Motor Skill Performance and Physical Activity in Preschool Children

Harriet G. Williams[1], Karin A. Pfeiffer[2], Jennifer R. O'Neill[1], Marsha Dowda[1], Kerry L. McIver[1], William H. Brown[3] and Russell R. Pate[1]

Children with better-developed motor skills may find it easier to be active and engage in more physical activity (PA) than those with less-developed motor skills. The purpose of this study was to examine the relationship between motor skill performance and PA in preschool children. Participants were 80 three- and 118 four-year-old children. The Children's Activity and Movement in Preschool Study (CHAMPS) Motor Skill Protocol was used to assess process characteristics of six locomotor and six object control skills; scores were categorized as locomotor, object control, and total. The actigraph accelerometer was used to measure PA; data were expressed as percent of time spent in sedentary, light, moderate-to-vigorous PA (MVPA), and vigorous PA (VPA). Children in the highest tertile for total score spent significantly more time in MVPA (13.4% vs. 12.8% vs. 11.4%) and VPA (5% vs. 4.6% vs. 3.8%) than children in middle and lowest tertiles. Children in the highest tertile of locomotor scores spent significantly less time in sedentary activity than children in other tertiles and significantly more time in MVPA (13.4% vs. 11.6%) and VPA (4.9% vs. 3.8%) than children in the lowest tertile. There were no differences among tertiles for object control scores. Children with poorer motor skill performance were less active than children with better-developed motor skills. This relationship between motor skill performance and PA could be important to the health of children, particularly in obesity prevention. Clinicians should work with parents to monitor motor skills and to encourage children to engage in activities that promote motor skill performance.

Obesity (2008) **16,** 1421–1426. doi:10.1038/oby.2008.214

INTRODUCTION

The prevalence of overweight is increasing in all children, including very young children (1). In the 1970s, the prevalence of overweight in preschool-age children was ~5% (ref. 2). The prevalence of overweight in children aged 2–5 in 2003–2004 was 12.6% for girls and 15.1% for boys (1). This increase in overweight has prompted scientists to examine correlates of weight status, including physical activity (PA), in preschool children. Professional groups recommend that young children participate in 120 min of moderate-to-vigorous PA (MVPA) daily, 60 min of which is structured and 60 min unstructured or in free play (3). Although some have assumed that young children are very active throughout the day (4,5), recent studies indicate that young children spend a majority of the day in sedentary activities and spend <5% of the day in MVPA (6–9). Pate *et al.* reported that 3–5-year-olds spend ~43 min of any given hour in sedentary activity (9). Reilly *et al.* also report that 3–5-year-olds spend 76–79% of their monitored hours in sedentary activities (7). Although reasons for these low activity levels are not well understood, several scientists have suggested that there may be a relationship between the status of children's motor skill performance and their levels of PA (10–14). Some studies have shown that older children with higher levels of motor skill performance tend to be more physically active than children with less well-developed motor skills (10,11,14). The potential nature of this relationship in preschool-age children has received little attention, in part, because of the perception that these young children are continuously engaged in active behaviors.

The preschool years are characterized by significant changes in the acquisition and performance of children's locomotor and object control skills. To date, few studies have examined potential relationships between preschoolers' level of motor skill performance and PA (15–17). Fisher *et al.* reported a low but positive correlation between total gross motor skill scores and level of participation in PA in 4-year-olds (17). They also noted that boys and girls in the upper quartiles of motor skill scores spent more time in MVPA than peers in lower quartiles (17).

[1]Department of Exercise Science, Arnold School of Public Health, University of South Carolina, Columbia, South Carolina, USA; [2]Department of Kinesiology, Michigan State University, East Lansing, Michigan, USA; [3]Department of Educational Psychology, Wardlaw School of Education, University of South Carolina, Columbia, South Carolina, USA. Correspondence: Harriet G. Williams (hwilliam@gwm.sc.edu)

Received 9 October 2007; accepted 11 February 2008; published online 3 April 2008. doi:10.1038/oby.2008.214

Two other investigators have found low but positive correlations between motor skill proficiency and indoor free-play in 5-year-olds (15) and participation in weekend PA in 3- and 4-year olds (16).

