Relations of preschoolers' visual motor and object manipulation skills with executive function and social behavior

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Purpose: The purpose was to examine specific linkages between early visual-motor integration skills and executive function, as well as between early object manipulation skills and social behaviors in the classroom over the preschool year. **Method**: 92 children between the ages of 3-5 years old (mean age 4.31 years) were recruited to participate in this study. Comprehensive measures of visual motor integration skills, object manipulation skills, executive function and social behaviors were administered in the fall and spring of the preschool year. **Results**: Our findings indicated that children who had better visual-motor integration skills in the fall had better executive function scores, ($B = .47$ [.20], $p < .05$, $\beta = .27$) in the spring of the preschool year after controlling for age, gender, Head-Start status, and site location, but not after controlling for children's baseline levels of executive function. In addition, children who demonstrated better object-manipulation skills in the fall showed significantly stronger social behavior in their classrooms (as rated by teachers) in the spring, including more self-control, (B - .03 [.00], $p < .001$, $\beta = .40$), more cooperation, ($B = .02$ [.01], $p < .01$, $\beta = .28$), and less externalizing/hyperactivity, ($B = -.02$ [.01], $p < .01$, $\beta = -.28$) after controlling for their social behavior in the fall and other covariates. **Conclusion**: Children's visual motor integration and object manipulation skills in the fall have modest to moderate relations with executive function and social behaviors later in the preschool year. These findings have implications for early learning initiatives and school readiness.

Keywords: School Readiness, Head Start

Relations of Preschoolers' Visual Motor Integration and Object Manipulation Skills with Executive Function and Social Behavior

Promoting children's readiness for school is an important societal and governmental priority as indicated by "Preschool for All" initiatives and Race to the Top: Early Learning Challenge Grants. Preparation early in children's schooling is linked to academic success later in life (M. M. McClelland, Acock, Piccinin, Rhea, & Stallings, 2013). Unfortunately, many children face difficulty once they enter school. To effectively promote school readiness, it is important to improve our understanding of how various aspects of school readiness relate to one another and develop. One area that is underexplored is how specific motor skills are related to the development of executive function and social behaviors, which are known school readiness outcomes, during the preschool period.

Aspects of fine motor skills, especially those that require integration of visual and motor systems, are emerging as an important factor for children's development of executive function, self-regulation, and later success in school (Becker, Miao, Duncan, & McClelland, 2014; Carlson, Rowe, & Curby, 2013). Specific gross motor skills, namely skills common in childhood play like ball skills, are also linked to children's social behavior (MacDonald, Lord, & Ulrich, 2013, 2014; Pagani & Messier, 2012). This study sought to identify how visual motor integration skills and object manipulation skills (ball skills) help to explain young children's development of executive function and social behaviors during preschool. We focus on executive function because it is foundational for children's development of cognitive and academic skills, and on social behaviors because managing emotions and behavior in classroom settings is also critical to success in school.

Neurocognitive Evidence Linking Motor Skills, Executive Function, and Social Behaviors

The development of motor processes are linked to the development of executive function, and the regulation of both cognition and emotion, and are present within the first year of life (Sheese, Rothbart, Posner, White, & Fraundorf, 2008). For children to adapt to motor and emotional challenges, their movement, emotion, and attention systems must work in unison, and are regulated through overlapping neural networks that develop simultaneously (Rueda, Posner, & Rothbart, 2004). The cerebellum is implicated in sensorimotor, cognitive, and emotional processes to monitor, adjust, and regulate behavior. As such, differences in motor development are likely reflected in executive functioning and in social behaviors requiring emotion regulation.

Theoretical Framework

Our research questions are rooted in the theoretical framework of learning to learn (Adolph, 2005). The idea of *learning to learn*, suggests that the motor system plays a key role in early learning, with brain systems involved in posture, gripping, vision and motor control acting in concert. Within the learning to learn framework, physical development changes balance and coordination, requiring that the child learn to move in a changing body. Thus, motor skill flexibility is an early form of learning, and may set the stage for higher level processing, such as executive function and social behaviors. Further evidence for a link between aspects of motor skills, namely visual motor integration skills and object manipulation skills with academic achievement and social behaviors, is found in work linking visual-spatial working memory to math and reading (St Clair-Thompson & Gathercole, 2006), and between balls skills (object manipulation skills) and social behaviors (Pagani & Messier, 2012).

Executive Function

Executive function includes working memory, attentional or cognitive flexibility, and inhibitory control (Cameron Ponitz, McClelland, Matthews, & Morrison, 2009). Working memory refers to the maintenance and manipulation of information; attentional or cognitive flexibility is the ability to maintain focus and adapt to changing goals or stimuli; and inhibitory control is the ability to stop a dominant response in favor of a more adaptive one. Academic outcomes are influenced by each aspect of executive function, and integration of these processes is important for school readiness (M. M. McClelland & Cameron, 2012). Executive function predicts academic achievement throughout schooling as well as better life course trajectories (Cameron Ponitz, et al., 2009; Moffitt et al., 2011). In one study, children with strong executive function skills at age four had 49% greater odds of finishing college by age 25 (M. M. McClelland, et al., 2013).

