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Physical Activity, Self-Regulation, and Early Academic Achievement in Preschool Children

Derek R. Becker and Megan M. McClelland
Human Development & Family Sciences, Oregon State University

Paul Loprinzi
Exercise and Sport Science, Bellarmine University

Stewart G. Trost
School of Human Movement Studies, The University of Queensland

Research Findings: The present study investigated whether active play during recess was associated with self-regulation and academic achievement in a prekindergarten sample. A total of 51 children in classes containing approximately half Head Start children were assessed on self-regulation, active play, and early academic achievement. Path analyses indicated that higher active play was associated with better self-regulation, which in turn was associated with higher scores on early reading and math assessments. *Practice or Policy:* Results point to the benefits of active play for promoting self-regulation and offer insight into possible interventions designed to promote self-regulation and academic achievement.

Recently, numerous studies have focused on the beneficial effects of physical activity on various aspects of cognition, showing that physical activity can improve both working memory (McMorris, Sproule, Turner, & Hale, 2011; Niederer et al., 2011) and attention (Chaddock, Erickson, Prakash, VanPatter, et al., 2010; C. L. Davis et al., 2011). The benefits of physical activity have also been found to extend into the classroom, with both physical activity and physical fitness showing a positive connection with academic achievement (Centers for Disease Control and Prevention, 2010; Donnelly & Lambourne, 2011). Although working memory and attention are strong predictors of academic achievement, self-regulation, which integrates working memory, attention, and inhibitory control, has been found to predict both early (Evans & Rosenbaum, 2008; McClelland et al., 2007) and long-term (McClelland, Acock, Piccinin, Rhea, & Stallings, 2013) academic success. Moreover, the component skills that form the construct of self-regulation are crucial for developing the habits and behaviors that carry children through a successful academic career. Although the primary components that make up self-regulation are linked to physical activity (Campbell, Eaton, & McKeen, 2002; C. L. Davis et al., 2011;

Correspondence regarding this article should be addressed to Derek R. Becker, 410 Waldo Hall, Oregon State University, Corvallis, OR 97331. E-mail: beckerde@onid.orst.edu

Niederer et al., 2011), little research has investigated the association between physical activity, self-regulation, and early academic achievement.

Physical activity can take many forms throughout the life span, and play is the primary means by which physical activity is achieved in early childhood (Burdette & Whitaker, 2005). Following the inception of No Child Left Behind (U.S. 107th Congress, 2002), the time devoted to recess has been on the decline (Center on Education Policy, 2008), with more focus given to meeting standardized requirements for mathematics and reading. The need for evidence-based practice in elementary education prompts a closer look at whether a reduction in recess is beneficial during the early school years. Given that a number of studies have demonstrated that physical activity (e.g., Donnelly & Lambourne, 2011) and self-regulation (e.g., McClelland & Cameron, 2012) are associated with academic achievement, the present study examined connections between active play, self-regulation, and achievement in a sample of preschool children.

Self-Regulation and Academic Achievement

In most preschools, physical and cognitive activities are a normative part of the curriculum, and it is within these early years that children are asked to exhibit some level of self-regulation for the first time. It is here where children are asked to shift from movement to focused attention, complete activities, and inhibit prepotent actions. These actions require fairly sophisticated cognitive processing that taps brain systems involved in both motor control and self-regulation (Diamond, 2000; Salmi et al., 2010).

Within a wide range of ages, self-regulation has consistently been linked to academic achievement. For example, self-regulation has predicted better school outcomes in prekindergarten and grade school (Evans & Rosenbaum, 2008; Howse, Calkins, Anastopoulos, Keane, & Shelton, 2003; McClelland et al., 2007), high school (Pagani et al., 2008), and college (McClelland , Acock, Piccinin, Rhea, & Stallings, 2013). Indeed, self-regulation is an important component of academic success, as it involves inhibition, working memory, and attention (McClelland & Cameron, 2012). We define *self-regulation* as the integration of these three key actions (i.e., inhibitory control, working memory, attention) and assess connections between self-regulation and active play.

The Definition of Physical Activity in Early Childhood

Physical activity is defined as any bodily movement produced by skeletal muscles that results in energy expenditure (Caspersen, Powell, & Christenson, 1985). Within the early developmental years, the physical activity of children may be more appropriately described as locomotor play or active play (Pellegrini & Smith, 1998). Active play increases from the toddler to the preschool period and then declines during the elementary school years, with a peak at around 4 to 5 years of age. Observational studies conducted in child care settings suggest that active play accounts for about 10% of all day care behavior (Brown et al., 2009). In the present study, we define *active play* as play that incorporates movement at a moderate to vigorous intensity (e.g., brisk walking and running) and assess whether a child's level of active play is associated with both self-regulation and academic achievement.

Self-Regulation, Active Play, and Academic Achievement

There is growing evidence to support links between physical activity, self-regulation, and school achievement. These connections emerge at the level of basic processing, with the body and brain working together to understand and interpret the world. This is demonstrated conceptually through embodied cognition, which links the mind to the physical body, arguing that the mind taps into perceptual and motor resources to represent and manipulate information. This theory postulates that the body and neural substrates underlying the motor system play a role in language comprehension (Fischer & Zwaan, 2008), memory (Barsalou, 1999), problem solving (Boncoddo, Dixon, & Kelley, 2010), and self-regulation (Balcetis & Cole, 2009). Within the framework of embodied cognition, mental processes are facilitated through the body's interactions with the physical world, offering insight into how physical activity could facilitate self-regulation.

Self-regulation involves a complex interaction between inhibitory control, attentional control, and working memory, actions that have been linked to coupling between movement, the body, and cognition. For example, Boncoddo et al. (2010) found that preschoolers who combined physical movements with verbalizations as they solved a complex problem showed a deeper understanding of cause and effect. In a separate study, children who gestured during the explanation of a math problem showed enhanced learning on subsequent problems (Broaders, Cook, Mitchell, & Goldin-Meadow, 2007). In an older sample, Wartenburger et al. (2010) found that adolescents with higher fluid intelligence displayed more representational hand and arm gestures when describing a geometric task and showed greater cortical thickness in the left pars opercularis, superior frontal cortex, and temporal cortex.

