throw objects. The FMQ measures the child's ability to use his or her hands and arms to grasp objects, stack blocks, draw figures, and manipulate objects.

The PDMS-2 is used in practice and research settings and takes approximately 45-60 minutes to administer (Folio & Fewell, 2000). Furthermore, the PDMS-2 has good reliability coefficients for subscales (Folio & Fewell, 2000) and concurrent reliability with the Movement Assessment Battery for Children (van Hartingsveldt, Cup, & Oostendorp, 2005) and the Bayley Scales of Infant and Toddler Development 3rd Ed (BSID-III) (Connolly, McClune, & Gatlin, 2012). Construct-identification validity for each subtest has been established through confirmatory factor analysis and goodness of fit indices (Folio & Fewell, 2000). Tucker and Lewis's (1973) index of fit was .96 and the root mean square of approximation (RMSEA) was .08, indicating a reasonable error of approximation (Brown & Cudeck, 1993). Inter-rater reliability for the current study was 0.84.

The current study examined specific motor skill mechanisms underlying behavioral self-regulation. Therefore, scores from similar skills within each subtest item were combined and Cronbach's alpha are reported for each. The gross motor subscales consist of stationary, locomotor, and object manipulation skills. The stationary subscale included 3 groups of items (1-foot balance, 2-foot balance, and postural control) with an intra-class correlation (ICC) of 0.77. The locomotor subscale included 6 groups of items (walking, running, stairs, jumping, hopping, rhythm and timing skills) with an ICC of 0.89. The object manipulation subscale included 3 groups of items (throwing, catching, and kicking) with an ICC of 0.73. The fine motor subscales consist of grasping and visual-motor integration skills. The grasping subscale consisted of 2 groups of items (grasping and dexterity) with an ICC of 0.64. The visual-motor subscale included 6 groups of items (copying, cutting, folding, manipulatives and building with and without a model) with and ICC of 0.89. Cronbach's alpha for the PDMS-2 was 0.87 and inter-rater reliability between assessors was 0.84.

Cognitive assessment. Two separate cognitive assessments were used for the current study. Cognitive abilities of participants from site 1 were assessed using the Mullen Scales of Early Learning: AGS edition (MSEL). The MSEL is a norm-referenced, standardized assessment of early learning for children age birth to 5 years and 8 months (Mullen, 1995). The MSEL manual reports good psychometric properties. The median split-half internal consistency was above 0.80 for 3 of the subscales, 0.79 for visual reception, and 0.75 for fine motor (as reported by the test manual). Test-retest reliability coefficients are 0.80 for intervals of one to two weeks and 0.70 for intervals of one to twenty-four months. Convergent reliability has been shown with the Bayley Scale of Infant Development (Johnson & Marlow 2006) as well as the Differential Ability Scales, with respect to nonverbal IQ and verbal IQ (Bishop, Guthrie, Coffing, & Lord, 2011). Cronbach's alpha for the MSEL, for this study was 0.90 and inter-rater reliability was 0.77.

The Early Stanford-Binet Intelligence Scales – 5th edition (SB5), abbreviated IQ test was used to assess cognitive abilities of participants in site 2. The Early SB5 is a norm-referenced, standardized assessment for individuals between the ages 2 to 7 years (Roid, 2003). The SB5 abbreviated IQ test is composed of the nonverbal fluid reasoning and verbal knowledge subtests and was used in cohort 2 in order to reduce time constraints. The Early SB5 manual reports good psychometric properties for both the full IQ and abbreviated test. Average internal consistency composite reliability for the abbreviated battery IQ is 0.91. Cronbah's alpha for the abbreviated battery was 0.78. Only one researcher collected SB5 data and the single measures ICC was 0.77.

The MSEL and the SB5 scores can be converted into ratio intellectual quotient (IQ) scores. Ratio IQ is the intelligent quotient of a person calculated as the ratio of the child's mental age (based on a standardized test) to chronological age (Colangelo & Davis, 1991). Non-verbal ratio IQ's (NVIQ) is calculated by dividing the nonverbal mental age by the chronological age and multiplying by 100. The same method is applied for calculating verbal ratio IQ's (VRIQ), using verbal mental age equivalents. Ratio IQ's are used with children with developmental disabilities when it is not possible extrapolate composite scores on standardized assessments (Bishop et al., 2011; Richler, Bishop, Kleinke, & Lord, 2007). Ratio IQ scores standardize cognitive assessments and were used as descriptive data in the current study.

Behavioral self-regulation. The Head-Toes-Knees-Shoulders Task (HTKS), extended version is a direct measure of behavioral self-regulation that assesses working memory, attentional flexibility, and inhibitory control (Ponitz et al., 2008). The measure consists of 30 items, with the highest possible score of 60. Children are given a score of '0' for an incorrect response; a '1' for a self-corrected response; and a '2' for a correct response. The task has three parts and takes approximately 10 minutes to administer and is scored live. During the first phase of the task, children are asked to respond to a simple command (e.g., "Touch your head"). In the second phase children are asked to do the opposite of the original instructions (e.g. "Touch your head" is responded by child touching their toes). As the assessment progresses additional commands are added and rules are changed increasing the difficulty of the task. The HTKS has reported high interrater reliability, scoring agreement, and test-retest reliability with alphas of .93 over a 3-month period in diverse populations (McClelland & Cameron, 2012; Tominey & McClelland, 2011; Wanless et al., 2011). In the current study the Cronbach's alpha for the HTKS was 0.92, and inter-rater reliability was 0.88.

Covariates. Covariates included age, ethnicity, and site location. NVRIQ and disability were not used as covariates based on strong relations with age and site. Children identified with a disability were primarily from one location and independent t-tests indicated significant differences between sites, thus site instead of disability were added to control for differences in variables. There was a significant difference in the HTKS scores for site 1 (M = 1.07, SD = .70) and site 2 (M = .89, SD = .60) conditions; t (160) = 1.67, p = .02. Although socioeconomic status (SES) variables are reported as predicting behavioral self-regulation they are not controlled for in the current study, as children at-risk are the target population. There was a significant difference in the HTKS scores for white (M = 1.00, SD = .65) and non-white (M = .80, SD = .59) conditions; t (160) = 1.82, p = .06; therefore ethnicity was used as a control variable.

Procedures

Data were collected in the fall of the preschool year. Data collection at site one took place in the child's home (approximately 1 hour in length) and preschool (approximately 30 minutes in length). Data collected in the homes consisted of a survey of demographic information from the child's parent/legal guardian and direct measures of motor skills. Data collected in the preschool consisted of direct assessments of cognition and behavioral self-regulation. Trained assessors, with experience working with preschool aged children collected data. Data collection at site two took place in the child's preschool (approximately 45 minutes in length). The demographic survey was sent home and completed by the child's parent/legal guardian and sent back in the provided envelope. Data collected at school consisted o direct measures of motor skills, behavioral self-regulation, and cognition. The primary researcher collected data collected at site two, between October and December.