Emerging in early childhood, executive function develops rapidly through the complex coaction of environmental and developmental processes (Blair & Raver, 2012). Early childhood is a sensitive period for the development of executive function processes, although it demonstrates relative plasticity throughout life (Lerner, 2006). Since executive function is an important component in early and later school success, identifying skills that help children hone their executive function during preschool is critical.

Visual Motor Integration Skills and Executive Function

Young children spend approximately 27- 66% of the school day in fine motor skill-based activities like drawing, tracing, stringing beats, cutting, and manipulating small objects (Verdine, Irwin, Michnick Golinkoff, & Hirsh-Pasek, 2014). Specific fine motor skills requiring visual motor integration (e.g. copying shapes and/or small block structures) may be particularly important to early learning and cognition (Carlson, et al., 2013). Although the specific mechanisms have not yet been identified, is it possible that visual motor activities provide children with the opportunity to practice key executive function skills that are fundamental to learning and cognition. Copying a shape or building a small block structure requires children to focus their attention (e.g., staying within the lines), hone their working memory (e.g., remembering what the shape or structure looked like) and use inhibitory control (e.g., avoid the temptation to get up and play with a friend). Emerging evidence is suggestive of such linkages; in a recent cross-sectional study significant positive associations among executive function, visual-motor skills, and early academic outcomes in preschool and kindergarten children were found (Becker, et al., 2014). In a longitudinal study examining a Swiss sample of preschoolers (5- 6 years of age at study entry), aspects of fine motor skills predicted academic outcomes later in the children's schooling (as assessed through the a manual dexterity scale from the Movement Assessment Battery for Children 2), however when executive function was included in the model fine motor skills were no longer predictive of later academic success (Roebers et al., 2014). This suggests that executive function may be an important link between early fine motor (e.g., visual motor) skills and children's academic outcomes. However, the specific role of visual-motor integration skills within executive function development requires further investigation.

The current study contributes to this important line of research by focusing on the links between visual motor integration skills and executive function during the preschool year, controlling for other motor skills (e.g., object manipulation). This approach allows us to hone in on specific, rather than general, linkages between motor skills and executive function. Although we recognize that visual-motor integration skills and executive function may develop reciprocally, this study focuses on the associations between early developing visual motor-integration skills and more advanced executive function during the preschool year, consistent with our theoretical framework of *learning to learn*. We utilize a measure designed to capture multiple and more complex visual motor integration skills as they begin to emerge (Peabody Developmental Motor Scales-2nd edition; PDMS-2). We expect that the visual-motor integration skills children exhibit on the PDMS-2 will be linked with their development of executive function skills that emerge later in the preschool period, assessed with the Head-Toes-Knees-Shoulders task (Cameron et al., 2012).

Relationship between Object Manipulation Skills and Social Behavior

Social behaviors, such as controlling emotions in the classroom and cooperating with peers and teachers, are related to children's success in school (Denham & Brown, 2010). Better social behaviors are positively associated with classroom functioning, school adjustment, motivation, and involvement in learning (Denham & Brown, 2010). Cooperation and emotional control are important for transitioning from preschool to school, and for early school performance (M. M. McClelland & Morrison, 2003).

In contrast, externalizing behaviors, including hyperactivity, inattention, aggression, and oppositional behaviors, are associated with difficulties in both academic and social domains (McWayne & Cheung, 2009). Children who exhibit more externalizing behaviors in preschool or elementary school often face challenges establishing positive relationships with peers, teachers (Bulotsky-Shearer, Dominguez, Bell, Rouse, & Fantuzzo, 2010; Whittaker & Harden, 2010), and family members (Larsson, Viding, Rijsdijk, & Plomin, 2008). Young children with externalizing behaviors also show less motivation to learn and fewer positive attitudes about learning in preschool, which is connected to lower achievement in elementary school (McWayne & Cheung, 2009).

Prior research on the development of social behavior has focused on identifying features of children's environments such as interactions with family members and preschool teachers. Yet emerging research indicates that young children's early gross motor skills may also play a role in social behaviors (MacDonald, et al., 2013, 2014; Pagani & Messier, 2012). Gross motor skills (especially object manipulation skills) provide the foundation for active play and for schoolyard activities that children use to socialize and interact with their peers. Object manipulation skills are used in games and activities that require reciprocal play, like playing catch or soccer, and passing and catching skills common in games like four square. Social behaviors such as self-control, cooperation, and avoiding externalizing or hyperactivity require regulation of emotion which has some commonality and overlapping neural pathways with executive function (Lewis & Todd, 2007). Yet decades of research highlight important differences between executive function and social behaviors, which suggest different pathways and precursors to development in each area. For example, executive function tends to predict cognitive and academic aspects of school success (e.g., McClelland & Cameron, 2012), whereas emotion regulation typically predicts more social outcomes (e.g., Denham & Brown, 2010). In one study, executive function predicted gains in academic achievement at the end of school, but not gains in social skills (Cameron Ponitz, et al., 2009).

