RESEARCH PAPER

Accelerometers for Measuring Physical Activity Behavior in Indian Children

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Received: April 21, 2008;Initial review: July 2, 2008; Accepted: December 22, 2008.

Objective: To examine the validity of accelerometers for characterizing habitual physical activity patterns in Indian children.

Design: Cohort study.

Setting: Holdsworth Memorial Hospital, Mysore.

Subjects: Children (N=103, mean age 6.6 years) selected from an ongoing birth cohort study.

Methods: Physical activity was measured over 7 days using accelerometers (MTI Actigraph) and concurrent parent-maintained activity diaries. Actigraph counts per minute representing sedentary (<10), light (<400), moderate (<3000) and vigorous (≥3000) activity were determined using a structured activity session in a separate group of 10 children. In 46 children chosen for validating accelerometers, time spent in different activity levels according to diaries was determined. Energy Expenditure (EE) was calculated from diaries using a factorial method.

Results: Ninety-eight children wore the monitor for ≥4 days. Total counts and time spent in different activity levels were similar in boys and girls (P>0.2). Among 46 children chosen for comparisons, time spent in sedentary (r =0.48, P=0.001), light (r=0.70, P<0.001) and moderate activities (r=0.29, P=0.054) according to diaries correlated with those derived from counts, and total Actigraph counts correlated with EE (r=0.42, P=0.004). Bland-Altman analysis showed systematic bias, and wide limits of agreement between these methods for time spent in different activity levels.

Conclusions: Accelerometers are a well tolerated and objective way of measuring activity behavior in free-living children. Though accelerometer counts correlate with time spent in activity of varying intensity and energy expenditure derived from parent-maintained diaries, wide limits of agreement show that the limitations of accelerometers need to be recognized in interpreting the data that they generate.

Keywords: *Accelerometers, Activity diaries, Child, India, Physical activity.*

Published online 2009 April 1. PII: S097475590800321-1

The low lean body mass, and high truncal adiposity ('thin-fat' phenotype) of Indians(1-3) may contribute to their high type 2 diabetes and cardiovascular disease risk(4). Rapid urbanization has reduced the scope for physical activity contributing to rising levels of childhood obesity(5). While in Western children, inverse associations have been found between physical activity and both adiposity(6) and cardiovascular risk factors(7), few studies using objective monitoring of physical activity have been done in Indian children.

We measured physical activity in pre-pubertal Indian children to describe physical activity pattern using accelerometers; establish cut-offs for time spent in sedentary, light, moderate and vigorous activities; and compare accelerometer data in a subset of children against activity levels and energy expenditure (EE) calculated using diaries.

Accompanying Editorials: Pages 1051-1054.

METHODS

The Mysore birth cohort was established to study the effect of gestational diabetes (GDM) on offspring risk factors(2,8,9). Women, with known GDM status delivered live, normal babies at the Holdsworth Memorial Hospital, Mysore (*N*=630, GDM=41). Offspring anthropometry, including triceps and subscapular skinfold measurements, was performed using standardized methods at birth, annually until 5 years, and 6-monthly thereafter. Percentage body fat (fat%) was measured using bio-impedance (Quadscan 4000 or 1500MDD, Bodystat, UK) from 5 years.

During 2004-2005, 105 children aged 6-7½ years were selected from the cohort representing offspring of diabetic mothers (ODM), sex-matched and BMI-matched children born to non-diabetic mothers, and (also from children of non-diabetic mothers) children in the highest and lowest fourths of 5-year subscapular skinfold distribution.

Children and their parents gave informed, verbal consent, and the hospital ethics committee approved the study.

Accelerometers

MTI Actigraph uniaxial accelerometers (AM7164, MTI Health Services, Florida, USA) measure body acceleration in the vertical plane as counts. Actigraphs were set to record counts at 1-minute intervals, and tied at the right hip to measure activity during waking hours for 7 consecutive days during school term. Written and verbal instructions were given to parents to remove the Actigraph during bathing, swimming, afternoon naps and at night before the child went to bed, to subsequently re-apply it, and to record these times. The remaining activities were considered representative of the child's total activity. Time-blocks when accelerometers were removed during the representative period were also recorded. In 46 children that we checked, this occurred in 9 children (range 15 to 140 minutes), and on more than one day in only one child. Three children had >60 minutes of data missing in a single day.