Of these three studies, only one used an objective measure of PA and included a large sample of children (N = 394) (17). Most have involved smaller samples of children (15) and/or employed a motor skills assessment that involved either 1–2 product scores of individual skills or a simple, subjective global rating of motor skill performance (15,17). We know of no studies that have (i) assessed motor skill performance using movement process characteristics (i.e., quality of movement performances) and (ii) included assessment of all the major fundamental locomotor and object control skills typically observed in preschool-age children. Given the importance of the role of PA in the prevention of obesity, it seems critical to further define and document the nature of this relationship in preschool children. The documentation of the existence of a strong relationship between motor skill performance and participation in PA could be significant in helping to counteract the trend toward increasing overweight in young children. Thus the purpose of this study was to examine and further define the potential relationship between the level of motor skill performance and participation in PA in preschool children. We used an objective measure of PA, a comprehensive assessment of all fundamental motor skills based on the quality of movement skill performances, and a large sample of racially diverse children.

METHODS AND PROCEDURES

Participants

Participants in this investigation were a part of the Children's Activity and Movement in Preschool Study (CHAMPS), a large, observational study of PA in preschool children. They attended one of three types of preschools: (i) commercial (n = 11), (ii) religious-based (n = 7), and (iii) Head Start programs (n = 4). All children from each school were invited to participate; if >18 children per school provided consent, children were randomly selected to participate. Motor skill performance (n = 297) and PA (n = 438) data were collected in 22 preschools on 3-, 4-, and 5-year-olds over an 18-month period (August 2004 to January 2006). To address the potential effect of seasonality, data collection occurred at each preschool in two waves so that data were collected during different times throughout the year. Five-year-olds were not included in the current sample (due to small sample size, n = 38); 61 three- and four-year-olds were excluded because of missing accelerometer (n = 60) or BMI (n = 1) data. The current sample consisted of 80 three- and 118 four-year-olds for whom complete data on motor skill performance, BMI, race, parent education, and PA were available (see Table 1). The sample was evenly distributed across various demographic characteristics, particularly sex (50% male) and race (54% African American; see Table 1). Written informed consent was obtained from each child's primary guardian prior to collection of data. The study was approved by the University of South Carolina Institutional Review Board.

Assessment of gross motor skill performance

The CHAMPS Motor Skill Protocol (CMSP) was used to assess gross motor skills. Two dimensions of gross motor performance were evaluated: locomotor and object control skills. The CMSP consists of behavioral descriptors or process characteristics of six locomotor (run, jump, slide, gallop, leap, and hop) and six object control skills (throw, roll, kick, catch, strike, and dribble) typically observed in preschoolers. The presence of these skills offers an important avenue to participation in PA for young preschool children; the reasoning is that the more and better developed these skills, the greater the possibilities for children to engage in physically active games and challenges. Reliability estimates for the CMSP range from R = 0.88–0.97 for locomotor, object control, and total scores (data not shown). Interobserver reliability (intraclass correlation) for test components was high: locomotor skills, R = 0.99; object control skills, R = 0.98; total test score, R = 0.94. Concurrent validity, based on Pearson correlations between the CMSP and the Test of Gross Motor Development-2 (TGMD-2), a widely used and established test of gross motor development (18), is R = 0.94 or above (data not shown). Construct validity as determined by the capacity of the test to discriminate among ages (i.e., "age differentiation") is good with higher scores for 4-year-olds than 3-year-olds and higher scores for 5-year-olds than 4-year-olds (data not shown).

Scores on the CMSP are based on ratings of movement process characteristics of locomotor and object control skills and a total test score. Movement process characteristics of each skill are rated as "1" (present) or "0" (absent); ratings of 0, 1, and 2 are used for throwing, striking, and hopping to indicate specific movements of the trunk, arm, and leg. The range of possible scores for locomotor skills is 0–73, for object control skills 0–80, and for total motor skill performance 0–153.