Most empirical research examining the link between object manipulation skills and social behaviors has focused on clinical samples (MacDonald, et al., 2013, 2014). For example, a study of school-aged children with autism spectrum disorder found that better object-manipulation skills, were related to better social skills controlling for other important variables such as IQ, ethnicity and gender (MacDonald, et al., 2013). In typically developing children, there is evidence to suggest that stronger gross motor skills, such as object manipulation skills, may support children's ability to navigate complex classroom environments with appropriate social behaviors (Pagani & Messier, 2012). In addition, when an intervention, focused on ball skills was implemented, children who improved object manipulation skills showed simultaneous improvements in aspects of social behaviors, yet the control group did not show the same improvements (Westendorp et al., 2014). Subsequently, the current study focuses on relations of object-manipulation skills to social behaviors in a typically developing sample of preschool-aged children. Object manipulation skills (e.g., throwing a ball with friends) should provide children with more opportunities to practice social skills (e.g. reciprocity, following rules, social problem solving), and refine the ability to control their bodies in socially acceptable ways, which taps into aspects of emotional regulation required for avoiding social behavior problems (e.g., aggression and hyperactivity).

Hypotheses

This study examined relations among visual-motor integration skills and object manipulation skills, and children's development of executive function and social behavior, during the preschool year. Based on theory and emerging evidence for specific relations between visual motor integration and executive function, and between object manipulation skills and social behavior, we posed two research questions:

Research question 1. Do children's visual-motor integration skills in the fall of preschool significantly relate to their executive function in the spring, and to residual change in executive function over the preschool year? Executive function is defined as attentional flexibility, working memory, and inhibitory control.

Research question 2. Do children's object manipulation skills in the fall of preschool significantly relate to their social behavior in the spring, and to residual change in social behavior over the preschool year? We defined social behavior as including cooperation, emotional components of self-control, and externalizing/hyperactive behaviors.

By including both visual-motor integration and object manipulation skills in the same study we are able to control for object manipulation skills when estimating the relationship between visual-motor integration and executive function. This also allowed us to account for visual-motor integration when estimating the link between object manipulation skills and social behaviors, thereby increasing the specificity of our findings.

Methods

Participants

Ninety-two preschool children between the ages of 3-5 years old (mean age= 4.31 years in the fall of preschool) were recruited from 28 preschool classrooms in two areas of Oregon (30% from site 1 and 70% from site 2). Twenty-one percent of participants attended Head Start programs, a federal program in the U.S. that promotes school readiness for children 3-5 years of age from families living in poverty, and 79% attended community-based preschools. The sample was comprised of 79.3% Caucasian, 17.3% non-white (5.4% African American, 7.6% Hispanic/ Latino, 2.2% Asian, 1.1% Middle Eastern and 1.1% Native American), and 4.3% unknown. Maternal education consisted of: 34.8% High school/GED, 3.3% Associate's, 22.8% Baccalaureate, 1.1% Master, 30.4% Doctorate (PhD, MD, JD), 7.6% Missing. Written informed consent was obtained from the parent and/or legal guardian for all participants and from all preschool teachers. Child assent was indicated by their engagement with the materials and/or project staff. The Institutional Review Board approved all study protocols.

Measures

Motor skill assessment. Subscales from the Peabody Developmental Motor Scales 2nd Ed (PDMS-2) were used to assess object-manipulation and visual motor-integration skills (Folio & Fewell, 2000). The PDMS-2 is a standardized assessment of motor skills in young children age birth to 5 years and takes approximately 30 minutes to administer the full version of the assessment. Each item on the PDMS-2 is scored 0 (skill is not emerging), 1 (skill resemblance but not mastery) or 2 (skill mastery based on criteria). A basal level is established when a child receives a score of 2 on three items in a row. A ceiling level is established when a child scores three 0's in a row. The subscales of the PDMS-2 included in this study were: object manipulation (Cronbach's alpha = .95), which measure the child's ability to throw, catch, kick, bounce and hit targets with balls (e.g. the child catches a ball with his/her arms bent and using only his/her hands). The scores for the object manipulation scale can range from 0-48. The second scale was the visual-motor integration scale, which measures the child's ability to perform visual perceptual and eye-hand coordination skills (Cronbach alpha = .95), such as tracing, copying, building with blocks, folding paper given specific instructions, and manipulating pellets into small containers (e.g., the child draws intersected lines and copies an existing shape). The scores for the visual motor integration subscale range from 0-142. Although the entire PDMS-2 was administered, only the visual motor integration and object-manipulation subscales were used in the analysis. This decision was based on prior research and a focus on identifying specific aspects motor skills linked with executive function and social behavior.