Missing Data. Demographic and predictor variables contained between .6% and 18.5% missingness. Maternal age and maternal education were the highest missing variables due to demographic questionnaires not being returned and this information was not available through school records. The outcome variables (behavioral self-regulation) contained approximately 1.2% missingness, due to children being absent or not participating in assessment. Missing data was assumed to be missing completely at random (MCAR). In order to identify the best data replacement technique missing data was analyzed to determine if missing data was missing at random or missing in a systematic way. Little's MCAR test reported: chi-square = 30.12, DF = 27, sig. = .31. Since the p-value is greater than .05 it is reasonable to accept the null hypothesis and conclude variables examined were not found to predict missingness, indicating MCAR was a reasonable assumption (Little, 1998). Missing data was imputed using the expectation maximization (EM) technique, which is the most appropriate technique when missing values are present on one or more variables and are missing completely at random. Imputing missing data has been shown to produce less biased estimates than listwise deletion (Acock, 2012). EM consists of two steps: an expectation step, followed by a maximization step. The expectation refers to the unknown underlying variables, using the current estimate of the parameter and conditioned upon the observations. The maximization step provides a new estimate of the parameters and uses an iterative process until convergence (Moon, 1996).

Analytic Strategy

SPSS 22 (IBMCorp. 2013) was used to perform all data analyses. Data were initially examined for normality using the Shapiro-Wilk test and outliers using the outlier labeling rule. The PDMS-2 total motor scores ranged from 263-477 (M = 386.54, SD = 42.06) and was normally distributed, with skewness of -.27 (SE = .19) and kurtosis of -.20 (SE = .38). The gross motor scores ranged from 103-282 (M = 216.10, SD = 29.93) and was normally distributed, with skewness of -.34 (SE = .19) and kurtosis of .64 (SE = .38). Fine motor scores ranged from 116-196 (M = 170.74, SD = 16.92) and was normally distributed, with skewness of -.63 (SE = .19) and kurtosis of -.08 (SE = .38). The HTKS task scores ranged from 0-91 (M = 19.6, SD = 23.63) and was non-normally distributed, with skewness of 1.21 (SE = .19) and kurtosis of .38 (SE = .38). Non-normally distributed data was transformed using base-10 log transformation (log10) and one point was added to each score prior to transformation so that the data did not contain any zero scores. The transformed HTKS scores were normally distributed, with skewness of -.11 (SE = .19) and kurtosis of -1.24 (SE = .38). Outliers were classified using the outlier-labeling rule, which leverages the interquartile range, thus is not dependent on distributional assumptions and ignores the mean and standard deviation, making it resistant to being influenced by extreme values (Hoaglin, Iglewicz, & Tukey, 1986; Tukey, 1977). Subtracting the 25th quartile from the 75th quartile and multiplying by g identified the value used to subtract from the lowest value or add to the highest value to identify outliers. Hoaglin and colleagues (1986) suggests *g* = 2.2 and is appropriate to use with small samples and normally distributed data. There was one lower end outlier for the gross motor scores and two upper end outliers for early literacy.

Univariate linear regressions were used to assess the association of potential independent variables with specific outcomes to examine the relative importance of each predictor in the presence of other predictors. Variables that predicted resilience in the univariate analyses were included in the hierarchical regression. These included age, ethnicity, site, fine motor skill total score, and gross motor skill total score. Some variables of interest, such as the behavioral self-regulation measure, were scored using non-equivalent scales, thus motor skill raw scores were used in analysis. The first model measured the association between gross motor skills and behavioral self-regulation while controlling for covariates. The second model measured the association between fine motor skills and behavioral self-regulation while controlling for covariates. The final model used hierarchical regression to establish which independent variables were the most predictive.

Results

Descriptive statistics are presented in Table 1. To increase variability the practice scores of the HTKS measure were included in the outcome, therefore possible scores ranged from 0-91 (mean = 19.60, SD = 23.63). The HTKS-extended version is used in research and practice scores have been included in previous research to increase variability (Fuhs, Nesbitt, Farran, & Dong, 2014). Bivariate correlations for all predictor and outcome variables in the analyses are presented in Table 2. An examination of correlations revealed that no independent variables were highly correlated, with the exception of motor skill subtests and total motor scores. Subscales of the PDMS-2 report high confirmatory factor analysis, therefore high correlations from PDMS-2 scores in the present study was expected. Bivariate correlations in the overall sample showed significant associations between gross motor skills, fine motor skills, total motor skills, self-regulation, and child age covariates. Correlations among self-regulation were highest with fine motor skills ($r = .56$, $p = .000$), and total motor skills ($r = .47$, $p = .000$).

Research Aim 1: To examine gross and fine motor skills of at-risk preschoolers.

Overall, participants scored lower than standardized norm scores. Age difference scores were calculated from participants' chronological age and age-equivalent scores (converted from raw scores) for the gross and fine motor subscales are presented in Figure 1. Participants age difference scores (converted from raw scores) for the gross motor subscales indicated a difference of -7.43 and -.610 for the fine motor subscales. Although this is not a comparative study participants with environmental risk factors scored higher in all subscales compared to participants with disabilities. Table 3 displays PDMS-2 scores by risk factor group and independent t-tests comparing subtests and subscales of the PDMS-2 in participants. Children with disabilities (M = 375.57, SD = 42.63) demonstrate significantly lower motor skills than children at-risk based on environmental factors (M – 396.00, SD = 39.39) condition; t(-3.17)= , p = .002; thus potentially placing them further behind motorically and at- risk for unhealthy outcomes.

Research Aim 2: To examine associations between motor skills and behavioral self-regulation.

Linear regression indicated children's gross motor skills were significantly associated with behavioral self-regulation after controlling for age, ethnicity, and site ($\beta = .45$, $p = .000$), independently explaining 37% of variance in the model (Table 4, Model 1). Fine motor skills had a significant association ($\beta = .51$, $p = .000$) with behavioral self-regulation scores after controlling for age, ethnicity, and site, independently explaining 39% of variance in the model (Table 4, Model 2). In the third model both gross motor skills ($\beta = .22$, $p = .03$) and fine motor skills ($\beta = .35$, $p = .001$) had significant associations with behavioral self-regulation after controlling for covariates, explaining 41% of variance in the model. Hierarchical regression analysis indicated covariates alone contributed 23% variance; covariates and gross motor skills contributed 39%, while covariates, gross motor skills and fine motor skills contributed 41% variance. The hierarchical model indicated fine motor skills contributed to behavioral self-regulation above and beyond covariates and gross motor skills.

Further hierarchical regression analysis examining associations between specific aspects of gross and fine motor subscale test items indicated significance. Age ($\beta = .16$, $p = .03$), visual motor skills ($\beta = .28$, $p = .01$) and stationary skills ($\beta = .17$, $p = .05$) demonstrated significant associations with behavioral self-regulation. Associations between gross motor subtest and fine motor subtest items are presented in Table 5, Model 4. Overall, age, stationary skills, and visual-motor integration skills explained a statistically significant amount of variance in children's behavioral self-regulation ($R^2 = .41$, $F(5, 156) = 21.73$, $p < .001$).

Discussion

School readiness initiatives include health and motor development as an important aspect towards school readiness, however previous research primarily reports the importance of cognitive and socio-emotional domains, leaving motor skills and development out of the equation (Duncan et al., 2007; Eisenberg, Valiente, & Eggum, 2010; Pagani, Fitzpatrick, Archambault, & Janosz, 2010). Although much research has been dedicated to improving school readiness in typically developing children, less has been conducted with preschool-aged children from at-risk populations. The present study describes the motor skills of children from at-risk populations as well as examining relations between specific aspects of motor skills and behavioral self-regulation.