Although movement is not necessary during higher level cognition, these studies show that cognition may be enhanced through movement by connecting motions and gesticulations with problem solving, learning, and intelligence. Because problem solving, learning, and intelligence require self-regulation (i.e., inhibitory control, attention, working memory), it is possible that active play could promote self-regulation. Furthermore, physical activity has been shown to improve aspects of working memory (McMorris et al., 2011) and attention (Chaddock, Erickson, Prakash, VanPatter, 2010), which are skills involved in self-regulation. Given that self-regulation is consistently linked to academic achievement (McClelland et al., 2007; McClelland et al., 2013; Pagani et al., 2008), active play could be linked to achievement via two paths: a direct path, with active play promoting skills leading to academic success; and an indirect path, with self-regulation mediating connections between active play and achievement. In the present study we examined both possibilities.

Connections Between Physical Activity, Movement, and Self-Regulation

Both animal and human studies show that typical, chronic, and acute exercise enhances memory, inhibitory control, and executive functions, skills associated with self-regulation. Animal studies investigating molecular and cellular changes following exercise have shown increased proliferation and survival of hippocampal neurons (Eadie, Redila, & Christie, 2005) and the upregulation of both brain-derived neurotrophic factor and vascular endothelial-derived growth factor (Cotman & Berchtold, 2002; Cotman, Berchtold, & Christie, 2007), which are linked to enhanced memory storage. Functional magnetic resonance imaging studies with children have shown that exercise increases activation in the prefrontal cortex (C. L. Davis et al., 2011) and is associated with greater dorsal striatal (Chaddock, Erickson, Prakash, Kim, et al., 2010) and hippocampal (Chaddock, Erickson, Prakash, VanPatter, et al., 2010) volume. Given that activation in the frontal cortex is linked to self-regulatory behaviors (Wagner & Heatherton, 2011), including inhibitory control (van Gaal, Ridderinkhof, Fahrenfort, Scholte, & Lamme, 2008; van Gaal, Ridderinkhof, Scholte, & Lamme, 2010) and working memory (Weerda, Muehlhan, Wolf, & Thiel, 2010), it is possible that higher levels of physical activity are related to stronger self-regulation.

Physical Activity, Physical Fitness, and Academic Achievement

Although the association between active play and early achievement has not been extensively examined, research investigating physical activity and physical fitness has observed positive connections between fitness levels and academic achievement (Smith & Lounsbery, 2009; Trudeau & Shephard, 2008). Experimental training studies with elementary and middle school students have demonstrated that children who participate in more vigorous activity achieve higher grades (Donnelly et al., 2009; Donnelly & Lambourne, 2011) and math achievement (C. L. Davis et al., 2011). In addition, higher levels of aerobic fitness have been linked to higher math and reading achievement in grade school students (Castelli, Hillman, Buck, & Erwin, 2007; Eveland-Sayers, Farley, Fuller, Morgan, & Caputo, 2009) and to higher grades and achievement in adolescent samples (Kwak et al., 2009; Ruiz et al., 2010). Yet the relationship between active play and academic achievement has not been extensively explored in preschool children, which is the focus of the present study.

Self-Regulation Mediating the Path from Active Play to Achievement

Research supports a positive link between active play that requires a high level of energy expenditure and synaptic growth in brain systems associated with self-regulation and academic achievement (C. L. Davis et al., 2011; van Gaal et al., 2010). However, even if synaptic growth is linked to active play, and this co-occurs with the development of self-regulation, these changes might not directly link to achievement in the early years. For example, evidence suggests that early socialization plays a large role in predicting achievement in prekindergarten children (Lee, Autry, Fox, & Williams, 2008). Thus, it is possible that active play could work via two paths: a direct path from active play to achievement, and an indirect path from active play to achievement through self-regulation. Thus, it is possible that active play significantly predicts academic achievement through strong self-regulation in young children.

Summary and Hypotheses

In the present study, we assess four research questions. First, we examine whether children's level of active play is significantly related to their self-regulatory skills. Based on previous research (e.g., Campbell et al., 2002; Hill et al., 2010; Niederer et al., 2011), we hypothesize that higher activity levels will be positively and significantly associated with higher levels of self-regulation. Second, we examine the direct connection between level of active play and academic achievement. Although several studies have shown that higher levels of physical activity are associated with greater achievement (C. L. Davis et al., 2011; Kristjánsson, Sigfúsdóttir, & Allegrante, 2010), little research has investigated the link between active play and achievement in younger samples. Consistent with previous work, we hypothesize that active play will be positively associated with both reading and math achievement scores. Third, we expect that self-regulation will be significantly related to academic achievement based on previous research with preschool children (e.g., Blair & Razza, 2007; McClelland et al., 2007) that has shown that strong self-regulation is related to better emergent literacy and math scores. Fourth, we examine whether self-regulation significantly mediates relations between active play and academic achievement. We anticipate that more active play will be related to stronger self-regulation, which will significantly predict stronger academic achievement in preschool children. In all analyses, we control for Head Start status and child age, as these variables have been found to relate significantly to self-regulation and achievement outcomes (Evans & Rosenbaum, 2008; Wanless, McClelland, Tominey, & Acock, 2011).

METHODS

Participants

Participants included 51 children attending preschool in a university child development center in Oregon. Children were sampled from a single center with multiple classrooms ($n = 3$), with approximately half of the children from low-income families as measured by enrollment in Head Start ($n = 25$). After attrition, 16 of the 25 children enrolled in Head Start, comprising 31% of the total sample, participated in Phase 2 of the study. The average age at the beginning of the study was 57.8 months (range = 46–70 months). A total of 22 of the children were female, and 29 were male. Mothers of children enrolled in Head Start had an average education level of 11.6 years ($SD = 2.8$). Mothers of children who were not enrolled in the Head Start program had an average education level of 16.3 years ($SD = 4.3$). Ten of the children had Spanish as a first language and were administered the tests in Spanish by a native Spanish speaker. Placement in the center is available to children who pay tuition and is also available at no cost to children enrolled in Head Start. Both Head Start and non–Head Start children were in the same classrooms and thus experienced the same quality of care.