Executive Function. The Head-Toes-Knees-Shoulders Task (HTKS) was administered to all children in the fall and spring to assess children's attentional flexibility, working memory, and inhibitory control, commonly referred to as executive function (M. McClelland et al., 2014). The HTKS requires children to pay attention, remember instructions, and do the opposite in response to the assessor's command (e.g., the child must touch his/her *head* when the assessor says to touch his/her *toes*). It takes 5–7 minutes to administer. There are a total of 30 test items, each scored 0 (incorrect), 1 (self-correct), or 2 (correct). A self-correct is defined as any motion toward the incorrect response, but which the child corrects without prompting (e.g., a child starts reaching for their toes and self-corrects to touch their head). Scores range from 0 to 60 where higher scores indicate higher levels of executive function. The HTKS has been found to be reliable and predictive of academic outcomes in diverse samples (M. McClelland, et al., 2014; M. M. McClelland & Cameron, 2012; Wanless et al., 2013). In this study, the Cronbach's alphas for the HTKS were .97 in the fall and spring.

Social behavior. The teacher form of the Social Skills Improvement System Rating Scale (SSIS-RS) was used to measure children's social behavior in classroom settings in the fall and spring. The SSIS-RS is a standardized assessment of social skills and problem behaviors for children ages 3-18 years and has strong psychometric properties (Gresham & Elliott, 2008). Each item asks teachers to indicate the frequency of children's behaviors from 0 (never) to 2 (always). This study used two subscales of social skills (self-control and cooperation) that have been shown to be important for children's school readiness (Sektnan, McClelland, Acock, & Morrison, 2010). The self-control subscale included 6 items, thus scores range from 0-12, specifically focused on the emotional aspects of self-control, with an internal consistency of .93 on both the fall and the spring assessments. Sample items include, "*stays calm when disagreeing with others*" and "*makes a compromise during a conflict.*" The cooperation subscale included 7 items, thus scores range from 0-14, with an internal consistency of .90 in both the fall and the spring. Sample items include, "*follows classroom rules*" and "*completes tasks without bothering others*." In addition, the current study includes a 15 item subscale, thus scores range from 0 – 30), representing negative social behaviors, labeled, "externalizing/hyperactivity", which was comprised of the externalizing and hyperactivity/inattention subscales (Cronbach's alpha = .93). Sample items include, "*acts without thinking*", "*gets distracted easily*", "*disobeys rules or requests*", and "*has difficulty waiting for turn*".

Covariates. Due to a relatively small sample size, covariates were limited to child age at the time the outcomes were assessed (spring), gender, Head-Start status, and site location (based on geographic location where site 1 was coded as “0” and site two was coded as “1”). Head Start status was selected because it represents family adversity (high correlations with both parent education and family income) and did not have any missing data.

Procedures

Data were collected over the course of one preschool year during the fall (beginning in September) and spring (beginning in April). The average time between fall and spring assessments for each participant was approximately 5 months. Fall data collection took place in the child’s home (approximately 1 hour in length) and preschool (approximately 30 minutes in length). Home data collection consisted of direct measures of motor skills and a survey of demographic information from the child’s parent/ legal guardian. Preschool data collection consisted of a direct assessment of executive function, and teacher ratings of the child’s social behavior. Spring data collection took place in the child’s preschool (approximately 30 minutes in length). This follow up data collection consisted of a direct assessment of executive function, and teacher-rated social behaviors. Data were collected by trained assessors, with experience working with 3-5 year old children.

Missing data. There were relatively few missing data in the fall; 4.35% missing for the visual-motor integration and object manipulation, due to children declining to complete the assessment. Three children (3.26%) dropped out of the study between the fall and spring assessment. However, fewer teachers returned the SSIS-RS forms in the spring. The most missing data occurred for the externalizing/hyperactivity subscale of the SSIS-RS (8.99% missing). To account for missing data, all models were estimated using full imputation maximum likelihood (FIML) under the missing-at-random (MAR) assumption. This approach provides less biased estimates (Acock, 2012). Given that the missing-data patterns are not related to the dependent variable, other variables included in the model can help explain the missingness (Schafer & Graham, 2002). No covariates were significantly related to missingness on the dependent variable, satisfying the assumption that missing-data patterns were not related to the outcomes of focus.

Data Analysis

Data were analyzed using Stata 13.1 (Stata Corp., 2013). All models were estimated using the structural equation modeling (*sem*) command with full information maximum likelihood estimation (FIML). Furthermore, all models estimated the outcomes simultaneously and standard errors were adjusted for clustering (children nested within classroom). The intraclass correlation coefficients (*ICC*) for the outcome variables were: HTKS (*ICC* = .19), SSIS-cooperation (*ICC* = .00), SSIS-self-control (*ICC* = .11), and SSIS-externalizing/hyperactivity (*ICC* = .12). Due to the small sample size (92 children nested in 28 preschools) multilevel models were not reasonable . Therefore, standard errors were adjusted using the generalized Huber/White/Sandwich estimator for clustering data (children nested within classroom). A priori alpha was established at $p < 0.05$.