As hypothesized, children at-risk demonstrated lower motor skills compared to standardized scores and lower levels of behavioral self-regulation. In addition, analyses indicate both gross and fine motor skills are positively associated with behavioral self-regulation. In particular, stationary skills (gross motor) and visual motor skills (fine motor) explained a statistically significant amount of variance in children's behavioral self-regulation. These findings extend to previous research indicating positive associations between fine motor skills and behavioral self-regulation (Becker et al., 2014; Cameron et al., 2012; Grissmer et al., 2010; MacDonald et al., in review; Son & Meisels, 2006; Westendorp et al., 2011). There are distinguishing features of the present study. First, the sample was diverse including socioeconomically disadvantaged children, children with disabilities, and children with other environmental or biological risk factors. Second, gross motor skills were positively associated with behavioral self-regulation. Previous research indicates fine motor tasks as better predictors of school readiness than gross motor tasks (Wolff, Gunnoe, & Cohen, 1985). Thirdly, previous research utilizes the HTKS task with typically developing children. This assessment rendered similar results in children with disabilities; children with better motor skills demonstrated better behavioral self-regulation.

One factor, which may account for the observed associations, is that there is reciprocal development between motor and behavioral self- regulation skills, thus sharing similar underlying processes. Behavioral self-regulation, as measured by the HTKS task, utilizes complex cognitive processes such as attentional flexibility, working memory, and inhibitory control (Ponitz, et al., 2008; McClelland & Cameron. 2012). Motor skills such as object-manipulation and visual motor integration are also more complex and demand more involvement of cognitive processes (Westendorp et al., 2011). Therefore, the similarities in the processes underlying behavioral self-regulation and motor skills may account for the current results. Behavioral aspects of self-regulation, regulated by executive functions, also overlaps with learning fine motor skills, and together these skills provide foundations for later learning.

This study contributes to the greater understanding of these relations in terms of how specific aspects of motor skills relate to behavioral self-regulation in at-risk children. Although gross motor skills were not significant in predicting behavioral self-regulation in combination with fine motor skills, initial analyses still provide important information. Gross motor skills have been reported to be associated with positive classroom behaviors. Gross motor and fine motor skills are distinct entities, however they work together and good motor abilities co-occur with improved social skills and task-oriented classroom behaviors (Pagani & Messier, 2012). The importance of gross motor skills is also noted in basic principles of development. For example, physical development proceeds in proximodistal directions, thus gross motor skills and competencies precede fine motor skills. Deficits or delays in gross motor skills can potentially hinder fine motor skills, which can ultimately affect behavioral aspects of self-regulation. The participants in the current study demonstrated lower motor skill scores compared to standardized norms. These results are similar to previous studies, indicating children from at-risk populations demonstrate lower motor skills (Goodway & Branta, 2003; Rintala & Loovis, 2013; Robinson & Goodway, 2009; Valentini & Rudisill, 2004). Despite the gaps in motor skill development early motor skill interventions indicate children can significantly improve their fundamental motor skills and ultimately remediate some deficits and delays through quality intervention (Brian, Goodway, & Sutherland, 2014; Goodway & Branta, 2003; Robins & Goodway, 2009). Motor skills, in the context of play also positively predict behavioral self-regulation and positive classroom behaviors (Barros et al., 2009; Becker, McClelland, et al., 2014; Mahar et al., 2006; Pagani & Messier, 2012). Although it seems clear that motor opportunities for young children are an important part of overall development there is an increasing trend towards reducing motor opportunities during the school day (Miller & Almon, 2009; Parsad, Lewis, & Greene, 2006). The National Center for Education Statistics reported that children who attend schools with high minority and high poverty rates in urban settings are more likely to have reduced recess time as compared to their peers in more affluent areas (Parsad et al., 2006; Ramstetter, Murray, & Garner, 2010). Reducing opportunities for play affects all children but may be more detrimental for children "at-risk", as they are less likely to have opportunities to play outside of school (Dyment & Coleman, 2012; Milteer et al., 2012; Mowan, 2010; Scott & Munson, 1994). Given the potential benefits of motor skill development, motor opportunities should be encouraged through practice and policy. Programs such as NAEYC emphasize the importance of physical development, including motor skill development as a core component of school readiness and overall healthy development, however dissemination into practice is not fully integrated into programs and school readiness initiatives.

The results regarding the relationship between fine motor skills and behavioral self-regulation in children from at-risk populations demonstrated a clear relationship between visual-motor integration and behavioral self-regulation: the better visual motor skills the higher HTKS scores, indicating better behavioral self-regulation. This finding is particularly of interest as previous studies examine relationships between fine motor skills and school readiness, through academic achievement. To the author's knowledge, there have not been any studies examining how motor skills predict behavioral self-regulation.

The results of the current study indicate a positive relationship between motor skills and behavioral self-regulation, however it is not without limitations. First, censored outcomes (floor and ceiling effects) were noted in the data, in other words, several participants scored "0" on the behavioral self-regulation score and lower motor skills decreased the range of variability in the motor assessments. Log transformations were used to create more normally distributed data. A second option would be to run the data through a different statistical program that utilizes the Tobit model (censored regression model) (Tobin, 1958). This model describes the relationship between a non-negative dependent variable and an independent (vector) variable. In addition, there is a normally distributed error term to capture random influences on the relationship. Second, although participants were from different regions in the United States, the majority was Caucasian. A more diverse sample may render different results. Third, the data collected was only cross-sectional. Longitudinal data would be beneficial to better understand the impact of motor skills on school readiness and identify the effects of motor skills on school readiness skills in higher grades. In addition, randomized control studies, utilizing a motor-based intervention, would also benefit the current literature. This type of study would potentially inform not only the benefits of an intervention to motor skills, but if improved motor skills had any short or long term effects on school readiness. Lastly, all participants were assessed during school hours and were pulled out of regular class routines. Researchers assumed participants put forth their best efforts during assessments. Furthermore, due to the numerous amounts of assessments, participants may have become tired or disinterested in the activities and assessments. Despite these limitations this study contributes to the current body of knowledge of school readiness, specifically the relationships between motor skills and behavioral self-regulation in children from at-risk populations.

Conclusion

The benefits of motor skill development have clearly been indicated in all areas of development and are a natural resource that children can use to help build their resilience to overcome challenges. Utilizing motor opportunities has the potential to promote and foster optimal child development, thus helping children develop the skills necessary to succeed in the classroom. The results of the current study provide potential information regarding programs focused on improving early developmental trajectories.

