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Physical Activity Measurement Methods for Young Children: A Comparative Study

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Many behavior patterns that impact on physical activity experiences are established in early childhood, therefore it is important that valid, reliable, and feasible measures are constructed to identify children who are not developing appropriate and healthy activity habits. In this study, measures of physical activity derived by accelerometry and pedometry are compared with direct observation of 5- and 6-year-old children (N = 24). The children were monitored for 30 min over 5 consecutive days during a 30-min free play session in their preprimary setting. The results for all measures were significantly correlated. When compared to direct observation, the coefficient of determination indicated that the pedometer (R^2 = .81) was able to more accurately predict all levels of physical activity compared to the accelerometer (R^2 = .59). When the children were grouped into low, moderate, and high activity levels using observation, the pedometer data were better able to separate the groups than the accelerometer data. These findings indicate that the pedometer is a better measure of free play physical activity in 5- and 6-year-old children compared to the accelerometer.

Key words: children, physical activity, measurement, pedometers, accelerometers, direct observation

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Physical activity is a well documented and recognized component of a healthy lifestyle, and childhood experiences with physical activity have an important impact on lifelong behavior. Some evidence suggests that physical activity levels are established when young (Malina, 1996; Pate, Baranowski, Dowda, & Trost, 1996). The development of a valid, reliable, and feasible measure for this preprimary age group that is able to quickly and accurately identify those children who are not developing appropriate and healthy activity habits has become a focus for contemporary research (Fulton et al., 2001). Ideally, such an instrument would be useful for studies with large populations and able to be meaningfully applied to children of a range of ages and cultural and international settings. To date, there is no agreed reliable and valid method of measuring physical activity levels in children participating in free play.

Measuring physical activity levels in young children offers unique challenges as their movement patterns are highly variable, nonstructured, and generally comprise short and frequent bursts of moderate to vigorous activity (Bailey et al., 1995; Nilsson, Ekelund, Yngve, & Sjostrom, 2002; Sallo & Silla, 1997). Another confounding factor is the differing rates of maturation and development among same-age children. Previous researchers investigating physical activity in young children have used a range of different measurement tools and protocols (Janz, Burns, Torner, & Levy, 2001; Klesges, Haddock, & Eck, 1990; Pate et al., 1996; Sallo & Silla, 1997); however, the lack of consistency of agreed, valid methods makes results difficult to compare. In addition, self-report, recall methods that are common in physical activity research with youth and adults are not appropriate with young children because of their inability to accurately recall their own activity levels (Baranowski, 1988). For these reasons, the choices of measurement methods suitable for young children available to researchers are limited. The most feasible measures for young children are proxy reports by parents or teachers or objective methods such as direct observation, heart rate monitors, or motion sensors such as accelerometers and pedometers.

Parent and teacher questionnaires have been used as proxy measures of physical activity with some success (Freedson & Evenson, 1991; Harro, 1997; Klesges et al., 1990; Manios, Kafatos, & Markakis, 1998; Mota & Queiros, 1996; Noland, Danner, Dewalt, McFadden, & Kotchen, 1990; Poest, Williams, Witt, & Atwood, 1989). This strategy is relatively inexpensive, quick to administer, and ideal for large studies, although it cannot be assumed that the parents or teachers will provide accurate or reliable information (Manios et al., 1998).

Direct observation methods usually involve time sampling methods (for a review, see McKenzie, Sallis, & Nader, 1991), and, given the labor intensive nature of such instruments, are most appropriate for relatively short observation periods and small samples. This protocol is considered to be the "gold standard" and is used to validate other methods of assessment (Freedson & Melanson, 1996; Klesges, Klesges, Swenson, & Philip, 1985). Tools such as the Children's Activity

Rating Scale (CARS) have been used to discriminate between different levels of energy expenditure in 5- and 6-year-old children (Puhl, Greaves, Hoyt, & Baranowski, 1990), 3- to 5-year-olds (Noland et al., 1990), and 4- to 5-year-olds (DuRant et al., 1993) with high interrater reliability (84.1%; Puhl et al., 1990) and within day test–retest repeatability (r = .81; Durant et al., 1993).