We examined two models for each outcome (executive function and social behaviors). The first model measured the association between fall assessments of visual-motor integration and object manipulation and spring assessments of the outcomes while controlling for covariates.

Model 1:

$$\text{Outcome}_{2i} = \beta_0 + \beta_1\text{gender}_\text{i} + \beta_2\text{age}_\text{2i} + \beta_3\text{site}_\text{i} + \beta_4\text{HeadStartstatus}_\text{i} + \beta_5\text{ObjectManipulation}_\text{1i} + \beta_6\text{VisualMotorIntegration}_\text{1i} + \text{e}$$

This equation represents the model for the outcome (e.g. executive function, social behavior) at time 2 (spring) for the "i"th child, predicted by the intercept (β_0), the estimated effects of the independent variables ($\beta 1 - \beta 6$), and error.

The second model was identical to the first model, except that executive function and social behaviors assessed in the fall were included as additional covariates. Thus, the first model measured the association between fall visual-motor integration and object manipulation with spring levels of executive function and social behaviors, whereas the second model measured the association between fall visual-motor integration and object manipulation with residual change in levels of executive function and social behaviors during the preschool year.

Model 2:

$$\mathrm{Outcome}_{2i} = \beta_0 + \beta_1 \mathrm{gender}_{\mathrm{i}} + \beta_2 \mathrm{age}_{2\mathrm{i}} + \beta_3 \mathrm{site}_{\mathrm{i}} + \beta_4 \mathrm{HeadStartstatus}_{\mathrm{i}} + \beta_5 \mathrm{Outcome}_{1\mathrm{i}} + \beta_6 \mathrm{ObjectManipulation}_{1\mathrm{i}} + \beta_7 \mathrm{VisualMotorIntegration}_{1\mathrm{i}}$$

All models were estimated using *sem*, and, following best practice allowed for the error variances of the outcome variables (i.e., executive function and social behaviors) to correlate. This allowed us to account for possible additional associations between children's executive function and social behaviors that are not explained by the model. For each model, we report the explained variance in the outcome (1- the unexplained variance); however, given that specific parameter estimates are based off of FIML estimators, we do not report the explained variance for each parameter. Given that p-values are potentially biased by sample size (Zhu, 2012), we focus our substantive interpretations on the standardized effect sizes of parameters.

Results

Descriptive statistics are presented in Table 1. Overall, children scored in the typical range for visual-motor integration and object manipulation skills for their age. Executive function scores are also similar to those observed in prior research with this age group. Although scores showed some nonnormality, they did not meet extreme skewness and kurtosis values (Kline, 2005). Average scores for teacher-rated social behavior show that children "*often*" exhibited self-control and cooperation, and "*seldom*" exhibit externalizing/ hyperactivity although substantial variability was observed in all social behavior outcomes. Bivariate analysis revealed statistically significant correlations among motor skills, executive function, and social behavior that ranged in size from low (e.g., between fall object manipulation and spring externalizing/hyperactivity) to moderate (e.g., between fall visual-motor integration and spring executive function), according to Zhu (2012), see Table 2.

Effect of visual-motor integration skills on executive function

Along with demographic controls, children's fall visual motor integration and object manipulation skills explained 45.56% of the variance in children's spring executive function. Children's visual motor integration skills assessed in fall had a statistically significant modest association, (B = .47 [.20], $p < .05$, β = .27) with their executive function scores assessed in the spring after controlling for covariates (Model 1, Table 3). One standard deviation from the mean in visual-motor integration skills was associated with approximately ¼ of a standard deviation in executive function. This effect size was similar to the size of the effect of Head Start status (a marker for family income and education). The unstandardized effect shows that a one-unit increase in visual-motor integration (which had a mean of 131 and a range from 96-144) was associated with nearly a half-unit increase in executive function (which had a mean of 25 and a range from 0-59). Once we included children's levels of executive function in the fall, which had a strong effect, (B = .59 [.09], $p < .01$, β = .60), the total explained variance in spring executive function increased to 65.57% (roughly 20% more variance explained than without fall executive function). However, visual-motor integration skills no longer had a statistically significant relation with executive function and the effect size dropped to $\beta = .10$ (Model 2, Table 3). In other words, visual-motor integration skills in the fall of preschool had a statistically significant relation with children's executive function level in the spring, but did not have a statistically significant relation with change in executive function during the preschool year.

Effect of object manipulation on social behavior

Along with demographic controls, children's fall visual motor integration and object manipulation skills explained 23.95% of the variance in children's spring self-control, 37.10% of the variance in children's spring cooperation, and 25.34% of the variance in children's spring externalizing/hyperactivity. Children who demonstrated better object-manipulation skills in the fall had statistically significant better social behavior in their preschool classrooms in the spring including more self-control ($B = .03$ [.01], $p < .001$, $\beta = .44$), more cooperation ($B = .02$ [.01], $p < .01$, $\beta = .33$), and less externalizing/hyperactivity ($B = -.02$ [.01], $p < .01$, $\beta = -.31$; Model 1, Table 4). One standard deviation from the mean in object manipulation skills was associated with approximately one-third of a standard deviation in each of the social behaviors. The unstandardized effects are quite small because a one-unit increase in object manipulation (which has a mean of 38, range from 12-48) represents very little change, in comparison to a one unit change in social behavior, which have means of 1-2 (ranges from 0-3).