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Table 1
Descriptive Statistics (N = 162

Variable	***% Yes***	***N***	***% No***	***N***
Child gender (female = yes, male = no)	38.3	62	61.7	100
Ethnicity (white = yes, non-white = no)	70.4	114	29.6	48
Site (1 = yes, 2 = no)	30.9%	50	69.1%	112
Disability	46.3%	75	53.7	87
Head Start Status	31.5%	51	68.5	111

Variable	***M***	***SD***	***Min***	***Max***
Child age in months	51.15	*8.43*	36	71
NVRIQ	84.02	24.51	0	172
Total Motor Score	386.54	42.06	263	477
Gross Motor Subscale	216.10	29.93	103	282
Stationary Items Total	48.75	6.49	4	60
Locomotor Items Total	148.67	19.78	66	178
Object Manipulation Items Total	31.72	7.69	13	49
Fine Motor Subscale	170.74	16.92	116	196
Grasping Items Total	45.95	4.73	16	52
Visual Motor Items Total	124.72	13.66	77	144
HTKS	19.60	23.63	0	91

Table 2
Bivariate Correlations for all predictors, outcomes, and covariates

	1	*2*	*3*	*4*	*5*	*6*	*7*
1. Age	-						
2. Ethnicity	*-.074*	-					
3. Site	*-.023*	*.082*	-				
4. Gross Motor	*.414***	*-.066*	*.363***	-			
5. Fine Motor	*.528***	*-.203***	*-.291***	*.569***	-		
6. PDMS Total	*.514***	*-.139*	*.136*	*.939***	*.808***	-	
7. HTKS	*.456***	*-.143*	*-.132*	*.456***	*.605***	*.573***	-

$^{\dagger}p < .10$, $*p < .05$, $**p < .01$

Table 3

PDMS-2 Scores by group and independent t-test results

	Disabilities (N= 75)	**Other at-risk factors (N = 87)**			95% CI	
	M (SD)	M (SD)	*t(160)*	*p*	LL	UL
GM subscale	213.27 (28.24)	218.55 (31.26)	-1.12	.26	-14.59	4.02
Stationary	47.25 (5.24)	50.55 (5.15)	-4.03	.000	-4.92	-1.68
Locomotor	139.60 (19.05)	156.49 (16.93)	-5.98	.000	-22.48	-11.31
Object Manipulation	28.68 (7.06)	34.34 (7.26)	-5.02	.000	-7.90	-3.43
Fine Motor Subscale	162.32 (17.37)	178 (12.70)	-6.62	.000	-20.36	-10.99
Grasping	4.51 (4.51)	47.20 (4.58)	-3.75	.000	-4.12	-1.27
Visual Motor	118.08 (14.47)	130.44 (9.89)	-6.42	.000	-16.16	-8.55

Table 4
Hierarchical Multiple Regression Analyses Predicting Behavioral Self-Regulation from PDMS-2 Gross and Fine Motor Subscales (N = 162)

	Model 1		Model 2		Model 3	
Predictor	ΔR^2	β	ΔR^2	β	ΔR^2	β
Block 1	.23**		.23		.23	
Age		.45**		.26**		.18*
Site		-.11		-.28**		-.10
Ethnicity		-.10		-.07		-.04
Block 2					.41**	
Fine Motor	.39**	.51**				.35**
Gross Motor			.37**	.45**		.03*

Note. All models included control variables (age, ethnicity, site). (1) Model added PDMS-2 gross motor subscale independently. (2) Model added PDMS-2 fine motor subscale independently. (3) Model added gross and fine motor subscales simultaneously.
ΔR^2 = Change in R^2. β = Standardized estimate.
†p < .10, *p < .05, **p < .01

Table 5
Hierarchical Multiple Regression Analyses Predicting Behavioral Self-Regulation from PDMS-2 Subtest Items (N = 162)

	Model 4	
Predictor	ΔR^2	β
Block 1	.48**	
Age		.16*
Site		.06
Ethnicity		-.04
Block 2	.63**	
Grasping		.07
Visual-Motor		.30**
Block 3	.66**	
Stationary		.18*
Locomotor		-.07
Object Manipulation		.18

Note. All models included control variables (age, ethnicity, site). (4) Model added grasping, visual-motor, stationary, locomotor, and object manipulation items.
ΔR^2 = Change in $R^{2.}$ β = Standardized estimate.
†p < .10, *p < .05, **p < .01

CHAPTER THREE

Motor Skills Predictive Values in Early Academic Achievement of At-Risk Preschoolers

Motor Skills Predictive Values in Early Academic Achievement of At-Risk Preschoolers

KEYWORDS: motor skill proficiency, early childhood, risk factors, disability, academic achievement, behavioral self-regulation

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Abstract

Purpose: The present study examined associations of fine and gross motor skills with early academic achievement, specifically early math and early literacy skills, in a sample of at-risk children between the ages of 3-5 years.

Methods: Children (*n* = 162) from two geographical areas in the U.S. were recruited for this study. Participants were identified as at-risk if parent report indicated at least one biological (e.g. disability) or environmental (e.g. low-income, single parent) risk factor. Motor skills were assessed using the Peabody Developmental Motor Scales -2, while early academic achievement was assessed using the applied problems and letter-word identification subscales of the Woodcock Johnson-III Tests of Achievement. This descriptive, cross-sectional study used hierarchical multiple regressions to examine effects of gross and fine motor skills on early academic achievement.

Results: Children's gross and fine motor skills had significant associations with early academic achievement. Gross motor skills had significant associations with early literacy ($\beta = .33$, $p = .000$) and early math ($\beta = .48$, $p = .000$) skills. Fine motor skills also had significant associations early literacy ($\beta = .47$, $p = .000$) and early math ($\beta = .64$, $p = .000$) skills. Gross motor skills were no longer significant when fine motor skills and covariates were added to the model. Further analysis indicated visual-motor integration skills are significantly associated with early literacy ($\beta = .50$, $p = .000$) and early math ($\beta = .62$, $p = .000$) skills, even after controlling for age, ethnicity, and site.

Conclusion: This study found positive relations, with specific aspects of motor skills and early academic achievement. The predictive value of motor skills also has implications for school readiness initiatives focused on improving early developmental trajectories for children from at-risk populations.

Introduction

Educational trajectories are framed by how children transition from preschool to kindergarten (Blair & Razza, 2007; McClelland, Acock, & Morrison, 2006; McClelland, Cameron, Connor, Farris, Jewkes, & Morrison, 2007; Ponitz, McClelland, Matthews, & Morrison, 2009). Numerous reports indicate many children are unequipped with the necessary skills to succeed in a more demanding classroom (Blair, 2002; Bulotsky-Shearer & Fantuzzo, 2011; McClelland, Morrison, & Holmes, 2000; Rimm-Kaufman, Pianta, & Cox, 2000). In order to be successful, children need to enter kindergarten with a foundation of competencies in language, cognition, social and emotional skills (Rimm-Kaufman et al., 2000; Shonkoff & Phillips, 2000). Children from at-risk populations, including children with disabilities, demonstrate difficulty with appropriate social behaviors, score lower on cognitive tests, and general academic performance (Blair, 2002; Carlson et al., 2009; Carlson, Jenkins, Bitterman, & Keller, 2011; Hebbeler, et al., 2007; NICHD Early Child Care Research Network, 2005; West, Denton, & Germino-Hausken, 2000). Cognitive and behavioral characteristics at school entry, which predict later achievement, have traditionally defined school readiness (Vitaro, Brendgen, Larose, & Tremblay, 2005). Other initiatives describe school readiness as demonstrated in health and motor skill development, socio-emotional development, motivation to learn, language and early literacy skills, and conceptual knowledge and application (National Governors Association [NGA] Task Force on School Readiness, 2005). Duncan and colleagues (2007) examined school entry academic, attention, and socio-emotional skills on later academic achievement using six longitudinal data sets, reporting the strongest predictors of later achievement to be school-entry math, reading, and attention skills. Although this study was one of the first comprehensive investigations examining predictability of school-entry skills on later performance it did not include school-entry motor skills. School-readiness outcomes in children with disabilities is limited, therefore the current study targets children with disabilities and from other at-risk populations in examining the role of motor skills in early academic achievement.