Table 1 Descriptive characteristics of the study sample

	Total (n = 198)	Three-year-olds (n = 80)	Four-year-olds (n = 118)
Sex			
Male	50.5%	51.2%	50.0%
Female	49.5%	48.8%	50.0%
Race			
African American	53.5%	60.0%	49.2%
White	34.9%	33.8%	35.6%
Other	11.6%	6.3%	15.3%
Parent education			
High school or less, some college	47.0%	43.8%	49.2%
Technical college, college, graduate school	53.0%	56.3%	50.9%
BMI, mean (s.d.), kg/m^2	16.2 (1.8)	16.2 (1.8)	16.2 (1.7)
z-BMI, mean (s.d.)	0.27 (2.2)	0.06 (3.3)	0.42 (1.1)
Age, mean (s.d.), years	4.2 (0.5)	3.6 (0.3)	4.5 (0.3)
Hours monitor worn per day	12.7 (1.6)	12.9 (1.5)	12.7 (1.6)

Procedures

Children from three types of preschools participated in the study; thus, motor skill assessment took place within and across a wide range of environmental circumstances and contexts (e.g., hallways, cramped spaces, and noisy gyms). Whenever possible, a gym or long hallway that was free of traffic and distraction was used. In some cases, it was not possible to avoid locations with distractions, and adults or other children temporarily interrupted the assessments. Testers recorded the level of distraction in all testing environments. These "environmental distraction" scores were an attempt to address differences in situational conditions in the three different types of participating schools. The distraction score included a rating of the nature and adequacy of the testing space, the noise level during testing, etc. Previous analyses indicated that environmental distraction scores had no effect on motor

skill performance scores (data not shown) and therefore were not considered in this analysis.

Data collection generally took 35–40 min per child and involved two testers. The same two testers administered the motor skill tests to all participants. One administered the CMSP and demonstrated the skills; the other observed and recorded movement performance data. The roles of testers were reversed throughout the study and counterbalanced across children. Data collection in each preschool lasted ~1 week, depending on the number of participating children and time constraints imposed by preschool personnel. Prior to a child performing each skill, two demonstrations were given, one with the tester facing the child and one facing the direction in which the child was to perform the skill. No additional demonstrations or feedback were provided. The order of presentation of locomotor skills was: run, jump, slide, gallop, leap, and hop. The order for object control skills was: throw, roll, kick, catch, dribble, and strike. The presence or absence of each process characteristic on two trials per skill was indicated by the tester and scored appropriately. Data used in the analyses were the total score for each category: locomotor, object control, and total test.

PA data: accelerometry

Total daily PA was measured using accelerometry (ActiGraph, model 7164; ActiGraph, Fort Walton Beach, FL). The actigraph is a uniaxial accelerometer that measures acceleration in the vertical plane; it is small (2.0 × 1.6 × 0.6 inches), light (1.5 ounces), and unobtrusive. Its acceleration signal is filtered by an analog bandpass filter (0.1–3.6 Hz) and digitized by an 8-bit analog-to-digital converter at a sampling rate of 10 samples per second, storing data in user-defined intervals (19). Monitors were initialized to save data in 15-s intervals to detect spontaneous PA of 3- and 4-year-old children.

Participants wore accelerometers on an elastic belt on the right hip (anterior to the iliac crest) during all waking hours and naps at school for 8–10 days and at home for 1 weekend. For analyses, up to 5 days of weekday data and 2 days of weekend data were used. Days on which total wear time was <5 h or >18 h were considered noncompliant days, and were not used in analyses. Weekdays on which the child did not attend school were not included in the analyses. Periods of ≥60 min of continuous zeroes were considered nonwear times and not considered in the calculation of total wear time. Participants with <3 days of monitor wear were excluded from the analyses.

Cutpoints developed specifically for preschool children by our research group were used to categorize each minute of wear as sedentary (<37.5 counts/15 s), light (38–419 counts/15 s), MVPA (≥420 counts/15 s) or vigorous PA (VPA) (≥842 counts/15 s) (20). Average minutes of sedentary, light, MVPA, and VPA were calculated for the total group and for 3- and 4-year-olds separately. Percent time spent in each activity intensity category was also calculated by dividing each participant's minutes of activity per day by their total wear time. Average percent time spent in sedentary, light, MVPA, and VPA per day was calculated for the total sample and by age group.

Anthropometric measures

Height was measured to the nearest 0.1 cm using a portable stadiometer (Shorr Productions; Olney, MD). Weight was measured to the nearest 0.1 kg using an electronic scale (model 770; Seca, Hamburg, Germany). The average of two measurements was used for both height and weight. BMI was calculated and expressed as kg/m^2.