Measures and Materials

Active play. Objective assessments of active play were obtained using the ActiGraph GT1M accelerometer (ActiGraph Corporation, Pensacola, FL). The ActiGraph is a small (3.8 × 3.7 × 1.8 cm), lightweight (27 g) accelerometer designed to detect vertical accelerations ranging in magnitude from 0.05 to 2.00 g, with a frequency response of 0.25–2.50 Hz. These parameters allow for the detection of normal human motion. The acceleration signal is digitized at a rate of 30 Hz and filtered, rectified, and integrated through a user-specified interval called an *epoch*. At the end of each epoch, the summed value, or activity count, is stored in memory and the integrator is reset. Because the 1-min epoch typically used for accelerometry may mask the intermittent activity patterns of young children, a 15-s epoch was used (Trost, McIver, & Pate, 2005). The ActiGraph is the most widely used accelerometer in pediatric research (Trost, 2007) and has been shown to be a valid and reliable tool for quantifying physical activity in preschool children (Pate, O'Neill, & Mitchell, 2010; Sirard, Trost, Pfeiffer, Dowda, & Pate, 2005).

At the beginning of each outdoor recess session, a research assistant attached an ActiGraph accelerometer to each child's right hip via an adjustable elastic belt. At the completion of recess the research assistant removed the accelerometer and transported it back to the laboratory for data downloading and storage. Stored activity counts were uploaded to a customized Excel visual basic macro for the determination of time spent in moderate to vigorous physical activity, which was called *active play*. Counts were classified using the intensity-related cutpoints developed by Pate, Almeida, McIver, Pfeiffer, and Dowda (2006).

Measure of Self-Regulation

Head–Toes–Knees–Shoulders task (HTKS). The HTKS was used to assess children's self-regulation (Cameron Ponitz, McClelland, Matthews, & Morrison, 2009). In this task, children are asked to touch their head or toes (or knees/shoulders in the alternate version) and are then asked to do the opposite of what the experimenter says. For example, the experimenter instructs children to touch their head when asked to touch their toes. There are two parts to the task: Part 1 includes two paired commands (head/toes or knees/shoulders), and children touch their toes when asked to touch their head and touch their head when asked to touch their toes). Part 2 includes four paired commands (head/toes, knees/shoulders). The possible score for each item is 0, 1, or 2: 0 denotes an incorrect response, 1 is a self-correct (motion toward the incorrect response, but the child stops and gives the correct response), and 2 points are given if a child gives the correct response without a movement toward the incorrect response. There are 20 test items and scores range from 0 to 40, with higher scores indicating higher levels of behavioral regulation. Recent research has shown that the HTKS is a reliable and valid measure of children's behavioral self-regulation in diverse populations (Cameron Ponitz et al., 2008, 2009; McClelland et al., 2007; Wanless, McClelland, Acock, 2011).

Academic Outcomes

Emergent literacy achievement. Children's letter skills and developing word-coding skills in English or Spanish were assessed using *W* scores from the Letter-Word Identification subtest of the Woodcock–Johnson Psycho-Educational Battery–III Tests of Achievement (Woodcock & Mather, 2000) or the Batería III Woodcock–Muñoz (Muñoz-Sandoval, Woodcock, McGrew, & Mather, 2005). Previous research has shown high reliability for preschool-age children on both the English and Spanish versions of the task (Schrank, 2005; Woodcock & Mather, 2000).

Math achievement. Early mathematical operations needed to solve practical problems, including counting objects, reading numbers, and basic addition and subtraction picture-problems, were measured using the Applied Problems subtest of the Woodcock–Johnson Psycho-Educational Battery–III Tests of Achievement (Woodcock & Mather, 2000) or the

Batería III Woodcock–Muñoz (Muñoz-Sandoval et al., 2005). In previous research, both the English and Spanish versions of the task demonstrated strong reliability for preschool-age children, at .94 and .93, respectively (Schrank et al., 2005; Woodcock & Mather, 2000).

Procedure

In the fall of the prekindergarten year (September), an invitation to participate in the study was extended to parents with a child attending the participating preschool. Consent forms were collected from 51 families. The study was divided into two phases: Phase 1 (January–February) and Phase 2 (April–May). Given the amount of rainfall experienced in western Oregon, April and May are optimal months for collecting data involving outdoor play.

During Phase 1, children's behavioral self-regulation and academic outcomes were assessed over 4 weeks. Children received the assessments in two short sessions (5–10 min) to prevent fatigue, and the order of assessments was randomized. In Phase 2, active play was measured during a 30-min outdoor play session. Prior to the start of the study children were told that the accelerometer would record their movement. The accelerometer provided no feedback to the children, and levels of physical activity have not been influenced by this method in the many studies that have used this procedure to assess physical activity. Before each play session, height and weight measurements were taken for each child. Next accelerometers were attached to the child's waist and a stopwatch recorded the exact time of placement. The child was allowed to play freely for the 30-min outdoor session.

ANALYTIC PLAN

Unadjusted associations among the primary variables were examined via bivariate correlations. Data analyses were run using Mplus Version 6.12 (Muthén & Muthén, 2010). Path analysis was used to evaluate self-regulation as a mediator between active play and academic achievement. The initial model included (a) a direct path from active play to the HTKS, (b) direct paths from the HTKS to academic achievement, and (c) direct paths from active play to academic achievement. Prior to the analysis, all variables were examined separately for accuracy of data entry and missing values, with the assumption of univariate analysis assessed. No outliers were found using a Z score greater than ± 3. For the achievement data, W scores were analyzed, which were developed with Rasch-based measurement models to create equal-interval scale characteristics and are useful for examining achievement scores within a year (Woodcock & Mather, 2000).

RESULTS

Descriptive Statistics and Preliminary Analyses

Data analyses for the present study included child gender, child age, Head Start status, a measure of self-regulation (HTKS), moderate to vigorous physical activity (i.e., active play), and emergent literacy and math achievement scores. Because of attrition, the sample size decreased from 51 at Phase 1 to 37 at Phase 2. In order to maximize power and deal appropriately with the missing data, we analyzed our data using full information maximum likelihood estimation in Mplus. Full

TABLE 1
Means and Standard Deviations for Predictor and Outcome Variables ($N = 51$)

Variable	*M*	*SD*	*Range*
Head–Toes–Knees–Shoulders task	16.62	14.22	0–37
Active play in minutes	8.17	4.30	0–16
Mathematics *W* score	441.14	23.47	363–453
Emergent literacy *W* score	346.36	39.99	276–467
Child age in months	57.78	4.79	46–70

Note. Possible scores for the Head–Toes–Knees–Shoulders task range from 0 to 40.

information maximum likelihood estimation utilizes all available information and has been shown to produce less biased estimates than listwise deletion (Acock, 2012; Enders, 2001).