Early skills and academic achievement

The definition of academic achievement (AA) varies among educators, policymakers and other educational stakeholders and shapes individual trajectories. AA has gained much attention since the passage of No Child Left Behind (NCLB) Act in 2001, which sets testing benchmarks in reading and math. Entwisle & Alexander (1990) refer to AA as a cumulative process encompassing mastery of new skills and improving existing skills and refers to a student's success in meeting short- or long-term goals in education and is sometimes called proficiency, quantifiable through tests or exams. An abundant amount of empirical research indicates mental ability test scores (e.g. IQ scores) are highly correlated with later academic achievement; however more recent research indicates mental ability is not the only determinant (Deary, Strand, Smith, & Fernandes, 2007; Johnson, McGue, & Iacono, 2006). Other early academic skills (e.g. attention-related skills) such as task persistence and self-regulation also effect AA (Entwisle, Alexander, & Olson, 2005; Mullis & Jenkins, 1990; O'Connor & Paunonen, 2007). Socio-demographic risk factors (e.g. single parents, low income) have repeatedly indicated a negative impact on AA. Furthermore, risk factors tend to accumulate because academic dificulties in one grade persist and make success in the following grades more difficult (Alexander, Entwisle, & Kabbani, 2001; Rumberger, 2001). Identifying other predictors of AA and understanding how they relate is an important step for decreasing gaps in achievement for children from various backgrounds.

Children at-risk

Children from at-risk populations are at a higher risk for poor outcomes in such areas as school performance, health and mental health due to family or life circumstance (Robbins, Stagman, & Smith, 2012). The term "at-risk" typically refers to children who are physically, medically, or psychologically in danger of failing to thrive, thus at risk for health disparities and includes children who are affected by diverse economic, environmental, and geographical factors (Winter et al., 2007). At-risk includes a range of characteristics that include specific biological and environmental factors. Environmental risk factors include children from diverse economic, environmental, and geographical backgrounds (Winter et al., 2007). Physical risk factors include chemical, biological, and physical influences such as prenatal drug exposure (e.g. alcohol and tobacco) and exposure to pollutants (e.g. air, water, noise, radiation) (Ettinger, 2004). Social risk factors include low socio-economic status, family composition and size, parental mental health, parental substance abuse, and community demographics (Ettinger, 2004). Approximately 11.4 million children under 6 years live in a low-income family and over 50% are affected by at least one additional risk factor (Robbins et al., 2012). Numerous studies indicate children from disadvantaged backgrounds are more likely to enter school unprepared and demonstrate poor academic and developmental outcomes (Burchinal, Peisner-Feinberg, Pianta, & Howes, 2002; Dearing, Berry, & Zaslow, 2006; Raver, 2004; Sektan, McClelland, Acock, & Morrison, 2010). Research also suggests multiple risk factors (e.g. low income, low maternal education, and English Language learners) exacerbate the potential for entering school unequipped to succeed (Dearing et al., 2006; Halle et al., 2009; Sektnan et al, 2010; Wanless, McClelland, Tominey, & Acock, 2011). Pungello and colleagues (2010) reported children exposed to three or more risk factors are at greater risk to experience school failure and maladaptive behaviors.

Biological risk factors include disability, genetic disorders, low birth weight, and premature births (Ettinger, 2004). Over the past 12 years the prevalence of developmental disabilities, in the United States, has increased 17% (Boyle et al., 2011). Furthermore, approximately 750,000 children between the ages of 3-5 years receive some type of special education services, such as physical, occupational or speech therapy, as noted on an Individualized Education Plan (IEP) (Department of Education, 2013). An IEP is a federally mandated written document under the Individual with Disabilities Education Act (IDEA, 2004), developed for any child eligible for special education and related services. IEP's are specifically tailored to a child's unique needs and includes present levels of educational performance, goals, special education and related services. Results from the Preschool Early Education Longitudinal Study (PEELS) indicated children with disabilities were functioning well below the population mean in motor skills, social behaviors, and early academic achievement (Carlson et al., 2011). Similarly, data from the National Early Intervention Longitudinal study reported children with an IEP entered kindergarten with poorer behavior and social skills, and difficulty with communication. Specifically, 4 out of 5 children who had received early intervention services were reported to become easily distracted and two-thirds were reported to act impulsively, according to their kindergarten teacher (Hebbeler et al., 2007). Research has consistently demonstrated negative relations between socio-economic risk and a range of developmental outcomes, including academic outcomes, however, the relations between developmental outcomes and biological risk (e.g. disability) are less clear (Duncan & Magnuson, 2005; Evans & Rosenbaum, 2008; McClelland et al., 2000; Sektan et al., 2010). Children with cumulative risk factors demonstrate lower developmental trajectories with negative implications for future educational outcomes. Identifying deficits and understanding how to minimize the effects of risk factors is important for implementing initiatives to reduce risk exposure and promote optimal development for all children. The participants in the current study include children with at least one biological or environmental risk factor.

Links between motor skills and academic achievement

Motor skill development has been identified as an important factor in school readiness, however the impact of motor skills on school readiness is less known. Emerging research indicates motor skills are an important component of school readiness yet few studies examine whether or not motor skills independently effect early school-readiness outcomes, such as early math and literacy achievement (Cameron et al., 2012; Grissmer, Grimm, Aiyer, Murrah, & Steele, 2010; Pagani, Fitzpatrick, Archambault, & Janosz, 2010). For example, research indicates behavioral self-regulation and inhibitory control are related to visuo-motor skills (a component of fine motor skills) which significantly predicts emergent literacy and math (Becker, Miao, Duncan, & McClelland, 2014). Similarly, Roebers and colleagues (2014) reported children's fine motor and intelligence skills, assessed at age 5-6 years, were interrelated and significantly predicted later school achievement. Research provides evidence that motor skills, as well as teacher-reported attention, at kindergarten positively predict later achievement (Grissmer et al., 2010).

Another potential area for confusion is how the term motor skills is interpreted. Several studies indicate relationships between motor skills and school-readiness, however the motor skill assessments used are primarily focused on fine motor skills, such as manipulatives and visual-spatial organization, thus neglecting gross motor skills (Becker et al., 2014; Cameron et al., 2012; Grissmer et al., 2010; Son & Meissels, 2006). Studies that incorporate gross motor skills assess a limited variety of skills or solely use parent reported skills. Researchers examining associations of motor performance from children aged birth to 4 years, using the Ages and Stages Questionnaire (ASQ), a parent reported motor assessment, with school age cognitive performance reported a significant predictive relationship between gross motor trajectories and the subtests of working memory and processing speed (Piek, Dawson, Smith, & Gasson, 2007). Using the Early Screening Inventory-Revised, fine and gross motor skills of typically developing children were assessed and fine motor skills were found to be predictive of higher achievement outcomes (Cameron et al., 2012). Although a gross motor component was used in the assessment it only included balance and locomotor skills such as walking a line, hopping and skipping, thus leaving out object manipulation skills, such as throwing, catching, or kicking.

The current study uses the Peabody Developmental Motor Scales-2 (PDMS-2), a comprehensive, standardized motor assessment encompassing gross and fine motor subscales (Folio & Fewell, 2000). The gross motor subscale includes test items in three categories: stationary, locomotor, and object-manipulation skills. The fine motor subscale includes test items in two categories: grasping and visual-motor integration skills. Utilizing a comprehensive assessment allows for further examination of specific underlying motor mechanisms associated with early academic achievement.