Heart rate monitors can be used to monitor physical activity as it is assumed that heart rate is linearly related to energy expenditure (Freedson & Evenson, 1991). The advantages of the heart rate monitor include accuracy in assessing and recording duration and intensity of exercise; furthermore, children find them comfortable and acceptable to wear. They cannot, however, be used to record frequency of activity within a limited time frame (Bailey et al., 1995), provide information on the type of activity, and they may be affected by other factors such as type of exercise, temperature, and stress (Freedson & Evenson, 1991), and efficiency of movement (O'Beirne, Larkin, & Cable, 1994).

Motion sensors, particularly accelerometers, are gaining credibility as measures of physical activity in young children. The uniaxial accelerometer is small and light and children find them comfortable and socially acceptable (Bar-Or, Bar-Or, Waters, Hirji, & Russell, 1996; Janz, 1994). They are reported to be highly reliable (r =.71 to .76) and valid with 5- and 6-year-old children (Janz, Paulos, Burns, & Levy, 1999), particularly when used over a short time period and in a controlled environment. The triaxial accelerometer is larger and heavier and therefore less suitable for young children. Accelerometers are, however, expensive, making them unsuitable for studies involving large samples.

Pedometers provide valid assessments of total volume of physical activity, are easy to use and inexpensive, and therefore ideally suited to large-scale studies (Tudor-Locke & Myers, 2001; Welk et al., 2000). These electronic devices count each vertical movement or step. Physical activity, therefore, is determined by the number of steps taken over a period of time. Recent advances in design have significantly improved the accuracy and reliability of the pedometer. Bassett et al.(1996) recorded steps and distance within 2% of actual values and Gretebeck and Montoye (1992) reported correlations between .73 and .79 for 3 to 4 days of monitoring. The pedometer has been validated against accelerometers (r = .99; Kilanowski, Consalvi, & Epstein, 1999), heart rate monitors (r = .78; Eston, Rowlands, & Ingledew, 1998), and direct observation (r = .96; Kilanowski et al., 1999) for children ages 7 and older. Although these results support the use of pedometers, there are some limitations. Pedometers are unable to measure intensity of activity or to accurately record activities such as cycling or skateboarding, both common activities in young children. These may affect the validity of the information gathered with young children given the episodic and variable nature of their play.

In 1998, a group of American researchers met to consider the assessment of physical activity in 2- to 5-year-old children (Fulton et al., 2001). After reviewing the current state of knowledge in this area, the panel recommended validity and feasibility studies of appropriate assessment methods. To better measure physical activity among 5- to 6-year-old boys and girls, this study was designed to compare the validity of accelerometer scores and pedometer counts to ratings obtained from directly observed free play. These comparisons will allow better interpretations of scores derived from activity monitors with this age group.

METHOD

Participants

The sample comprised 24 children (*M* = 66.6 months, *SD* = 3.5 months) attending three, randomly selected and geographically spread, preprimary centers in the Perth metropolitan area. Eight children, four boys and four girls were selected by the teacher of each center. To ensure a range of activity levels that were representative of this age group, the teacher was encouraged to choose four children XX perceived as high active and four children XX perceived as low active children (two boys and two girls in each category). Informed consent was obtained from the parents or caregivers of all participants.

Procedure

Physical activity patterns were monitored over 5 consecutive days during 30 min of free play using a pedometer, accelerometer, a direct observation tool, and video to check the reliability of direct observations. Gretebeck and Montoye (1992) found that 4 to 5 days of data collection are necessary to determine a person's habitual activity level.

The testing team comprised eight observers (one per child), a video operator, and one researcher to initialize the accelerometers. Prior to the data collection days, a training session was conducted with the research team on the testing protocol. In particular, the team practiced using a modified CARS (DuRant et al., 1993) observation form with videotaped footage of children playing in a preprimary session to maximize interrater agreement. Once in the field, an additional researcher independently observed one child per testing session to establish interrater reliability.

On each day an accelerometer and a pedometer were secured to a velcro strap attached around each child's waist prior to them exiting into the outdoor area. After several minutes of free play, an event marker was recorded against the accelerometer data, the pedometer was reset, and the stopwatch started. Each observer stood unobtrusively around the outdoor area to observe and code the child's activity over the next 30 min of free play.

The outdoor environments for each center were typical of an early childhood setting and included both fixed and portable equipment such as ladders, planks, climbing frames, slides, swings, bikes, balls, and small play equipment such as bats and bean bags. The children were encouraged to interact as normally as possible with other children and to freely choose play activities with minimal teacher intervention. Sallis, Patterson, McKenzie, and Nader (1988) also used a 30-min observation time, along with a similar protocol to measure physical activity levels in preprimary children. At the end of the observational period, the pedometer count was recorded and the instruments removed.