The data downloaded to a computer was processed using a special software program. The first and last days were excluded, as they were incomplete, showed artifacts related to monitor applying and removing, or movements recorded after removal but before downloading the data. Days with ≥500 minutes of registered activity were considered representative and included. 2 children were excluded (one ODM who refused monitoring after 1 day, and his control), leaving 103 children.

Defining activity levels of differing intensity: Ten similar-aged children in one school (not from the cohort) performed structured activities representing sedentary, light, moderate and vigorous intensity-levels, for 10-minutes each, while wearing Actigraphs. These sessions were led and paced by research staff. The data were used to define cut-off accelerometer counts for activity levels, defined empirically based on the average minimum and maximum counts/minute recorded for these activities (***Table* I**).

Time spent in different activity levels in the study children were calculated based on these cut-offs.

Diaries:Parents and teachers were requested to keep a diary of the child's activities simultaneously during Actigraph monitoring. They wrote codes from a list for the predominant activity of the child during each 15-minute period.

Sixty-six of 103 children had legible diaries of ≥10 hours (11 hours –16.5 hours, mean=13.5 hours) for ≥4 days. In 46 diaries, representing different groups, chosen for comparisons with Actigraphs (39 with 6 days) activities were assigned to different activity levels (***Table* I**). The time of accelerometer removal or missing information were excluded. Information was missing in 15 children (15 minutes-2 hours in a day, mean=35 min/d).

To compare total activity, Physical Activity Ratios (PAR) were assigned to diary activities from a published compendium(10). Basal metabolic rate (BMR) was predicted using sex- and age-specific equations(11). EE for the recordable time was calculated by a 'factorial method', based on PAR, duration of activities and BMR, and the average for all days was calculated.

Statistical methods: Time spent vigorously active (both methods) were log-transformed for normality. Correlations were used to compare total counts with

TABLE I RANGE OF MEAN COUNTS PER MINUTE FOR BOYS AND GIRLS (N=10) DURING A STRUCTURED ACTIVITY SESSION AND RANGES OF COUNTS SUBSEQUENTLY SELECTED TO REPRESENT SEDENTARY, LIGHT, MODERATE AND VIGOROUS ACTIVITIES

Activity	Minimum-maximum mean counts/child/minute		Activity level	Cut off count	Corresponding activities
	Boys	Girls			
Sitting passive watching TV	0-3	0-0	sedentary	<10	Sitting, sitting and TV watching
Sitting active writing or drawing	2-463	0-178	light	10-399	Standing/reading-writing/travelling/eating/drinking/drawing/singing/talking
Walking slow to moderate speed	592-2708	1292-2832	moderate	400-2999	Playing indoor-outdoor/standing travelling/dancing/music playing/walking
Running	2738-8533	3986-4758	vigorous	≥3000	Running/cycling/swimming/March past/jumping

EE from diaries and the time spent in different activity levels according to both methods. Agreement between actigraphs and diaries was tested using Bland and Altman plots (activity pattern) and *kappa* statistics by cross-tabulations. T-tests were used to compare boys and girls.

RESULTS

***Table* II** shows the children's anthropometry measured at 7.5-years of age. Girls were significantly more adipose than boys; there were no differences in other measurements.

Periods of registered activity ranged from 2 days (N=1) to 6 days (N=76); ≥4 days were available for 98 (95%) children. All available days were used for analysis. Average registered time was 774 minutes/day (~13 hours, 579 minutes-936 minutes). Children spent <20 minutes/day in vigorous activities. Boys and girls were similar in activity counts, and time spent in sedentary, light, moderate and vigorous activities but boys accumulated a higher percentage of total counts in vigorous activity, and girls a higher percentage of total counts in light activity (***Table* III**).

All available days (4-6 days) were used for comparisons. Among the 46 children selected, actigraphs correlated with diaries for average registered time (r=0.73, P<0.001), time spent in sedentary (r=0.48, P=0.001), light (r=0.70, P<0.001) and moderate activities (r=0.29, P=0.054), but not vigorous activities (r=0.03, P=0.8).