Prior to the analyses, we ran a series of *t* tests to check for gender differences on active play (moderate to vigorous physical activity), the measure of self-regulation (i.e., HTKS), and the two measures of achievement. No significant differences were found on any of the study variables. Thus, group means and standard deviations were combined for boys and girls (see Table 1), with bivariate correlations displayed in Table 2.

As can be seen in Table 2, active play was positively correlated at .46 with the HTKS self-regulation measure and positively correlated at .16 with math achievement. At the same time, active play was unrelated to emergent literacy achievement. Age was positively correlated with active play and HTKS scores, whereas Head Start status was inversely correlated with the two measures of achievement and self-regulation (see Table 2). Thus, age and Head Start status were included as control variables in all path models.

Relations Between Active Play, Self-Regulation, and Academic Achievement

The initial path model with all paths specified showed good model fit, $\chi^2(3) = 2.359$, $p = .501$, comparative fit index = 1.00, Tucker–Lewis index = 1.047, root mean square error of approximation = .00 (see Figure 1). For the first research question, path estimates revealed that active play was positively and significantly related to the HTKS self-regulation task ($\beta = .43$, $p = .001$). The second research question assessed whether active play significantly predicted

TABLE 2
Bivariate Correlations Between Predictor and Outcome Variables ($N = 51$)

Variable	*1*	*2*	*3*	*4*	*5*	*6*
1. Head Start status	—					
2. Head–Toes–Knees–Shoulders task	.35*	—				
3. Active play	.07	.46**	—			
4. Math	.51**	.51**	.16	—		
5. Emergent literacy	.34**	.39*	−.055	.48**	—	
6. Child age	−.20	.36*	−.09	.10	.20	—

*$p < .05$. **$p < .01$. All tests are two-tailed.

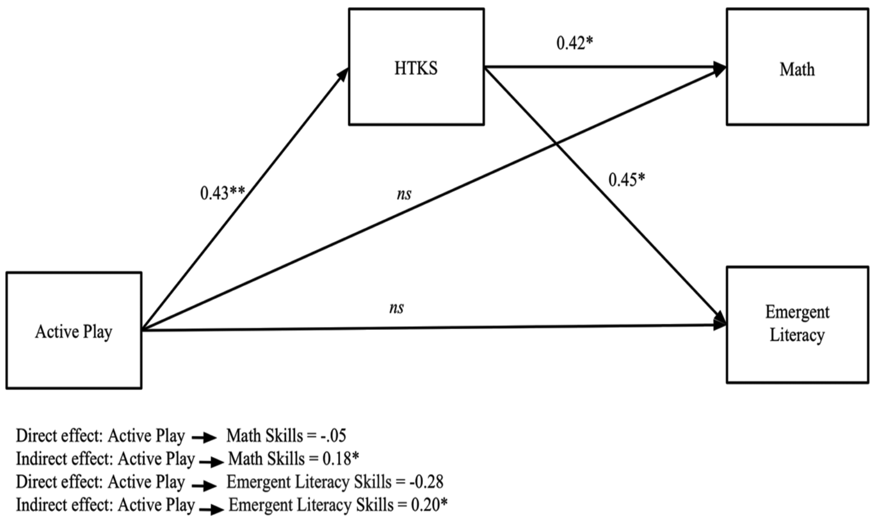

FIGURE 1 Path model showing direct and indirect effects of active play on math and emergent literacy through self-regulation. Head Start status, measurement errors, correlations between endogenous outcome variables, and non-significant paths between active play and math and emergent literacy are not included in model for clarity of presentation. HTKS = Head–Toes–Knees–Shoulders task. $^{*}p < .05$. $^{**}p < .01$.

emergent literacy and math achievement scores. Path estimates revealed that active play did not significantly predict math ($\beta = -.05$ $p = .718$) or emergent literacy ($\beta = -.28$, $p = .062$) scores.

The third research question examined the direct effect of self-regulation on academic achievement, showing that stronger HTKS scores were related to stronger emergent literacy ($\beta = .45$, $p = .002$) and math ($\beta = .42$, $p = .002$) scores after Head Start status ($\beta = .44$, $p = .000$) and child age ($\beta = .44$, $p = .000$) were controlled for.

The final research question examined whether self-regulation significantly mediated relations between active play and academic achievement. Results indicated that there was a significant indirect effect between active play and math scores through children's self-regulation (on the HTKS; $\beta = .18$, $p = .03$) and a significant indirect effect between active play and emergent literacy through self-regulation ($\beta = .20$, $p = .035$). These results indicate that more active play was related to stronger self-regulation on the HTKS, which was then related to stronger math and emergent literacy achievement.

DISCUSSION

This study examined whether higher levels of active play in preschool significantly predicted self-regulation and performance on literacy and math achievement and whether self-regulatory skills significantly mediated the relationship between active play and achievement. Several significant direct and indirect effects emerged from this study. In support of our first hypothesis, we found a significant direct effect between active play and performance on the HTKS, with higher levels of active play predicting better self-regulation. However, contrary to our second hypothesis, higher levels of active play were not significantly related to emergent literacy or math skills. We found support for the third hypothesis, with children who performed better on the HTKS demonstrating higher literacy and math achievement. Finally, our final hypothesis was supported with a significant indirect path from active play to early math and literacy skills through self-regulation on the HTKS.

Active Play and Self-Regulation

In terms of our first research question, children who spent more time in moderate to vigorous physical activity (active play) during outdoor play performed better on the self-regulation HTKS task. The hypothesized path from active play to better self-regulation is consistent with research showing that high levels of physical activity are linked to inhibitory control (Campbell et al., 2002), working memory (McMorris et al., 2011; Niederer et al., 2011), and attention (Chaddock, Chaddock, Erickson, Prakash, VanPatter, et al., 2010). Given that the HTKS taps working memory, attention, and inhibitory control, the link between active play and self-regulation is consistent with these studies and offers a unique perspective on the role of active play during early development.