Measures

Accelerometer. The model used for this study was the Manufacturing Technology Inc. (MTI) Actigraph Model AM7164. This instrument has been successfully used in research with children (Fairweather, Reilly, Grant, & Paton, 1999; Janz, 1994; Janz, Witt, & Mahoney, 1995). It has been validated against direct observation during short structured play sessions in 4-year-olds ($r = .87$; Fairweather et al., 1999) and against heart rate monitoring over 3 days with 7- to 15-year-olds ($r = .5–.74$; Janz, 1994). It is small, measuring 5.1 cm × 3.8 cm × 1.5 cm, and weighs 43 g. The monitor provides counts which represent acceleration over a specified interval of time. An epoch of 10 sec was used in this study to account for the short bursts of activity typical of young children. Longer epochs are unable to detect those short periods of high activity counts (Nilsson et al., 2002). The score used for these analyses was the counts per 10-sec interval totaled over 30 min.

Pedometer. The Yamax Digiwalker (SW-200), has been validated against energy expenditure with older children (mean age 9.2 years; $r = .78$ to .92; Eston et al., 1998). This model simply records the number of steps taken and was found to be the most accurate of a number of models at slow-to-moderate speeds (Bassett et al., 1996). The score used for this study was the number of steps over 30 min.

Direct observation. The direct observation coding system was based on the CARS (DuRant et al., 1993), which is capable of discriminating between different levels of energy expenditure in 5- and 6-year-old children (Finn & Specker, 2000; Puhl et al., 1990). This scale is used to rate activity at 60-sec intervals on five levels: stationary with no movement; stationary with movement; translocation—slow, easy movement; translocation—medium, moderate movement; and translocation—fast, very intense movement. To better align the observation records with the accelerometer epochs of 10 sec, the behavior was coded either 1 to 5 every 10 sec. This meant that scores would range between a low of 180 to a high of 900 over the 30 min of observation.

Statistical Analyses

The mean daily score for the pedometer, accelerometer, and direct observations was determined based on 5 days of data. These results were used for all data analyses. The relationship between measures was examined using Pearson product–moment correlations and coefficient of determination. *T* tests were used to explore gender differences. A one-way analysis of variance (ANOVA) explored differences in measures among children categorized as high, medium, or low active based on the direct observation measures.

RESULTS

Interrater reliability of the observations was established by comparing results between two independent observers of one child, and between one observer and an independently coded videotape for one child each testing day. The coding of all videotapes was completed by one of the research team. The percentage agreement between observers was 99% and between observers and videotape was 93%.

The descriptive statistics for each measure, based on mean scores for the 5 days of observation, are presented in Table 1 for a sample size of 24 and 23. This was to demonstrate the impact on the accelerometer data of one participant who spent almost all of four out of the five observation occasions on a swing. The action of the swing inflated her mean accelerometer count, and in turn the overall female results. As this outcome is of interest to the study, the results for both sample sizes are reported; however, this outlier was removed from all further analyses. No other children played on the swings during the observations. Boys were significantly more active than girls for the accelerometer scores, $t(22) = 2.49$, $p < .05$; pedometer counts, $t(22) = 3.18$, $p < .01$; and CARS direct observation scores, $t(22) = 3.61$, $p < .01$.

TABLE 1
Mean and Standard Deviation for Each Measure With and Without Data from One Female Outlier

		Total Group		*Boys*	*Girls*	
Measure	*Unit*	*N* = 24	*N* = 23	*n* = 12	*n* = 12	*n* = 11
Accelerometer	Cts/30 min	58,388 (36,032)	52,272 (20,462)	61,430 (18,099)	55,345 (48,651)	42,280* (18,716)
Pedometer	Steps/30 min	1,145 (387)	1,128 (389)	1,317 (353)	970 (351)	908** (284)
Direct observation	Score/30 min	467 (40)	466 (40.6)	490 (35)	444 (31)	440** (30)

Note. Significant difference between boys and girls: *$p < .05$. **$p < .01$. ($n = 23$).