Statistical analyses

Descriptive statistics were calculated for the total sample and by age groups. To compare our outcomes with outcomes from other published studies, bivariate correlations between motor skill performance scores and PA variables were determined for the total group and by age. Correlations between motor skill performance and *z*-BMI were also calculated for the total sample. A series of mixed model analyses of covariance with PA (sedentary, light, MVPA, or VPA) as the dependent variable and age-specific tertiles of motor skill performance scores as the group factor were run. Models were analyzed using proc mixed (21) with preschool as a random variable and were adjusted for BMI, race, sex, parent education, and age (total group). Two analyses with BMI or *z*-BMI as the dependent variable and tertile of motor skill performance scores as the group factor were also completed.

RESULTS

Average motor performance scores for the overall sample were 81.5 for total score, 38.0 for locomotor score, and 43.5 for object control. Using only those portions of the CMSP that are comparable to the TGMD-2, average scores for our children were similar to average scores on the TGMD-2 for this age group (data not shown) (18). Four-year-olds had higher scores than three-year-olds on all three motor performance components (Table 2).

In the main analysis, we examined data relative to time spent wearing accelerometers and expressed PA data as percent time spent at different activity intensity levels (sedentary, light, MVPA, and VPA). On average, children spent half the day (~55%) engaging in sedentary behaviors and ~12% of the day in MVPA. Based on the average wearing time of the monitors (12.7 h; Table 1), this translates into ~7 h of sedentary activity and 90 min of MVPA. Three- and four-year-olds were not different in terms of amount of time spent in different intensity levels of PA.

We used Pearson correlations to compare linear associations between motor skill performance scores and percent time spent in PA intensity levels for the total group and by age. There was essentially no association between motor skill performance scores and percent time spent in sedentary or light activity; correlations were low (range: $r = -0.06$ to -0.17), negative, and nonsignificant (Table 3). In contrast, there were significant, positive correlations between motor skill performance scores and percentage of time spent in both MVPA and VPA. For the total group there was a statistically significant relationship between total motor performance scores and PA for MVPA ($r = 0.20$) and VPA ($r = 0.26$). Correlations between object control scores (MVPA, $r = 0.19$; VPA, $r = 0.24$) and PA

Table 2 Motor skill performance scores and physical activity

	Total mean ± s.d.	Three-year-olds ($n = 80$) mean ± s.d.	Four-year-olds ($n = 118$) mean ± s.d.
CHAMPS Motor Skill Performance Score			
Locomotion	38.0 (11.1)	31.7 (9.8)	42.2 (9.9)
Object control	43.5 (11.0)	38.0 (9.1)	47.3 (10.8)
Total	81.5 (19.1)	69.7 (15.0)	89.5 (17.4)
Physical activity			
Percent time sedentary	54.8 (6.3)	54.6 (7.0)	54.8 (9.9)
Percent time light	32.6 (4.3)	32.6 (4.6)	32.6 (4.1)
Percent time MVPA	12.6 (3.6)	12.7 (4.2)	12.6 (3.2)
Percent time VPA	4.5 (1.0)	4.6 (2.1)	4.5 (1.8)

MVPA, moderate-to-vigorous physical activity; VPA, vigorous physical activity.

Table 3 Pearson correlations between physical activity and motor skill performance

Motor skill performance	Physical activity			
	Percent time sedentary	Percent time light	Percent time MVPA	Percent time VPA
Total sample				
Locomotion	–0.10	0.01	0.16*	0.21**
Object control	–0.09	–0.03	0.19*	0.24**
Total	–0.11	–0.01	0.20**	0.26***
Three-year-olds				
Locomotion	–0.06	0.04	0.06	0.10
Object control	–0.08	–0.06	0.20	0.22
Total	–0.09	–0.01	0.16	0.20
Four-year-olds				
Locomotion	–0.16	–0.002	0.31**	0.37***
Object control	–0.13	–0.02	0.26*	0.32***
Total	–0.17	–0.01	0.33***	0.41***

MVPA, moderate-to-vigorous physical activity; VPA, vigorous physical activity.
*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

were slightly higher than those for locomotor scores (MVPA, $r = 0.16$; VPA, $r = 0.21$) for the total group.

When 3- and 4-year-olds were examined separately, data indicated that correlations between total motor skill performance scores and PA were significant for 4-year-olds but not for 3-year-olds (Table 3). Correlations between both locomotor and object control scores and PA were also significant for 4-year-olds but not for 3-year-olds. Correlations for locomotor scores for 4-year-olds were slightly higher (MVPA, $r = 0.31$; VPA, $r = 0.37$) than object control scores (MVPA, $r = 0.26$; VPA, $r = 0.32$).