Further support for a connection between self-regulation and active play can be tied to the inherent motor component built into the HTKS, which fits with both cognitive and brain research linking movement with cognition. This is found in the growing evidence showing that children use their bodies to communicate, memorize, learn, solve problems, and self-regulate (Balcetis & Cole, 2009; Barsalou, 1999; Boncoddo et al., 2010; Fischer & Zwaan, 2008; Niedenthal, Barsalou, Winkielman, Krauth-Gruber, & Ric, 2005). These connections are also supported by research on the cerebellum (a region of the brain involved in balance and motor control), which shows that this network is also involved in the coordination of thought, attention, and working memory (Adolph, 2005; Diamond, 2000; Salmi et al., 2010; Shohamy, Myers, Kalanithi, & Gluck, 2008).

It could also be argued that some aspect of coordination is promoted by active play and that this is driving the link between play and the HTKS. Although this is plausible, it is unlikely, because children are still required to focus on the task rules, remember these rules, and inhibit prepotent cognitive and bodily movements. These actions require attention, working memory, and inhibitory control and have all been found to be related to physical activity (C. L. Davis et al., 2011), self-regulation (Cameron Ponitz et al., 2009), and achievement (McClelland et al., 2007). If gross motor movement is driving the connection between the HTKS and active play it would also need to account for the attention, working memory, and inhibitory skills needed to successfully perform the task. It is possible that during these early developmental years active play enhances connections between neural systems involved in both motor and cognitive control (Salmi et al., 2010) and that these connections are being tapped by the HTKS.

Self-Regulation and Academic Achievement, Direct and Indirect Effects

Contrary to our second hypothesis, we found that higher levels of moderate to vigorous active play were not directly related to emergent literacy or math achievement. Previous research looking at links between play and achievement focused on sociodramatic play, which has been found to elicit a higher form of syntactic language (Vedeler, 1997) and produce variability in vocabulary output (Levy, Wolfgang, & Koorland, 1992; Saracho & Spodek, 2006). Studies looking at math and reading with older children show that children who participate in more vigorous activity and those who are physically fit have higher math and reading scores (C. L. Davis et al., 2011; Eveland-Sayers et al., 2009). The present study is one of the first to examine connections between active play and academic achievement with a prekindergarten sample, with our findings suggesting an indirect link between active play and higher achievement through self-regulation rather than a direct link between the two.

Given that active play did not predict literacy or math achievement in this sample, active play within a preschool population might have less to do with achievement and more to do with promoting the behavioral components of executive and self-regulatory skills associated with academic proficiency. Research shows that growth in self-regulation over the academic year significantly predicts gains in emergent literacy and math skills in prekindergarten children (McClelland et al., 2007). Self-regulatory skills that are promoted by active play could be related more to growth in achievement over the academic year as children are exposed to new learning opportunities.

For our third research question, results showed that better self-regulation predicted higher literacy and math scores, which is consistent with previous studies (e.g., Blair & Razza, 2007; McClelland et al., 2007). Across both academic outcomes, children who performed better on self-regulation as measured by the HTKS had higher achievement (Cameron Ponitz et al., 2009). Finally, active play was significantly and indirectly related to math and emergent literacy achievement through self-regulation. In other words, more active play was related to higher self-regulation, which in turn was related to higher math and emergent literacy achievement. These results suggest that children who spent more time in active play were more likely to have higher self-regulation, which was then related to higher math and emergent literacy achievement in preschool.

Research shows that the prefrontal cortex is involved in self-regulatory behaviors (Arnsten & Li, 2005), projects to brain areas involved in motor activity (E. E. Davis, Pitchford, Jaspan, McArthur, & Walker, 2010; Diamond, 2000), and experiences rapid development during the prekindergarten years (Posner, Rothbart, Sheese, & Voelker, 2012). These connections suggest that children benefit from being physically active. The findings in the present article support a connection between active play and self-regulation and suggest that aspects of self-regulation could be beneficial if children are encouraged to be physically active. The present study shows that allowing time for physical activity could augment the learning process in young children, suggesting that active play may help promote academic achievement indirectly through stronger self-regulation.

Limitations and Future Directions

This study reveals important links between active play, self-regulatory skills, and early achievement and is one of the first to have investigated the relationship between natural active play and measures of achievement and self-regulation in preschool children. However, this study must be replicated and expanded upon to draw definitive conclusions, and there are limitations that should be addressed in future work. First, the number of participants was small ($n = 51$), which may have limited our ability to detect significant effects. It is possible that a larger sample would have provided greater power to detect a significant relationship between active play and math and emergent literacy. Second, active play was only measured at one time point because this was a preliminary study to assess relations between play and self-regulation. Data were thus collected to inform and support future work examining these relations. Measuring active play on more than one occasion might have elucidated stronger effects between active play, self-regulatory skills, and the achievement variables. Finally, the present analysis does not allow for the assessment of unidirectional or bidirectional effects between active play and self-regulation. Assessing play longitudinally could allow for the assessment of directionality between active play and self-regulation and should be explored in future work.

Considering these limitations, future studies should expand on the current study with a larger sample and measure physical play several times throughout a normative week. In addition to the quantity of play, the quality of children's play (e.g., sociodramatic play) also has important implications for the development of self-regulation (Bodrova & Leong, 2006). For example, incorporating movement into the classroom curriculum has been shown to be a viable approach to increasing activity levels (Trost, Fees, & Dzewaltowski, 2008). Future work should explore the unique and interactive effects of sociodramatic, active play, and classroom movement curricula to assess connections with gross motor and sedentary measures of self-regulation. This will give a better understanding of the benefits of active versus social play on self-regulatory skills and achievement and better elucidate the connection between movement and self-regulation.