The relationship between direct observation and the accelerometer and pedometer data was investigated using the Pearson product–moment correlation coefficient and the coefficient of determination. There were moderate to strong correlations for all measures (Table 2), the relationship was particularly strong (.90) between the pedometer data and direct observation scores. The accelerometer data only shared 59% of variance with the direct observation compared to 81% for the pedometer data.

The CARS observation scores were used to group the participants into three tertiles, representing low, medium, and high activity levels. The mean scores for each activity group are shown in Table 3. A CARS score of 443 or below equated to an overall activity level of low, between 443 and 490 equated to a medium activity level, and over 490 equated to a high or vigorous activity level. A one-way ANOVA was conducted to test whether the pedometer and accelerometer scores were able to discriminate between the three groups based on the direct observation scores. There were statistically significant differences between groups for both the accelerometer, $F(2, 21) = 19.93$, $p \leq .001$; and pedometer scores, $F(2, 21) = 25.65$, $p \leq .001$. Post hoc analyses, using the Tukey honestly significant difference test, indicated that the significant difference for the accelerometer data was between the low active and moderate active groups only, whereas significant differences were evident between all activity groups for the pedometer data. The gender composition differed markedly between the high and low active groups; there were more low active girls ($n = 6$) than boys ($n = 2$), and more high active boys ($n = 7$) than girls ($n = 1$).

DISCUSSION

This study provides evidence that the pedometer is a better measure of physical activity in young children when engaged in a variety of free play activities as compared to the accelerometer. Although significant correlations were recorded be-

TABLE 2
Pearson Product-Moment Correlations and Coefficients of Determination for 5 Days (N = 24 and N = 23)

	Direct Observation			
	r		R^2	
Measure	*N = 24*	*N = 23*	*N = 24*	*N = 23*
Accelerometer	.50	.77*	.25	.59
Pedometer	.90	.90*	.81	.81

*$p < .01$.

tween the Yamax pedometer, accelerometer, and direct observation measures, the relationship was stronger (.90) between the pedometer counts and the criterion measure, the direct observation scores. Interestingly, the accelerometer was more affected by some play patterns than the pedometer. This was demonstrated by the high accelerometer count generated by the swinging motion of the child on the swing that was unrelated to her physical exertion. When her data were removed, the correlation between the accelerometer and direct observation increased from .50 to .77, whereas the correlation between the pedometer and direct observation did not change (.90 in both samples), indicating that the pedometer was more stable under these conditions. Mukeshi, Gutin, Anderson, Zybert, and Basch (1990) found a similar pattern in the relationship between accelerometer data and direct observation for 2- to 3-year-old children when playing outdoors ($r = .16$) compared to indoors ($r = .47$). They concluded that the accelerometer was less accurate when measuring the more variable play patterns of children of this age.

To date, the authors are unaware of other research comparing measures generated by both accelerometer and pedometer for children engaged in specific free play patterns such as swinging and climbing. Where swinging activities were included in structured activities such as swinging from gymnastics equipment, no mention was made of extreme counts (Fairweather et al., 1999; Metcalf, Voss, & Wilkin, 2002). Eston and colleagues (1998) compared heart rate, triaxial accelerometer, uniaxial accelerometer, and pedometer data gathered while 9-year-old children were engaged in catching, jumping, sitting, and drawing. They reported that the triaxial accelerometer ($r = .83$) more accurately assessed energy levels than the uniaxial accelerometer used in this study ($r = .78$) or the pedometer ($r = .80$). In another study involving 9- to 11-year-old children engaged in walking, bench stepping, hopscotch, basketball, aerobics, and running while wearing triaxial and uniaxial accelerometers (Ott, Pate, Trost, Ward, & Saunders, 2000), triaxial accelerometer counts were more highly associated with predicted energy expenditure ($r = .66$–$.73$) than the uniaxial accelerometer counts ($r = .53$–$.64$). Kilanowski et al. (1999) reported lower correlations between pedometer and accelerometer data for 7- to 10-year-old children engaged in classroom activities compared to recreational activities such as soccer, basketball, and dancing (Kilanowski et al., 1999). As with our study, these researchers found slightly higher correlations between pedometer and direct observation measures than with the accelerometer data when engaged in both recreational activities ($r = .97$ pedometer, $r = .94$ accelerometer) and classroom activities ($r = .80$ pedometer, $r = .70$ accelerometer). None of the researchers reported earlier included activities such as swinging, hanging, and spinning that are typical of preschool children and also involve high levels of acceleration. Based on the findings mentioned earlier and the results of this study, it appears that the accelerometer may be more susceptible to measurement error than the pedometer when used with young children engaged in free play activities such as swinging and spinning.