We also examined the correlations between *z*-BMI and motor skill performance and PA. Correlations between *z*-BMI and motor skill performance scores ranged from 0.03 to 0.13; none was significant. The correlation between *z*-BMI and MVPA was low but significant ($r = 0.14$); correlations between *z*-BMI and other PA levels were slightly lower and not significant (sedentary, $r = –0.09$; light, $r = 0.01$; VPA, $r = 0.13$). There was also no significant association between *z*-BMI and tertile of motor skill performance.

Using analyses of covariance, we examined associations between tertiles of motor skill performance scores and percent time spent in PA intensity levels and controlled for sex, BMI, race, parent education, and preschool. For the total sample, children in the highest tertile of total motor skill performance scores spent significantly more time in MVPA (13.4% vs. 12.8% vs. 11.4% of the day) and VPA (5% vs. 4.6% vs. 3.8%) than children in middle and lower tertiles. There were no differences in time spent in sedentary behavior across tertiles of total motor skill performance scores (Table 4).

With respect to locomotor scores, children in the highest tertile of motor skill performance scores spent significantly less time in sedentary activity than children in other tertiles and significantly more time in both MVPA (13.4% vs. 11.6%) and

Table 4 Physical activity by tertile of motor skill performance scores adjusting for sex, BMI, race, and parent education, with preschool center as a random variable

Motor skill performance tertiles by component	Percent time sedentary	Percent time light	Percent time MVPA	Percent time VPA
	Mean (s.e.)	Mean (s.e.)	Mean (s.e.)	Mean (s.e.)
Controlling for age (using age-specific tertiles of MD scores)				
Total score				
Low	56.1 (0.9)	32.5 (0.6)	11.4 (0.5)[a]*	3.8 (0.3)[a]**
Intermediate	54.5 (0.9)	32.6 (0.6)	12.8 (0.5)	4.6 (0.3)
High	53.7 (0.9)	32.9 (0.6)	13.4 (0.5)	5.0 (0.3)
Locomotor				
Low	55.7 (0.9)[b,]*	32.6 (0.6)	11.6 (0.5)[c]*	3.8 (0.3)[c]**
Intermediate	55.6 (0.9)	31.9 (0.6)	12.5 (0.5)	4.5 (0.3)
High	53.1 (0.9)	33.5 (0.6)	13.4 (0.5)	4.9 (0.3)
Object control				
Low	55.7 (0.9)	32.5 (0.6)	11.8 (0.5)	4.0 (0.3)
Intermediate	54.5 (0.9)	32.7 (0.6)	12.8 (0.5)	4.5 (0.3)
High	53.9 (1.0)	33.0 (0.7)	13.1 (0.5)	4.8 (0.3)
Three-year-olds				
Total score				
Low	57.5 (1.7)	31.4 (1.2)	11.3 (1.1)	3.9 (0.5)
Intermediate	53.6 (1.7)	33.5 (1.2)	12.9 (1.0)	4.4 (0.5)
High	53.8 (1.6)	32.9 (1.1)	13.3 (0.9)	5.1 (0.5)
Locomotor				
Low	56.2 (1.9)	32.1 (1.2)	11.8 (1.1)	4.0 (0.6)
Intermediate	55.3 (1.9)	32.0 (1.3)	12.9 (1.1)	4.7 (0.6)
High	53.8 (1.6)	33.3 (1.1)	12.9 (0.9)	4.8 (0.5)
Object control				
Low	56.4 (1.7)	32.0 (1.1)	11.7 (1.0)	4.3 (0.5)
Intermediate	54.0 (1.7)	33.2 (1.1)	12.9 (1.0)	4.5 (0.5)
High	53.5 (1.7)	33.0 (1.2)	13.6 (1.0)	5.0 (0.5)
Four-year-olds				
Total score				
Low	55.8 (1.1)	32.8 (0.7)	11.4 (0.6)[a]*	[d]
Intermediate	55.4 (1.0)	31.9 (0.7)	12.7 (0.5)	[d]
High	53.4 (1.1)	33.3 (0.7)	13.4 (0.6)	[d]
Locomotor				
Low	56.2 (1.0)[b]*	32.4 (0.7)	11.4 (0.5)[c]*	3.7 (0.3)[a]**
Intermediate	55.4 (1.0)	32.0 (0.7)	12.5 (0.5)	4.5 (0.3)
High	52.8 (1.1)	33.7 (0.7)	13.6 (0.6)	5.1 (0.3)
Object control				
Low	55.4 (1.1)	32.8 (0.7)	11.9 (0.6)	3.9 (0.3)
Intermediate	55.1 (1.1)	32.2 (0.7)	12.7 (0.6)	4.6 (0.3)
High	54.0 (1.2)	33.1 (0.8)	13.0 (0.6)	4.8 (0.3)