Conclusion

Results from this study add to a growing body of research demonstrating the benefits of physical activity in promoting academic success and shed new light on the need to allow time for recess during the school day. Moreover, this study connects the concept of active play with embodied cognition, self-regulation, and academic achievement by showing that higher levels of active play positively predict self-regulation scores and early math and literacy skills. Results suggest that active play may have a positive indirect effect on academic achievement by promoting behavioral self-regulation and highlight the advantage of allowing time for recess during the school day. Overall, this study underscores the importance of promoting early physical activity in children by demonstrating that active play is linked to the self-regulatory skills that predict academic success.

REFERENCES

Acock, A. C. (2012). What to do about missing values. In H. Cooper, P. M. Camic, D. L. Long, A. T. Panter, D. Rindskopf, & K. J. Sher (Eds.), *APA handbook of research methods in psychology: Vol. 3. Data analysis and research publication*, (pp. 27–50). Washington, DC: American Psychological Association.

Adolph, K. E. (2005). Learning to learn in the development of action. In J. J. Rieser, J. J. Lockman, & C. A. Nelson (Eds.), *Minnesota Symposia on Child Psychology: Vol. 33. Action as an organizer of learning and development* (pp. 91–122). Mahwah, NJ: Erlbaum.

Arnsten, A. F. T., & Li, B.-M. (2005). Neurobiology of executive functions: Catecholamine influences on prefrontal cortical functions. *Biological Psychiatry*, *57*(11), 1377–1384. 10.1016/j.biopsych.2004.08.019

Balcetis, E., & Cole, S. (2009). Body in mind: The role of embodied cognition in self-regulation. *Social and Personality Psychology Compass*, *3*, 759–774. doi:10.1111/j.1751-9004.2009.00197.x

Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences*, *22*, 577–660. doi:10.1017/s0140525X99002149

Blair, C., & Razza, R. P. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. *Child Development*, *78*, 647–663.

Bodrova, E., & Leong, D. J. (2006). Self-regulation as a key to school readiness: How early childhood teachers can promote this critical competency. In M. Zaslow & I. Martinez-Beck (Eds.), *Critical issues in early childhood professional development*, (pp. 203–224). Baltimore, MD: Brookes.

Boncoddo, R., Dixon, J. A., & Kelley, E. (2010). The emergence of a novel representation from action: Evidence from preschoolers. *Developmental Science*, *13*, 370–377. doi:10.1111/j.1467-7687.2009.00905.x

Broaders, S. C., Cook, S. W., Mitchell, Z., & Goldin-Meadow, S. (2007). Making children gesture brings out implicit knowledge and leads to learning. *Journal of Experimental Psychology: General*, *136*, 539–550. doi:10.1037/0096-3445.136.4.539

Brown, W. H., Pfeiffer, K. A., McIver, K. L., Dowda, M., Addy, C. L., & Pate, R. R. (2009). Social and environmental factors associated with preschoolers' nonsedentary physical activity. *Child Development*, *80*, 45–58. doi:10.1111/j.1467-8624.2008.01245.x

Burdette, H. L., & Whitaker, R. C. (2005). Resurrecting free play in young children: Looking beyond fitness and fatness to attention, affiliation, and affect. *Archives of Pediatrics & Adolescent Medicine*, *159*, 46–50.

Cameron Ponitz, C., McClelland, M. M., Jewkes, A. M., Connor, C. M., Farris, C. L., & Morrison, F. J. (2008). Touch your toes! Developing a direct measure of behavioral regulation in early childhood. *Early Childhood Research Quarterly*, *23*, 141–158. doi:10.1016/j.ecresq.2007.01.004

Cameron Ponitz, C., McClelland, M. M., Matthews, J. S., & Morrison, F. J. (2009). A structured observation of behavioral self-regulation and its contribution to kindergarten outcomes. *Developmental Psychology*, *45*, 605–619. doi:10.1037/a0015365

Campbell, D. W., Eaton, W. O., & McKeen, N. A. (2002). Motor activity level and behavioral control in young children. *International Journal of Behavioral Development*, *26*(4), 289–296. doi:10.1080/01650250143000166

Caspersen, C. J., Powell, K. D., & Christenson, G. M. (1985). Physical activity, exercise, and physical fitness: Definitions and distinctions for health-related research. *Public Health Reports*, *100*(2), 126–131.

Castelli, D. M., Hillman, C. H., Buck, S. M., & Erwin, H. E. (2007). Physical fitness and academic achievement in third- and fifth-grade students. *Journal of Sport & Exercise Psychology*, *29*(2), 239–252.

Center on Education Policy. (2008). *As schools spend more time on reading and math, magnitude of curriculum—narrowing effect is revealed*. Washington, DC: Author.

Centers for Disease Control and Prevention. (2010). *The association between school based physical activity, including physical education, and academic performance*. Atlanta, GA: U.S. Department of Health and Human Services.

Chaddock, L., Erickson, K. I., Prakash, R. S., Kim, J. S., Voss, M. W., VanPatter, M., . . . Kramer, A. F. (2010). A neuroimaging investigation of the association between aerobic fitness, hippocampal volume, and memory performance in preadolescent children. *Brain Research*, *1358*, 172–183. doi:10.1016/j.brainres.2010.08.049

Chaddock, L., Erickson, K. I., Prakash, R. S., VanPatter, M., Voss, M. W., Pontifex, M. B., . . . Kramer, A. F. (2010). Basal ganglia volume is associated with aerobic fitness in preadolescent children. *Developmental Neuroscience*, *32*(3), 249–256.

Cotman, C. W., & Berchtold, N. C. (2002). Exercise: A behavioral intervention to enhance brain health and plasticity. *Trends in Neurosciences*, *25*(6), 295–301. doi:10.1016/S0166-2236(02)02143-4.