The aims of the present study were twofold. The first aim examined associations between motor skills and early literacy skills. The second aim examined associations between motor skills and early math skills. Each question specifically examined the subscales (gross motor and fine motor) and the subsets of each subscale (stationary, locomotor, object manipulation, grasping, and visual-motor integration) underlying early academic achievement in at-risk preschoolers. Based on previous research, which indicates better motor skills are positively associated with better academic achievement in preschool aged children (Ericsson, 2008; Lopes et al., 2012; Pagani & Messier, 2012; Piek et al., 2007; and Westendorp et al., 2011), it is expected that children with better motor skills will demonstrate higher academic achievement as measured through early literacy and math skills.

Methods

Participants

Children identified with at least one biological or one environmental risk factor through parent report (n = 162) were recruited for this study from local preschool programs from two geographic locations in the Pacific Northwest (n = 50) and one geographic area in the Midwest (n = 112). Participants identified with a disability (n = 75) per parent report or as indicated on the child's individualized education plan (IEP) and participants identified as at-risk with at least one parent-reported environmental risk factor (e.g. low-income, single parent, English language learner, residential mobility) (n = 87) were enrolled into the study. Participants included 100 boys and 62 girls between the ages of 36- 71 months (M = 51.15 months, SD = 8.43 in the fall of preschool). The sample consisted of 114 Caucasian and 48 non-white children (16.8% African American, 6% Latino, 1.8% Middle Eastern, 1.2% Asian, and 2.9% Bi-racial or other). Sixty-nine percent (n = 111) of the participants attended a community-based preschool center and 31% (n = 51) were enrolled in Head Start, a federally funded program promoting comprehensive early childhood education services to low-income children and families.

Recruitment flyers and parental consent forms were sent home through preschool classrooms. Written informed consent was obtained from each participant's parent and/or legal guardian. Child assent was obtained from each child prior to assessments as indicated verbally or by their engagement with materials or assessor. Trained research assistants conducted each assessment in accordance with each test manual. The Institutional Review Board approved all methods and procedures for this descriptive, cross-sectional study. Data collected from the Pacific Northwest site(s) was part of a larger study and data collection occurred in the child's home and school, while data collected from the Midwest location occurred in the child's school.

Measures

Demographic questionnaire. A demographic questionnaire was sent home and completed by the primary caregiver. The questionnaire consisted of questions about the participant and family background. Participant questions included child age, gender, ethnicity, native language, and disability diagnosis (if applicable). Parent questions included relationship to child, age, educational level, employment level, marital status, income, times moved, and public assistance (if applicable).

Motor skill assessment. The Peabody Developmental Motor Scales 2nd Ed (PDMS-2) is a normed and standardized motor assessment of gross and fine motor skills in children age birth to 5 years (Folio & Fewell, 2000). The PDMS-2 is composed of two distinct scales of motor skills: gross and fine motor skills. The gross motor scale consists of the subscales reflexes, stationary, locomotor, and object manipulation skills. The reflexes subscale was not used in this study, as it is only administered to children birth to 11 months. The fine motor subscale consists of grasping and visual-motor integration skills. The gross motor subscale measures the ability to utilize the large muscle systems to move from place to place, assume a stable posture, react to environmental changes, and catch/throw objects. The fine motor subscale measures the child's ability to use his or her hands and arms to grasp objects, stack blocks, draw figures, and manipulate objects.

The PDMS-2 is used in practice and research settings and takes approximately 45-60 minutes to administer (Folio & Fewell, 2000). Furthermore, the PDMS-2 has good reliability coefficients for subgroups (Folio & Fewell, 2000) and concurrent reliability with the Movement Assessment Battery for Children (van Hartingsveldt, Cup, & Oostendorp, 2005) and the Bayley Scales of Infant and Toddler Development

3rd Ed (BSID-III) (Connolly, McClune, & Gatlin, 2012). Construct-identification validity for each subtest has been established through confirmatory factor analysis and goodness of fit indices (Folio & Fewell, 2000). Tucker and Lewis's (1973) index of fit was .96 and the root mean square of approximation (RMSEA) was .08. Inter-rater reliability for the current study was 0.84.

The current study examined motor skill mechanisms underlying early academic achievement. Therefore, similar skills within each subscale were combined and inter-class correlations (ICC) are reported for each. The gross motor subscales consist of stationary, locomotor, and object manipulation skills. The stationary subscale included 3 groups of items (1-foot balance, 2-foot balance, and postural control) with an ICC of 0.77. The locomotor subscale included 6 groups of items (walking, running, stairs, jumping, hopping, rhythm and timing skills) with an ICC of 0.89. The object manipulation subscale included 3 groups of items (throwing, catching, and kicking) with an ICC of 0.73. The fine motor subscales consist of grasping and visual-motor integration skills. The grasping subscale consisted of 2 groups of items (grasping and dexterity) with an ICC of 0.64. The visual-motor subscale included 6 groups of items (copying, cutting, folding, manipulatives and building with and without a model) with and ICC of 0.89. Conbach's alpha for the PDMS-2 total score was0.87 and iter-rater reliability was 0.84.

Cognitive assessment. Two separate cognitive assessments were used for the current study. Cognitive abilities of cohort 1 were assessed using the Mullen Scales of Early Learning: AGS edition (MSEL). The MSEL is a norm-referenced, standardized assessment of early learning for children age birth to 5 years and 8 months (Mullen, 1995). The MSEL manual reports good psychometric properties. The median split-half internal consistency was above 0.80 for 3 of the subscales, 0.79 for visual reception, and 0.75 for fine motor (as reported by the test manual). Test-retest reliability coefficients are 0.80 for intervals of one to two weeks and 0.70 for intervals of one to twenty-four months. Convergent reliability has been shown with the Bayley Scale of Infant Development (Johnson & Marlow 2006) as well as the Differential Ability Scales, with respect to nonverbal IQ and verbal IQ (Bishop, Guthrie, Coffing, & Lord, 2011). Cronbach's alpha for the MSEL was 0.90 and inter-rater reliability was 0.77.

The Early Stanford-Binet Intelligence Scales – 5th edition (SB5), abbreviated IQ test was used to assess cognitive abilities in cohort 2. The Early SB5 is a norm-referenced, standardized assessment for individuals between the ages 2 to 7 years (Roid, 2003). The SB5 abbreviated IQ test is composed of the nonverbal fluid reasoning and verbal knowledge subtests and was used in cohort 2 in order to reduce time constraints. The Early SB5 manual reports good psychometric properties for both the full IQ and abbreviated test. Reliability for the abbreviated battery IQ subscales is 0.91. Cronbah's alpha for the abbreviated battery was 0.78. Only one researcher collected SB5 data and the single measures ICC was 0.77.

The MSEL and the SB5 scores can be converted into ratio intellectual quotient (IQ) scores. Ratio IQ is the intelligent quotient of a person calculated as the ratio of the child's mental age (based on a standardized test) to chronological age (Colangelo & Davis, 1991). Non-verbal ratio IQ's (NVIQ) is calculated by dividing the non-verbal mental age by the chronological age and multiplying by 100. The same method is applied for calculating verbal ratio IQ's (VRIQ), using verbal mental age equivalents. Ratio IQ's are used with children with developmental disabilities when it is not possible extrapolate composite scores on standardized assessments (Bishop et al., 2011; Richler, Bishop, Kleinke, & Lord, 2007). Ratio IQ scores standardize cognitive assessments and were used as descriptive data in the current study.