MVPA, moderate-to-vigorous physical activity; VPA, vigorous physical activity.
[a]Low tertile differs from intermediate and high tertiles. [b]High tertile differs from low and intermediate tertiles. [c]Low and high tertiles differ. [d]Data not shown due to sex by motor skill performance status interaction. See Figure 1 for further detail.
*$P \leq 0.05$; **$P < 0.01$.

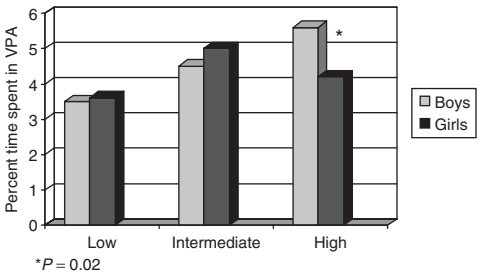

Figure 1 Motor skill performance by sex interaction among 4-year-olds.

VPA (4.9% vs. 3.8%) than children in the lowest tertile. There were no PA differences among tertiles of motor skill performance for object control scores.

Age-specific results for analyses of covariance indicated that patterns of PA participation for different levels of motor skill performance for both 3- and 4-year-olds were similar to those for the total group. However, differences in PA participation across tertiles of motor skill performance (total score) were significant only for 4-year-olds (**Table 4**). Four-year-old children in the highest tertile of total motor skill performance scores spent significantly more time in both MVPA (13.4% vs. 12.7% vs. 11.4%) and VPA (5% vs. 4.7% vs. 3.6%) than children in the lower two tertiles. There were no differences in percent time spent in sedentary or light PA. With respect to locomotor scores, children in the highest tertile spent significantly more time in VPA than other children (5.1% vs. 4.5% vs. 3.7%) and significantly more time in MVPA than children in the lowest tertile (13.6% vs. 11.4%). In addition children in the highest two tertiles spent significantly less time in sedentary activity than children in the lowest tertile. Again, there were no PA differences among tertiles of motor skill performance for object control scores.

We also examined each analysis to test for interactions between tertiles of motor skill performance and sex. The only significant interaction was for total score for 4-year-olds ($P = 0.02$); girls in the highest tertile spent significantly less time in VPA than boys in the highest tertile (**Figure 1**).

DISCUSSION

This study supports the small but growing body of evidence that points to an important relationship between level of motor skill performance and children's participation in PA (15–17). For example, Fisher *et al.* (17) reported an association between quartiles of motor skill performance and time spent in MVPA. We found that young children with better-developed motor skills (highest tertile) spent significantly more time in both MVPA and VPA and significantly less time in sedentary behaviors than children with less well-developed motor skills. Thus evidence from our study supports the assertion that the level of motor skill performance may be an important factor in promoting a physically active lifestyle in preschool children.

As it has been reported in previous studies (1,3,15), we found correlations between motor skill status and percent time spent in MVPA and VPA to be low but positive and statistically significant. We found higher correlations than those reported by Fisher *et al.* (17), the most definitive study on PA and motor skill performance to date. Fisher *et al.* (17) reported low but positive correlations between total PA ($r = 0.10$) and percent time in MVPA ($r = 0.18$) and VPA ($r = 0.02$). We found slightly higher correlations (MVPA, $r = 0.20$; VPA, $r = 0.26$) for the total group and even higher correlations between locomotor scores and participation in PA for 4-year-olds ($r = 0.31$ and 0.37). Similar correlations were also found for 4-year-olds for object control skills. These data suggest that age, as would be expected, may be an important factor in elucidating the nature of the relationship between level of motor skill performance and PA in young preschool children. We believe that differences in methods used to assess both PA participation and motor skill status may account, in part, for differences in outcomes of the two studies. We used a 15-s epoch to assess PA level and a comprehensive, qualitative assessment of all 12 major fundamental motor skills; Fisher *et al.* (17) used 1-min epochs and a single product assessment of motor skill status. In this respect, our methods provided a more comprehensive picture of both PA participation and motor skill status and, thereby, may have resulted in a fuller description and analysis of the nature and extent of the relationship in preschoolers.