Cotman, C. W., Berchtold, N. C., & Christie, L.-A. (2007). Exercise builds brain health: Key roles of growth factor cascades and inflammation. *Trends in Neurosciences*, *30*, 464–472. doi:10.1016/j.tins.2007.06.011

Davis, C. L., Tomporowski, P. D., McDowell, J. E., Austin, B. P., Miller, P. H., Yanasak, N. E., . . . Naglieri, J. A. (2011). Exercise improves executive function and achievement and alters brain activation in overweight children: A randomized, controlled trial. *Health Psychology*, *30*(1), 91–98. doi:10.1037/a0021766

Davis, E. E., Pitchford, N. J., Jaspan, T., McArthur, D., & Walker, D. (2010). Development of cognitive and motor function following cerebellar tumour injury sustained in early childhood. *Cortex*, *46*, 919–932. doi:10.1016/j.cortex.2009.10.001

Diamond, A. (2000). Close interrelation of motor development and cognitive development and of the cerebellum and prefrontal cortex. *Child Development*, *71*, 44–56. doi:10.1111/1467-8624.00117

Donnelly, J. E., Greene, J. L., Gibson, C. A., Smith, B. K., Washburn, R. A., Sullivan, D. K., . . . Williams, S. L. (2009). Physical Activity Across the Curriculum (PAAC): A randomized controlled trial to promote physical activity and diminish overweight and obesity in elementary school children. *Preventive Medicine*, *49*, 336–341. doi:10.1016/j.ypmed.2009.07.022

Donnelly, J. E., & Lambourne, K. (2011). Classroom-based physical activity, cognition, and academic achievement. *Preventive Medicine*, *52*(Suppl.), S36–S42. doi:10.1016/j.ypmed.2011.01.021

Eadie, B. D., Redila, V. A., & Christie, B. R. (2005). Voluntary exercise alters the cytoarchitecture of the adult dentate gyrus by increasing cellular proliferation, dendritic complexity, and spine density. *Journal of Comparative Neurology*, *486*(1), 39–47. doi:10.1002/cne.20493

Enders, C. K. (2001). The performance of the full information maximum likelihood estimator in multiple regression models with missing data. *Educational and Psychological Measurement*, *61*, 713–740.

Evans, G. W., & Rosenbaum, J. (2008). Self-regulation and the income-achievement gap. *Early Childhood Research Quarterly*, *23*, 504–514.

Eveland-Sayers, B. M., Farley, R. S., Fuller, D. K., Morgan, D. W., & Caputo, J. L. (2009). Physical fitness and academic achievement in elementary school children. *Journal of Physical Activity & Health*, *6*(1), 99–104.

Fischer, M. H., & Zwaan, R. A. (2008). Embodied language: A review of the role of motor system in language comprehension. *Quarterly Journal of Experimental Psychology*, *61*, 825–850. doi:10.1080/17470210701623605

Hill, L., Williams, J. H. G., Aucott, L., Milne, J., Thomson, J., Greig, J., . . . Mon-Williams, M. (2010). Exercising attention within the classroom. *Developmental Medicine & Child Neurology*, *52*, 929–934. doi:10.1111/j.1469-8749.2010.03661.x

Howse, R. B., Calkins, S. D., Anastopoulos, A. D., Keane, S. P., & Shelton, T. L. (2003). Regulatory contributors to children's kindergarten achievement. *Early Education & Development*, *14*, 101–119.

Kristjánsson, Á. L., Sigfúsdóttir, I. D., & Allegrante, J. P. (2010). Health behavior and academic achievement among adolescents: The relative contribution of dietary habits, physical activity, body mass index, and self-esteem. *Health Education & Behavior*, *37*(1), 51–64. doi:10.1177/1090198107313481

Kwak, L., Kremers, S. P. J., Bergman, P., Ruiz, J. R., Rizzo, N. S., & Sjöström, M. (2009). Associations between physical activity, fitness, and academic achievement. *Journal of Pediatrics*, *155*, 914–918. doi:10.1016/j.jpeds.2009.06.019

Lee, J., Autry, M. M., Fox, J., & Williams, C. (2008). Investigating children's mathematics readiness. *Journal of Research in Childhood Education*, *22*(3), 316–328.

Levy, A. K., Wolfgang, C. H., & Koorland, M. A. (1992). Sociodramatic play as a method for enhancing the language performance of kindergarten age students. *Early Childhood Research Quarterly*, *7*(2), 245–262. doi:10.1016/0885-2006(92)90007-l

McClelland, M. M., Acock, A. C., Piccinin, A., Rhea, S. A., & Stallings, M. C. (2013). Relations between preschool attention span-persistence and age 25 educational outcomes. *Early Childhood Research Quarterly*, *28*(2), 314–324. doi:10.1016/j.ecresq.2012.07.008

McClelland, M. M., & Cameron, C. (2012). Self-regulation in early childhood: Improving conceptual clarity and developing ecologically-valid measures. *Child Development Perspectives*, *6*(2), 136–142. doi:10.1111/j.1750-8606.2011.00191.x

McClelland, M. M., Cameron, C. E., Connor, C. M., Farris, C. L., Jewkes, A. M., & Morrison, F. J. (2007). Links between behavioral regulation and preschoolers' literacy, vocabulary and math skills. *Developmental Psychology*, *43*, 947–959.

McMorris, T., Sproule, J., Turner, A., & Hale, B. J. (2011). Acute, intermediate intensity exercise, and speed and accuracy in working memory tasks: A meta-analytical comparison of effects. *Physiology & Behavior*, *102*, 421–428. doi:10.1016/j.physbeh.2010.12.007

Muñoz-Sandoval, A. F., Woodcock, R. W., McGrew, K. S., & Mather, N. (2005). *Bateria III Woodcock-Muñoz: Pruebas de aprovechamiento* [Bateria III Woodcock-Muñoz: Achievement Tests]. Itasca, IL: Riverside.

Muthén, L. K., & Muthén, B. O. (2010). *Mplus user's guide*. (6th ed.). Los Angeles, CA: Authors.

Niedenthal, P. M., Barsalou, L. W., Winkielman, P., Krauth-Gruber, S., & Ric, F. (2005). Embodiment in attitudes, social perception, and emotion. *Personality and Social Psychology Review*, *9*(3), 184–211. doi:10.1207/s15327957pspr0903_1

Niederer, I., Kriemler, S., Gut, J., Hartmann, T., Schindler, C., Barral, J., & Puder, J. (2011). Relationship of aerobic fitness and motor skills with memory and attention in preschoolers (ballabeina): A cross-sectional and longitudinal study. *BMC Pediatrics*, *11*(1), 34.