The explained variance increased in each model once controlling for children's fall social behavior (i.e., 42.89% of the variance explained for self-control, 54.32% of the variance explained for cooperation, and 33.07% of the variance explained for externalizing/hyperactivity). Notably though, the effects for object manipulation remained similar in magnitude and statistical significance (Model 2, Table 4). Furthermore, they were similar in size to the effects of the fall measurement of social behaviors on the outcomes, and thus illustrate their meaning in understanding children's social behaviors. In other words, children's object-manipulation skills had statistically significant relations with change in teacher-rated social behaviors over the preschool year. Social behaviors were relatively stable between fall and spring (β ranging from .25 for externalizing/ hyperactivity to .49 for emotional aspects of self-control). Object manipulation skills assessed in fall had modest effects on change in social behavior over the preschool year (β ranged from -.28 for externalizing/hyperactivity to .40 for self-control) after controlling for all covariates (Model 2, Table 4).

Post-hoc analysis

In addition to our primary analysis, we conducted a post-hoc analysis to test whether our findings held when also controlling for children's fall executive function in the models predicting social behavior outcomes, and controlling for children's fall social behaviors in the models predicting executive function. All variables included in the models presented in Tables 3 and 4 were also included in these post-hoc analyses. All previously reported significant findings from our original analyses (Tables 3 and 4) remained significant with the new paths included. The only statistically significant new effect identified in the post-hoc analyses was that children with better executive function skills in the fall of preschool had fewer externalizing/hyperactivity behaviors in the spring of preschool holding all other variables constant (B = -.01 [.00], $p < .05$, $\beta = -.20$). Moreover, fall executive function was associated with a 3.52% increase in explained variance for externalizing/hyperactivity (i.e., explained variance in model with executive function – explained variance in model without executive function).

Discussion

This study found that preschool children's visual motor integration skills are associated with their executive function, and that their object manipulation skills are linked with social behaviors. This would support the concept that these specific motor skills play a role in school readiness competencies. These results partially support our first hypothesis, namely that children's visual motor integration skills, and not object manipulation, assessed upon entering preschool had significant relations with children's executive function at the end of their first academic year, but not with change in executive function over the year. Our second hypothesis was fully supported, showing that children's object manipulation skills, and not visual motor integration skills, assessed upon entering preschool had significant relations with children's social behaviors near the end of their first academic year, as well as with change in social behavior during the preschool year. These findings add to a growing body of evidence linking aspects of children's motor skills with executive function and social behaviors (Becker, et al., 2014; Carlson, et al., 2013; Pagani & Messier, 2012).

Visual-motor integration skills and executive function

Our study examined the relationship between visual motor integration skills and executive function over the course of one preschool year. Although we recognize that visual-motor integration skills and executive function likely develop reciprocally, the current study focused on one aspect of this reciprocal relationship: the contributions of early developing visual motor-integration skills to more complex executive function later during the preschool year. This focus was based on the theoretical framework of learning to learn, which postulates that motor skills form the foundation for early learning (Adolph, 2005). Subsequently, we utilized a measure of visual-motor integration skills designed to include early developing skills and a measure of executive function (HTKS) requiring more advanced integration of attention, working memory, and inhibition. Although visual motor integration skills did not have strong relations to change in executive function over the preschool year, individual differences in visual motor integration skills early during the preschool year (average age 4.3 years) had significant relations to executive function approximately 5 months later. Combined with recent evidence of a concurrent effect of executive function on visual-motor skills at age 5.7 years (Becker, et al., 2014), this suggests that visual motor skills lay the foundation for the development of executive function skills.

However, it is important to note that research has not generally shown a direct contribution of visual-motor integration to developmental changes in executive function over time, or vice versa. Neither Becker and colleagues' cross sectional study (2014) nor our analysis detected an effect of visual-motor integration skills on executive function when controlling for baseline levels of executive function. This lack of an association between visual-motor integration skills on *change* in children's executive function over the preschool year *could* be attributable to the stability in the executive function scores from fall to spring where a very moderately high correlation was observed (.77), and possibly due to the short time frame between assessments (approximately 5 months). In addition, it is possible that aspects of the processes involved in visual motor integration skills and aspects of the processes involved in executive function overlap. For example, aspects of the HTKS task may tap into visual motor skills like coordinating movements to touch the toes. Although the HTKS is capable of measuring change over the preschool period, 37% and 15% of children had scores of zero on this measure in the fall and spring, respectively. Future studies that seek to understand the contribution of visual-motor integration skills to changes in children's executive functioning should use longer spans of time between repeated assessment periods.