PA of children in our study was observed an average of 12.7 h per day over a period of up to 7 days. Children with the highest levels of motor skill performance spent 2% more time in MVPA (13.4% vs. 11.4%) and 1.2% more time in VPA (5.0% vs. 3.8%) than children with the poorest motor skills. Although this difference may seem trivial, it translates into 12 more min (per 12 h) spent in MVPA, with ≥2 min of that time spent in VPA, for children with better motor skills. If this difference was a consistent feature of a child's behavior across a typical 5-day school week and 2 weekend days, the total time spent in PA could amount to ~84 more min spent in MVPA, with 10 more min spent in VPA, for children with better motor skills. Add to this the decreased time spent in sedentary behaviors by children with better-developed skills, and the potential contribution of the level of motor skill performance to an active lifestyle in young children is difficult to deny.

The relationship between level of motor skill performance and PA participation was stronger for 4-year-olds than for 3-year olds. Four-year-olds with higher levels of motor skill performance spent significantly more time in both MVPA and VPA than those with lower levels of skill performance. Although the association between higher levels of skill performance and more time spent in PA for 3-year-olds was similar to that for 4-year-olds, the associations were not significant. The reasons for this are not fully understood. Three-year-olds had lower scores on measures of motor skill performance and were, as a group, more variable in their performance characteristics. These observations suggest, as would be expected, that many of the fundamental motor skills examined were still emerging in 3-year-olds and thus the motor skill repertoire available to them for participation in PA was likely more limited than for 4-year-olds. The number of 3-year-olds in our sample also was smaller than the number of 4-year-olds. It may also be that motor skill performance simply plays a lesser role

in the PA behavior of 3-year-olds. To our knowledge, our data on motor skill performance and PA participation are the only data on 3-year-olds; no other published study has examined this population as an independent age group (16,17).

The relationship between PA and locomotor skills was stronger than the relationship between PA and object control skills. Children with higher levels of locomotor skill performance spent significantly more time in both MVPA and VPA and less time in sedentary behaviors than children with lower levels of locomotor skill performance. These data suggest that performance of adequate locomotor skills may be an important element in promoting an active lifestyle in young children. Raudsepp and Pall (12) reported a relatively high correlation (r = 0.55) for 7–8-year-olds between skill in jumping and participation in "jumping-related activities" observed in after school activities. Clearly the opportunity (e.g., space, encouragement) to practice such skills must be considered, since previous literature has shown preschool setting to be associated with participation in PA (8,9). To our knowledge, no other published research has addressed the potential role of locomotor skills in the early development of a physically active lifestyle in young children.

Overall, the strengths of our study include (i) the use of a comprehensive, qualitative assessment of movement characteristics of all major fundamental motor skills to capture a fuller description of motor skill status; (ii) a racially diverse sample of children from 22 preschools of three different types; (iii) an objective, quantitative measure of PA; and (iv) a relatively large sample size. Only Fisher *et al.* (17) had a larger sample than the current study. Although age-related issues were not a primary focus of our study, an important limitation may be the smaller sample of 3-year-olds compared to 4-year-olds. This may have limited our ability to examine age-related differences in the role that level of motor skill performance plays in the PA behaviors of younger preschoolers. The actigraph accelerometer may underestimate PA because it (i) is not water-resistant and thus any activity participated in the water would not be included and (ii) is not as reliable in capturing cycling activity. Because of the cross-sectional nature of our study, we cannot infer a causal relationship between motor skill performance and PA.

Our study provides strong support for the potential importance of motor skill performance in young children's PA behaviors. Children with poorer motor skill performance tended to be less physically active than children with better-developed motor skills. Although considerable attention is given to motor skill performance in a small population of children with severe developmental delays, little, if any, attention is devoted to such development in most other children. Children in our study were not developmentally delayed, yet it was clear that children with poorer motor skills were less physically active than those with better motor skills. This relationship between motor skill performance and participation in PA could potentially be important to the overall health of the young child, particularly in terms of preventing obesity. Future longitudinal studies are needed to determine the nature of the impact of motor skill performance on the health of the child and to examine the issue of the impact of age and sex on this relationship. Still, this rapidly growing body of evidence presents a challenge to clinicians to work actively with parents of all children to monitor motor skill performance and to encourage them to seek opportunities to engage young children in activities that promote motor skill performance, even in the absence of obvious motor skill delays.