One explanation for the lower relationship between accelerometer data and direct observation scores found in this study could relate to the chosen epoch setting of 10 sec rather than the more commonly used 60 sec. Nilsson et al. (2002) found that epoch setting particularly important among high active children. The length of time spent at high and very high intensity activity recorded by different accelerometers set at epochs between 5 and 60 sec were significantly different for the same child during the same activity session (Nilsson et al., 2002). This discrepancy was thought to be due to the interaction between the sampling procedure used by the accelerometers and the children's activity patterns. Nilsson et al. (2002) suggested that further research is needed to better understand the accelerometer counts derived with young children because the correspondence with energy expenditure at different levels of intensity is probably different between age groups (Nilsson et al., 2002).

Another explanation may involve the model of accelerometer. As reported earlier, the triaxial accelerometer rather than the uniaxial accelerometer may be less prone to measurement error among young children (Eston et al., 1998; Ott et al., 2000); however, this model is bulkier and less comfortable for young children to wear.

Gender Differences

The finding that preschool boys were more active than the girls during free play time is also consistent with other studies using a range of different measures (Janz et al., 1999; Poest et al., 1989; Vincent & Pangrazi, 2002), and this difference increases with age (Silva, Birkbeck, Russell, & Wilson, 1984). A meta-analysis of 127 studies found that boys were more active than girls at every age level (Eaton & Enns, 1986).

Activity level differences between boys and girls were highlighted by the uneven representation in each activity group (Table 3). More boys were classified as

TABLE 3
Mean Physical Activity Measures for Low, Medium, and High Activity Groups Based on Direct Observation Scores

	Activity Level						
	Low		*Medium*		*High*		
Measure	*Men (n = 2)*	*Women (n = 6)*	*Men (n = 3)*	*Women (n = 4)*	*Men (n = 7)*	*Women (n = 1)*	*F*
Accelerometer	30,721	9,987	58,000	13,773	68,809	13,318	19.93*
Pedometer	733	205	1,149	190	1,506	246	25.65*

Note. $N = 23$
$^*p < .001$.

high active, as they were observed participating in more vigorous activities during the free play period. Janz et al. (1999) also found boys spent more time involved in vigorous and very vigorous activity than girls, and observed no gender differences between 5- and 6-year-olds in total time spent in moderate activity. A number of researchers have found that boys were more involved in rough-and-tumble play than girls (Cratty, Ikeda, Martin, Jennett, & Morris, 1970; Pfister, 1993; Reilly & Stratton, 1995). Boys' games often involved speed, strength, endurance, and aggression whereas girls' games were more likely to include turn-taking, orderly sequences, partial involvement, and solitary practice (Ignico, 1989).

In conclusion, the strong correlation between the Yamax pedometer and direct observation during physical activity, .90 in our study and .96 in the study by Kilanowski and colleagues (1999), indicate that the pedometer may be useful in research studies to provide a simple, reliable, and valid measure with this age group; however, additional research is needed with larger samples to ensure generalizability.

Future Research

The pedometer is rapidly becoming the preferred method of measuring physical activity in large populations; however, further studies involving particular subgroups and protocol are necessary. For example, the unit of measure adopted for this study with the pedometer was step counts for 30 min, whereas other researchers may report steps per day. To bridge the gap between research and practice, standardized methods of collecting and reporting data are necessary. Steps taken over a defined time period is the method recommended by several researchers (Rowlands et al., 1997; Tudor-Locke & Myers, 2001). Tudor-Locke (2002) suggested an index of steps taken in 30 min when undertaking different activities be developed to facilitate interpretation of pedometer data. These preliminary findings, shown in Table 3, suggest that young children engaged in medium level free play activity involving activities such as walking or running at a moderate pace, skipping, or hopping, would average 1,149 steps over 30 min. On the other hand, if they were mainly sitting, standing, or digging in the sand, they would take approximately 733 steps over 30 min. By comparison, adults take 3,100 to 4,000 steps over 30 min when walking consistently at moderate intensity (Welk et al., 2000; Wilde, Sidman, & Corbin, 2001). The erratic nature of children's physical activity when engaged in free play would in part account for the large discrepancy between the adult and child steps.

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