Object-manipulation skills and social behaviors

Social behaviors, including cooperation, emotional aspects of self-control and avoidance of externalizing behaviors are important to a healthy transition into school, as well as to motivation, involvement in learning, and relationships with peers and teachers (Bulotsky-Shearer, et al., 2010; Whittaker & Harden, 2010). This study observed that children's object-manipulation skills have strong relations with development of positive social skills (cooperation, emotional aspects of self-control) and avoidance of negative behaviors (externalizing/hyperactivity) in preschool classrooms. These findings have implications for school readiness initiatives. The relations of object manipulation skills to decreasing externalizing behavior helps explain possible mechanisms in the development of social behaviors and offers a novel perspective for potential interventions. Most efforts to promote positive, or decrease negative, social behaviors have directly targeted children's interactions with parents, teachers, and peers. The findings from this study and other researchers suggest that the gross motor skills that young children used in active play are also important to their social behaviors in the classroom. Future research could investigate whether adding an object manipulations component (e.g., kickball, playing catch) to existing social skills interventions in preschools could augment intervention effects. The current study was not able to examine reciprocal associations among object manipulation skills and social behaviors due to limitations in measurement, but did find an effect of object manipulation on social behaviors even after controlling for earlier social behaviors, and for executive function. Subsequently, future research should examine reciprocal associations between object manipulation skills and social behavior since children who have positive strong social behaviors may be included by peers in more gross motor games and activities, which could in turn contribute to refinement of motor skills.

Additionally, future research should further investigate the potential contributions of executive function to specific social behaviors, such as the link with externalizing/hyperactivity identified in our post hoc analysis. It would be important to know if children's object manipulation skills and executive function might combine to jointly explain even more variance in their social behaviors. For example, it could be that a solid grasp of object manipulation skills are particularly helpful in the development of social behaviors for children who struggle with executive function.

Limitations

There are several limitations worth noting. The sample was relatively small (n= 92), which limits statistical power and there was limited ethnic diversity (80% white), which decreases the generalizability of findings. Despite data collection in the fall and spring of the preschool year, there was an average of only 5 months between assessment periods, and there was no longer-term follow-up in this study (i.e., assessment beyond the preschool year). In addition analyses and study design did not allow for reciprocal development to be tested. Future research with longer periods of time between assessments, reciprocal analyses (e.g., executive function predicting visual motor integration skills and vice versa) and with follow-up during the transition into kindergarten will be important for refining our understanding of associations among specific motor skills and children's development of executive function and social behavior. Future research should also utilize multiple measures of executive function and motor skills to better assess these skills in young children.

Implications and Conclusions

Overall, the present study advances our understanding of relations among visual motor integration skills and object manipulations skills and aspects of children's school readiness executive function and social behaviors. Our results suggest that visual motor integration skills help to explain individual differences in children's executive function, and that object-manipulation skills have meaningful relations with changes in social behavior during the preschool year. This level of specificity is important to advancing our understanding of children's development and lays a critical foundation for future examination of strategies to promote school readiness. Although more research is needed, this study suggests that visual motor integration and object manipulation skills play a role in children's school success and school readiness efforts (i.e. Preschool for All initiatives, Race to the Top: Early Learning Challenge, etc.).

What does this article add?

Emerging evidence indicates that motor skills are important to children's development of self-regulation, social behaviors and ultimately school-readiness; however specific aspects of motor skills and the mechanisms most salient in these relationships are relatively unknown. The findings of this study indicate that early visual motor integration skills are linked to later executive function skills of preschool aged children although visual motor integration skills were not related to change in executive function over the preschool year. Our findings also indicated that object manipulations skills, are important in change in social behaviors over the course of a preschool year. Although more work is needed to further investigate these relationships, the findings of this study provide initial insight into the potential role of these skills in school readiness initiatives.

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Table 1

Descriptive Statistics

Variables	*N*	%Male	%Female		
Child gender	92	64	36		
		%Yes	%No		
Head Start Status	91	21	79		
	N	*M*	*SD*	Min	Max
Child age in years (fall)	88	4.31	0.68	3.12	5.75
Child age in years (spring)	83	4.73	0.69	3.41	6.21
Motor skills (fall)					
Visual-motor	87	130.92	11.04	96	144
Object manipulation	87	37.55	7.82	12	48
Self-regulation (fall)	89	19.20	20.10	0	60
Self-regulation (spring)	86	25.19	19.51	0	59
Teacher-rated social behavior					
Self-control (fall)	88	1.71	0.60	0.14	3
Self-control (spring)	81	1.94	0.56	0.29	3
Cooperation (fall)	89	1.94	0.60	0.67	3
Cooperation (spring)	81	1.97	0.57	0.83	3
Externalizing/ hyperactivity (fall)	89	0.81	0.50	0	2.07