Pagani, L. S., Vitaro, F., Tremblay, R. E., McDuff, P., Japel, C., & Larose, S. (2008). When predictions fail: The case of unexpected pathways toward high school dropout. *Journal of Social Issues*, *64*(1), 175–193. doi:10.1111/j.1540-4560.2008.00554.x

Pate, R. R., Almeida, M. J., McIver, K. L., Pfeiffer, K. A., & Dowda, M. (2006). Validation and calibration of an accelerometer in preschool children. *Obesity*, *14*, 2000–2006. doi:10.1038/oby.2006.234

Pate, R. R., O'Neill, J. R., & Mitchell, J. (2010). Measurement of physical activity in preschool children. *Medicine & Science in Sports & Exercise*, *42*, 508–512.

Pellegrini, A. D., & Smith, P. K. (1998). The development of play during childhood: Forms and possible functions. *Child Psychology & Psychiatry Review*, *3*(2), 51–57. doi:10.1017/s1360641798001476

Posner, M. I., Rothbart, M. K., Sheese, B. E., & Voelker, P. (2012). Control networks and neuromodulators of early development. *Developmental Psychology*, *48*, 827–835. doi:10.1037/a0025530

Ruiz, J. R., Ortega, F. B., Castillo, R., Martín-Matillas, M., Kwak, L., Vicente-Rodríguez, G., . . . Moreno, L. A. (2010). Physical activity, fitness, weight status, and cognitive performance in adolescents. *Journal of Pediatrics*, *157*, 917–922. doi:10.1016/j.jpeds.2010.06.026

Salmi, J., Pallesen, K. J., Neuvonen, T., Brattico, E., Korvenoja, A., Salonen, O., & Carlson, S. V. (2010). Cognitive and motor loops of human cerebro-cerebellar system. *Journal of Cognitive Neuroscience*, *22*, 2663–2676. doi:10.1162/jocn.2009.21382

Saracho, O. N., & Spodek, B. (2006). Young children's literacy-related play. *Early Child Development and Care*, *176*, 707–721. doi:10.1080/03004430500207021

Schrank, F. A. (2005). Woodcock-Johnson III tests of cognitive abilities. In D. P. Flanagan & P. L. Harrison (Eds.), *Contemporary intellectual assessment: Theories, tests, and issues* (pp. 371–401). New York, NY: Guilford Press.

Shohamy, D., Myers, C. E., Kalanithi, J., & Gluck, M. A. (2008). Basal ganglia and dopamine contributions to probabilistic category learning. *Neuroscience and Biobehavioral Reviews*, *32*(2), 219–236. doi:10.1016/j.neubiorev.2007.07.008

Sirard, J. R., Trost, S. G., Pfeiffer, K. A., Dowda, M., & Pate, R. R. (2005). Calibration and evaluation of an objective measure of physical activity in preschool children. *Journal of Physical Activity & Health*, *2*(3), 345–357.

Smith, N. J., & Lounsbery, M. (2009). Promoting physical education: The link to academic achievement. *Journal of Physical Education, Recreation & Dance*, *80*(1), 39–43. doi:10.1080/07303084.2009.10598266

Trost, S. G. (2007). Measurement of physical activity in children and adolescents. *American Journal of Lifestyle Medicine*, *1*, 299–314.

Trost, S. G., Fees, B., & Dzewaltowski, D. (2008). Feasibility and efficacy of a ''move and learn'' physical activity curriculum in preschool children. *Journal of Physical Activity & Health*, *5*(1), 88–103.

Trost, S. G., McIver, K. L., & Pate, R. R. (2005). Conducting accelerometer-based activity assessments in field-based research. *Medicine & Science in Sports & Exercise*, *37*, S531–S543.

Trudeau, F., & Shephard, R. J. (2008). Physical education, school physical activity, school sports and academic performance. *International Journal of Behavioral Nutrition and Physical Activity*, *5*, 10.

U.S. 107th Congress. (2002). *Public Law 107–110*. Retrieved from http://www2.ed.gov/policy/elsec/leg/esea02/107-110.pdf

van Gaal, S., Ridderinkhof, K. R., Fahrenfort, J. J., Scholte, H. S., & Lamme, V. A. F. (2008). Frontal cortex mediates unconsciously triggered inhibitory control. *Journal of Neuroscience*, *28*, 8053–8062. doi:10.1523/jneurosci.1278-08.2008

van Gaal, S., Ridderinkhof, K. R., Scholte, H. S., & Lamme, V. A. F. (2010). Unconscious activation of the prefrontal no-go network. *Journal of Neuroscience*, *30*, 4143–4150. doi:10.1523/jneurosci.2992-09.2010

Vedeler, L. (1997). Dramatic play: A format for ''literate'' language? *British Journal of Educational Psychology*, *67*(2), 153–167.

Wagner, D. D., & Heatherton, T. F. (2011). Giving in to temptation: The emerging cognitive neuroscience of self-regulatory failure. In K. D. Vohs & R. F. Baumeister (Eds.), *Handbook of self-regulation: Research, theory, and applications*, (2nd ed., pp. 41–63). New York, NY: Guilford Press.

Wanless, S. B., McClelland, M. M., Acock, A. C., Cameron Ponitz, C. C., Son, S. H., Lan, X., . . . Li, S. (2011). Measuring behavioral regulation in four societies. *Psychological Assessment*, *23*, 364–378. doi:10.1037/a0021768

Wanless, S. B., McClelland, M. M., Tominey, S. L., & Acock, A. C. (2011). The influence of demographic risk factors on children's behavioral regulation in prekindergarten and kindergarten. *Early Education & Development*, *22*, 461–488. doi:10.1080/10409289.2011.536132

Wartenburger, I., Kühn, E., Sassenberg, U., Foth, M., Franz, E. A., & van der Meer, E. (2010). On the relationship between fluid intelligence, gesture production, and brain structure. *Intelligence*, *38*(1), 193–201. doi:10.1016/j.intell.2009.11.001

Weerda, R., Muehlhan, M., Wolf, O. T., & Thiel, C. M. (2010). Effects of acute psychosocial stress on working memory related brain activity in men. *Human Brain Mapping*, *31*, 1418–1429.

Woodcock, R. W., & Mather, N. (2000). *Woodcock Johnson Psycho-Educational Battery-III*. Itasca, IL: Riverside.