Academic outcomes. The Woodcock Johnson Psycho-Educational Battery-III Tests of Achievement (WJ-III; Woodcock & Mather, 2000) will be used to assess children's academic achievement through early literacy skills (letter-word identification subtest) and early math skills (applied problems subtest). The WJ-III is widely used, normed, and standardized assessment. The applied problems, and letter-word identification subtests have strong psychometric properties in preschool children and represent the proxies most commonly used to assess emergent literacy and math (McGrew & Woodcock, 2001; Woodcock & Mather, 2001). Research has demonstrated strong reliability and validity (Cronbach's alpha > .80) in preschool samples in both subtests (Schrank et al., 2005; Woodcock & Mather, 2000). Each subtest takes approximately 5 minutes to administer and total raw scores will be attained and used for analysis. Cronbach's alpha for the WJ-III was .70 and inter-rater reliability was .70.

Early literacy skills. The Letter-Word Identification subtest measures emerging literacy skills using letter recognition, and reading out lout (Woodcock & Mather, 2000). Previous research has shown high reliability for preschool-aged children (Schrank et al., 2005; Woodcock & Mather, 2000).

Early math skills. The Applied Problems subtest measures early mathematical skills using counting, calculation skills, and quantitative reasoning (Woodcock & Mather, 2000). Previous research has demonstrated reliability for preschool-aged children (Schrank et al., 2005; Woodcock & Mather, 2000).

Covariates. Covariates were limited to age, ethnicity, and site location. NVRIQ, disability, and Head Start status were not used as covariates due to multicollinearity. Children identified with a disability were primarily from one location and independent t-tests indicated significant differences between sites, thus site instead of disability were added to control for differences in variables. There was a significant difference in the letter-word identification scores for site 1 (M = .98, SD = .26) and site 2 (M = .81, SD = .32) conditions; t (160) = 3.38, p = .001. Significant difference was also indicated with the applied problems scores for site 1 (M = 14.84, SD = 5.30 and site 2 (M = 10.14, SD = 4.81) conditions; t (160) = 5.56, p = .000.

Socioeconomic status (SES) variables were not controlled for since they are at-risk identifiers and at-risk children are the target population. However, there was a significant difference in the applied problem scores for white (M = 12.41, SD = 5.08) and non-white (M = 9.65, SD = 5.72) conditions; t (160) = 3.05, p = .003, therefore, ethnicity was used as a control variable.

Procedures

Data collection at site one took place in the child's home (approximately 1 hour in length) and preschool (approximately 30 minutes in length). Data collected in the homes consisted of a survey of demographic information from the child's parent/legal guardian and direct measures of motor skills. Data collected in the preschool consisted of the direct assessment of cognition. The demographic survey, PDMS-2 and SB5 were conducted in the fall of the preschool year. Early academic achievement data was collected in the spring of the preschool year, approximately 5 months later, at the school. Trained assessors, with experience working with preschool aged children collected data. Data collection at site two took place in the child's preschool during the fall and consisted of the PDMS-2, SB-5 abbreviated version, and WJ-III subtest (approximately 45 minutes in length). The demographic survey was sent home and completed by the child's parent/legal guardian and sent back in the provided envelope. The primary researcher collected data collected at site 2.

Missing Data. Demographic and predictor variables contained between .6% and 18.5% missingness. Maternal age and maternal education were the highest missing variables due to demographic questionnaires not being returned and this information was not available through school records. The outcome variables (early literacy and early math) contained approximately 1.2% to 2.5% missingness, due to children being absent or not participating in assessment. Missing data was assumed to be missing completely at random (MCAR). In order to identify the best data replacement technique missing data was analyzed to determine if missing data was missing at random or missing in a systematic way. Little's MCAR test reported: chi-square = 30.12, DF = 27, sig. = .31. Since the p-value is greater than .05 it is reasonable to accept the null hypothesis and conclude variables examined were not found to predict missingness, indicating MCAR was a reasonable assumption (Little, 1998). Missing data was imputed using the expectation maximization (EM) technique, which is the most appropriate technique when missing values are present on one or more variables and are missing completely at random. Imputing missing data has been shown to produce less biased estimates than listwise deletion (Acock, 2012). EM consists of two steps: an expectation step, followed by a maximization step. The expectation refers to the unknown underlying variables, using the current estimate of the parameter and conditioned upon the observations. The maximization step provides a new estimate of the parameters and uses an iterative process until convergence (Moon, 1996).

Analytic Strategy

SPSS 22 (IBMCorp. 2013) was used to perform all data analyses. Data were examined for normality using the Shapiro-Wilk test and histograms and outliers were identified using the outlier-labeling rule. Skewness and kurtosis are presented in Table 1 with descriptive data. Non-normally distributed data (letter-word identification) was transformed using base-10 log transformation (log10) and one point was added to each score prior to transformation so that the data did not contain any zero scores. The transformed early literacy scores were normally distributed, with skewness of -.42 (SE = .19) and kurtosis -.18 (SE = .38). Outliers were classified using the outlier-labeling rule, which leverages the interquartile range, thus is not dependent on distributional assumptions and ignores the mean and standard deviation, making it resistant to being influenced by extreme values (Hoaglin, Iglewicz, & Tukey, 1986; Tukey, 1977). Subtracting the 25th quartile from the 75th quartile and multiplying by *g* identified the value used to subtract from the lowest value or add to the highest value to identify outliers. Hoaglin and colleagues (1986) suggests $g = 2.2$ and is appropriate to use with small samples and normally distributed data. There was one lower end outlier for the gross motor scores and two upper end outliers for early literacy.

Univariate linear regressions were used to assess the association of independent variables with specific outcomes to examine the relative importance of each predictor in the presence of other predictors. Variables that predicted resilience in the univariate analyses were included in the hierarchical analyses.

Early literacy. The first model measured the association between gross motor skills and early literacy while controlling for known covariates. The second model measured the association between fine motor skills and early literacy while controlling for covariates. The final model used hierarchical regression to establish which independent variables were the most predictive. Covariates were entered into the first block, as significant differences between age, site and ethnicity existed. Gross motor total score and fine motor total score were entered into the second block simultaneously. Variables were entered in blocks in order to determine whether or not the second blocks added any further variance above and beyond the first block. Further analyses examining the association between subtest items (grasping and visual motor skills) and early literacy were conducted utilizing hierarchical regression analyses.

Early math. The first model measured the association between gross motor skills and early math while controlling for covariates. The second model measured the association between fine motor skills and early math while controlling for covariates. The final model used hierarchical regression to establish which independent variables were the most predictive. Covariates were entered into the first block, as significant differences between age, site and ethnicity existed. Gross motor total score and fine motor total score were entered into the second block. Variables were entered in blocks in order to determine whether or not the second blocks added any further variance above and beyond the first block. Further analyses were conducting to examine associations between fine motor subtest items (grasping and visual motor skills) and early math skills.

Results

Descriptive statistics are presented in Table 1. Bivariate correlations for all predictor and outcome variables in the analyses are presented in Table 2. Bivariate correlations in the overall sample showed significant associations between gross motor skills; fine motor skills, total motor skills, early literacy skills, early math skills, child age, and site covariates. Correlations among early literacy were highest with early math skills ($r = .56$, $p = .000$) and total motor skills ($r = 51$, $p = .000$). Correlations among early math were highest with fine motor skills ($r = .71$, $p = .000$) and total motor skills ($r = .56$, $p = .000$).