Table 2

Bivariate Correlations for all Predictors, Outcomes, and Covariates

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Gender [a]	—													
2. Age (spring)	-.07	—												
3. Head Start status[b]	.02	.07	—											
4. Site	-.02	-.25†	-.34†	—										
5. Visual-motor (fall)	-.14	.73**	-.15	-.01	—									
6. Object manipulati on (fall)	-.02	.53*	-.04	-.12	.64**	—								
7. Executive function (fall)	-.11	.61**	-.07	-.17	.57*	.46*	—							
8. Externalizing/hyperactivity (fall)	.21†	-.10	.12	-.08	-.22†	-.25†	-.36†	—						
9. Cooperation (fall)	-.26†	.31†	-.06	.11	.38†	.32†	.38†	-.79**	—					
10. Self-control (fall)	-.16	.40*	-.29†	-.14	.43*	.33†	.50*	-.54*	.61**	—				
11. Executive function (spring)	-.13	.56*	-.20†	-.21†	.56*	.42*	.77**	-.26†	.31†	.44*	—			
12. Externalizing/ hyperactivity (spring)	.39†	-.05	.14	.03	-.15	-.23†	-.23†	.55*	-.53*	-.40*	-.31†	—		
13. Cooperation (spring)	-.49*	.22†	-.01	-.04	.34†	.37†	.31†	-.62**	.69**	.45*	.30†	-.78**	—	
14. Self-control (spring)	-.19	.15	-.12	.14	.27†	.37†	.27†	-.55*	.59*	.54*	.34†	-.72**	.71**	—

[a]0 = male,1 = female; [b]0 = no, 1 = yes

†*Low correlation*, **Moderate correlation*, ***Moderately high correlation* (based on Zhu, 2012)

Table 3

Effect of visual-motor (fine motor) skills on executive function in the spring of the preschool year.

(N = 92)

	Model 1	Model 2
	B (SE) *β*	*B* (SE) *β*
Covariates		
Gender [a]	-2.61 (3.77) -.06	-2.57 (2.69) -.06
Age (spring)	8.09 (4.41) .29†	2.18 (3.96) .08
Site [c]	-9.11 (4.00) -.21*	-5.05 (3.78) -.12
Head Start status [b]	-13.44 (4.39) -.28**	-10.81 (3.78) -.23*
Children's scores in the fall		
Executive function		0.59 (0.09) .60**
Object manipulation	0.14 (0.22) .06	0.07 (0.20) .03
Visual-motor integration	0.47 (0.20) .27*	0.18 (.26) .10

[a] 0 = female, 1=male; [b] 0 = not Head Start, 1 = Head Start; [c] 0 = site 1, 1= site 2
Note. *B* = Unstandardized Estimate. *SE* = Standard Error. *β* = Standardized Estimate.
†p < .10. *p < .05. **p < .01.

Table 4

Effects of object manipulation (gross motor) skills on social behavior outcomes in the spring of the preschool year (N = 92)

	Social Behavior Outcomes					
	Model 1			Model 2		
	Self-control *B* (*SE*) β	Cooperation *B* (*SE*) β	Externalizing/ Hyperactivity *B* (*SE*) β	Self-control *B* (*SE*) β	Cooperation *B* (*SE*) β	Externalizing/ Hyperactivity *B* (*SE*) β
Covariates						
Gender [a]	-0.22 (0.12) -.19†	-0.56 (0.11) -.47**	0.43 (0.09) .40**	-0.16 (0.10) -.14	-0.47 (0.09) -.42**	0.39 (0.10) .38**
Age (Spring)	-0.02 (0.12) -.03	-0.03 (0.10) -.04	0.09 (0.12) .13	-0.07 (0.10) -.09	-0.03 (0.09) -.04	0.05 (0.11) .08
Site [c]	0.25 (0.18) .21	-0.01 (0.09) .01	0.05 (0.15) .05	0.43 (0.18) .37*	-0.03 (0.08) -.03	0.04 (0.14) .03
Head Start status [b]	-0.09 (0.18) -.06	-0.04 (0.15) -.03	0.22 (0.14) .17	0.14 (0.14) .11	-0.02 (0.11) -.01	0.18 (0.13) .15
Children's scores in the fall						

Baseline of outcome				0.45 (0.09) .49**	0.37 (0.07).41**	0.25 (0.11) .25*
Object manipulation	0.03 (0.01) .44**	0.02 (.01) .33**	-0.02 (.01) -.31**	0.03 (0.00) .40**	0.02 (.01) .28**	-0.02 (.01) -.28**
Visual-motor integration	-0.00 (0.01) -.03	0.00 (.01) .07	0.00 (.01) .04	-0.01 (0.01) -.15	-0.00 (.01) -.03	0.00 (.01) .10

[a] 0 = female, 1=male; [b] 0 = not Head Start, 1 = Head Start; [c] 0 = site 1, 1= site 2

Note. *B* = Unstandardized Estimate. *SE* = Standard Error. β = Standardized Estimate.

[†] $p < .10$. * $p < .05$. ** $p < .01$.