ACKNOWLEDGMENTS

We express our appreciation for Chevy Brown, MPH, and Shaverra Jones, BS, for their outstanding work as motor skill performance testers. We also thank Gaye Groover Christmus, MPH, for editorial assistance. This study was supported by two grants from the National Institutes of Health (R01HD043125-04 and R01HD043125-02S1).

DISCLOSURE

The authors declared no conflict of interest.

REFERENCES

1. Ogden CL, Carroll MD, Curtin LR *et al*. Prevalence of overweight and obesity in the United States, 1999-2004. *JAMA* 2006;295:1549–1555.
2. Ogden CL, Troiano RP, Briefel RR *et al*. Prevalence of overweight among preschool children in the United States, 1971 through 1994. *Pediatrics* 1997;99:E1.
3. National Association for Sport and Physical Education. *Moving into the Future: National Standards for Physical Education,* 2nd edn. NASPE: Reston, VA, 2004.
4. Goodway JD, Smith DW. Keeping all children healthy: challenges to leading an active lifestyle for preschool children qualifying for at-risk programs. *Fam Community Health* 2005;28:142–155.
5. O'Connor JP, Temple VA. Constraints and facilitators for physical activity in family day care. *Aust J Early Child* 2005;30:1–9.
6. Montgomery C, Reilly JJ, Jackson DM *et al*. Relation between physical activity and energy expenditure in a representative sample of young children. *Am J Clin Nutr* 2004;80:591–596.
7. Reilly JJ, Jackson DM, Montgomery C *et al*. Total energy expenditure and physical activity in young Scottish children: mixed longitudinal study. *Lancet* 2004;363:211–212.
8. Finn K, Johannsen N, Specker B. Factors associated with physical activity in preschool children. *J Pediatr* 2002;140:81–85.
9. Pate RR, Pfeiffer KA, Trost SG, Ziegler P, Dowda M. Physical activity among children attending preschools. *Pediatrics* 2004;114:1258–1263.
10. Graf C, Koch B, Kretschmann-Kandel E *et al*. Correlation between BMI, leisure habits and motor abilities in childhood (CHILT-project). *Int J Obes Relat Metab Disord* 2004;28:22–26.
11. Okely AD, Booth ML, Patterson JW. Relationship of physical activity to fundamental movement skills among adolescents. *Med Sci Sports Exerc* 2001;33:1899–1904.
12. Raudsepp L, Pall P. The relationship between fundamental motor skills and outside-school physical activity of elementary school children. *Pediatr Exerc Sci* 2006;18:426–435.
13. Ulrich B. Perceptions of physical competence, motor competence, and participation in organized sport: Their interrelationships in young children. *Res Q Exerc Sport* 1987;58:57–67.
14. Wrotniak BH, Epstein LH, Dorn JM, Jones KE, Kondilis VA. The relationship between motor proficiency and physical activity in children. *Pediatrics* 2006;118:e1758–e1765.
15. Butcher J, Eaton O. Gross and fine motor proficiency in preschoolers: Relationships with free play behavior and activity level. *J Hum Mov Stud* 1989;16:27–36.
16. Saakslahti A, Numminen P, Niinikoski H *et al*. Is physical activity related to body size, fundamental motor skills, and CHD risk factors in early childhood? *Pediatr Exerc Sci* 1999;11:327–340.
17. Fisher A, Reilly JJ, Kelly LA *et al*. Fundamental movement skills and habitual physical activity in young children. *Med Sci Sports Exerc* 2005;37:684–688.
18. Ulrich D. *Test of Gross Motor Development*, 2nd edn. Examiner's Manual. Pro-Ed, Inc.: Austin, TX, 2000.
19. Tryon WW, Williams R. Fully proportional actigraphy: a new instrument. *Behav Res Methods Instrum Comput* 1996;28:392–403.
20. Pate RR, Almeida MJ, McIver KL, Pfeiffer KA, Dowda M. Validation and calibration of an accelerometer in preschool children. *Obesity (Silver Spring)* 2006;14:200–206.
21. SAS Institute. *SAS/STAT 9.1 User's Guide*. SAS Institute, Inc., 2004.