Research Aim 1: To examine associations between motor skills and early literacy skills.

Children's gross motor skills had significant associations ($\beta = .33$, $p = .000$) with early literacy after controlling for covariates, explaining 21% of variance in the model (Model 1, Table 4). Children's fine motor skills had significant associations ($\beta = .47$, $p = .000$), explaining 28% of variance in the model, after controlling for covariates (Model 2, Table 4). Once gross motor and fine motor were entered into the same model simultaneously only fine motor indicated significant associations (β = .43, p = .000) with early literacy (Model 3, Table 4). Further analysis examining associations between fine motor subtest items (grasping and visual-motor integration) and early literacy indicated significant associations with visual-motor integration (β = .50, p = .000) explaining 30% of the variance (Model 4, Table 4). Overall site and visual-motor integration skills explained a statistically significant amount of variance in children's early literacy (R^2 = .55, F(5, 156) = 13.36, *p* < .001).

Research Aim 2: To examine associations between motor skills and early math skills.

Initial linear regression indicated children's gross motor skills had a significant association (β = .48, p = .000) with early math skills after controlling for covariates, explaining 52% of variance in the model (Model 1, Table 5). Fine motor skills had a significant association (β = .64, p = .000) after controlling for covariates, explaining 62% of variance in the model (Model 2, Table 5). When gross and fine motor were combined in the same model fine motor skills had a significant association (β = .57, p = .000), with early math, however gross motor skills were no longer significant (β = .11, p = .187) (Model 3, Table 5). Further analysis examining the fine motor mechanisms underlying early math skills indicated a significant association with visual-motor integration skills (β = .62, p = .000) (Model 4, Table 5). Overall, site and visual-motor integration skills explained a statistically significant amount of variance in children's early math skills (R^2 = .63, F (5, 156) = 11.16, *p* < .001).

Discussion

The current study examines the contributions of motor skills to early academic achievement, and includes analyses encompassing specific aspects of gross and fine motor predictors. Analyses indicate that gross and fine motor skills make independent contributions to school readiness skills. Previous research indicates positive associations between motor skills and academic achievement (Cameron et al., 2012; Son & Meisels, 2006; Ericsson, 2008; Pagani & Messier, 2011; Piek et al., 2008; Vuijk, Hartman, Mombarg, Scherder, & Visscher, 2011). A unique feature of the present study is that gross motor skills were included in the analyses and the sample consisted of children from at-risk populations, including children with disabilities. Using hierarchical regression analyses to directly examine the predictability of motor skills for early academic achievement indicated both gross and fine motor skills uniquely contributed to early literacy and math skills in at-risk preschoolers.

Predictability of motor skills for early literacy skills.

The results regarding the relationship between gross motor skills and early literacy in children from at-risk populations demonstrate a clear relationship between visual-motor integration and early literacy. These results are similar to previous studies reporting significant relationships between visual-motor skills and early literacy (Cameron et al., 2012; Son & Meisels, 2006). Fine motor skills, particularly visual motor skills, (e.g. blocks, design copy, and draw-a-person) have been reported to make a significant contribution to children's entry-level achievement, specifically literacy related domains (Cameron et al., 2012). Gross motor skills were also significant, when run separately, but their effect sizes were small.

Predictability of motor skills for early math skills.

The second aim of this study was to examine whether specific relationships between subscales of motor skills and early math skills existed in at-risk children. Results indicated both gross and fine motor skills significantly predicted early math skills. Object manipulation skills, a subset of gross motor skills, significantly contributed to early math skills, specifically catching. These findings are similar to Westendorp and colleagues (2011) who examined relationships between motor skills and academic achievement in children with learning disabilities, reporting a positive trend between math and object control skills. Similarly a predictive relationship for gross motor trajectory and cognitive ability has also been reported (Piek et al., 2007). The fine motor, specifically visual-motor skills, results indicated a positive relationship with early math skills, similar to other studies (Cameron et al., 2012; Pagani & Messier, 2012; Son & Meisels, 2006).

The results of this study not only extend to previous research indicating motor skills are positively associated with early academic achievement but also offers two unique contributions. First, the sample was diverse including socioeconomically disadvantaged children, children with disabilities, and children with other environmental or biological risk factors. Previous studies including children from at-risk populations typically include children from urban, low SES populations

(McClelland & Tominey, 2011; Ponitz et al., 2009; Rimm-Kaufman et al., 2009; Sektnan et al., 2010; Wanless et al., 2011). Studies including children with disabilities are often comparative. The current study includes a diverse sample including socioeconomically disadvantaged children, children with disabilities, and children with other environmental or biological risk factors. Second, results indicate similar patterns for children with disabilities compared to typical peers examining associations between motor skills and early academic achievement (Becker et al., 2014; Son & Meisels, 2006; Westendorp et al., 2011). In other words, children with better motor skills perform better on measures of early academic achievement.

The results of the current study indicate a positive relationship between gross and fine motor skills and early math skills, however, it is not without limitations. First, the majority of participants were Caucasian, even though participants were from two different regions in the United States, thus a more diverse sample may render different results. Second, the data collected was only cross-sectional. Longitudinal data may help better understand the impact of motor skills on early math skills and identify the effects of motor skills on later academic achievement. In addition, randomized control studies, utilizing a movement based intervention, would also benefit the current literature. This type of study would potentially inform not only the benefits of an intervention to motor skills, but if improved motor skills had any short or long term effects on academic achievement. Lastly, all participants were assessed during school hours and were pulled out of regular class routines. Researchers assumed participants put forth their best efforts during assessments. Furthermore, due to the numerous amounts of assessments, participants may have become tired or disinterested in the activities and assessments. Despite these limitations, this study contributes to the current body of knowledge of factors effecting early math skills, especially the relationships between motor skills and early math skills in children from at-risk populations.

Conclusion

The benefits of motor skill development have clearly been indicated in all areas of development and are an accessible resource that children from all abilities can use. Utilizing motor opportunities has the potential to promote and foster optimal child development, thus helping children develop the skills necessary to succeed academically. Understanding how developmental constructs, such as motor skills, relate to early academic achievement may provide beneficial information for developing comprehensive strategies to help children transition into first grade, especially in at-risk populations.

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Table 1

Descriptive Statistics

Variable	***% Yes***	***N***	***% No***	***N***
Child gender (female = yes, male = no)	38.3	62	61.7	100
Ethnicity (white = yes, non-white = no)	70.4	114	29.6	48
Site (1 = yes, 2 = no)	30.9%	50	69.1%	112
Disability	46.3%	75	53.7	87
Head Start Status	31.5%	51	68.5	111

Variable	***M***	***SD***	***Min***	***Max***
Child age in months	51.15	*8.43*	36	71
NVRIQ	84.02	24.51	0	172
Total Motor Score	386.54	42.06	263	477
Gross Motor Subscale	216.10	29.93	103	282
Stationary Items Total	48.75	6.49	4	60
Locomotor Items Total	148.67	19.78	66	178
Object Manipulation Items Total	31.72	7.69	13	49
Fine Motor Subscale	170.74	16.92	116	196
Grasping Items Total	45.95	4.73	16	52
Visual Motor Items Total	124.72	13.66	77	144
Letter-Word Identification (early literacy)	8.19	6.24	0	43
Applied Problems (early math)	11.59	5.41	0	25