With the exception of sedentary activities on Day 6, day-to-day correlations were consistent (Days 1-6

TABLE II AGE AND PHYSICAL CHARACTERISTICS (MEASURED AT 7.5 YEARS) OF THE STUDY SUBJECTS

	Girls (N max=67)	Boys (N max=36)	P
Age (years)	6.6 (0.4)	6.6 (0.4)	0.5
Weight (kg)	21.7 (4.0)	21.8 (3.2)	0.9
Height (cm)	121.8 (4.7)	123.1 (5.9)	0.2
BMI (kg/m^2)	14.5 (2.0)	14.3 (1.3)	0.6
*Subscapular skinfold (mm)	8.0 (6.2,10.3)	6.2 (4.9,7.5)	0.002
Triceps skinfold (mm)	10.4 (3.5)	7.4 (2.1)	<0.001
Fat % (Bio-impedance)	28.3 (5.7)	21.7 (5.2)	<0.001

*Values presented are mean (SD) and *geometric mean (IQR), P for the difference between boys and girls.*

TABLE III ACTIGRAPH MEASURED MEAN TOTAL COUNTS AND PHYSICAL ACTIVITY LEVELS IN THE STUDY SUBJECTS

	Girls (*N* max=67)	Boys (*N* max=36)	*P*
Total counts	403813.1 (110313)	414372.5 (107388)	0.6
Counts/ minute	523.6 (137.3)	537.6 (145.0)	0.6
Registered daily activity time (min)	769.5 (71.1)	777.9 (72.8)	0.6
Sedentary activity (min)	153.0 (44.3)	155.7 (50.2)	0.8
% of registered time	19.9% (5.6)	20.1% (6.4)	0.9
*% of counts accumulated	0.09% (0.05)	0.07% (0.05)	0.1
Light activity (min)	338.4 (53.6)	347.6 (62.0)	0.4
% of registered time	43.9% (5.5)	44.7% (5.8)	0.5
*% of counts accumulated	14.2% (6.8)	11.5% (5.1)	0.04
Moderate activity (min)	260.4 (54.6)	252.3 (51.4)	0.5
% of registered time	33.9% (6.9)	32.6% (6.3)	0.4
*% of counts accumulated	70.4% (9.7)	68.3% (10.1)	0.3
†Vigorous activity (min)	13.7 (7.8, 25.0)	16.3 (11.0, 26.4)	0.3
% of registered time	2.3 (1.6)	2.6 (1.5)	0.4
*% of counts accumulated	15.9 (11.2)	20.4 (11.6)	0.06

*Values presented are mean (SD) and †geometric mean (IQR); *Based on a single day data.*

Sedentary: *r*=0.34, 0.29, 0.25, 0.31, 0.29, –0.06; Light: *r*=0.70, 0.68, 0.69, 0.73, 0.55, 0.56; Moderate *r*=0.50, 0.58, 0.32, 0.20, 0.30, 0.38).

Bland-Altman analysis showed systematic bias between diary and Actigraphs on the average time spent at all intensity levels (*P*<0.01 for all) (***Fig.* 1**). Bias was small for sedentary and moderate levels. For light activities, the level of bias increased with increasing duration of activity. At all intensity levels, the limits of agreement were wide, indicating poor agreement between the methods.

Actigraph counts correlated positively with EE (*r*=0.42, *P*=0.004) (***Fig.*2**). In a cross-tabulation, 24 of the 46 children were placed in the equivalent activity and EE tertiles, while 4 were placed in extreme opposite categories; level of agreement (*kappa* statistics) was *k* = 0.28 (*P* = 0.007) (***Table* IV**).

In all children, counts correlated inversely with subscapular skinfolds (*r* = –0.28, *P* = 0.006); triceps skinfolds (*r* = –0.22, *P* = 0.03) and fat% (*r* = –0.29, *P* = 0.005; adjusted for age, sex, maternal GDM status [no/yes]).

DISCUSSION

This study reports the use of accelerometers for measuring habitual activity in Indian children. Accelerometers were well tolerated. Actigraph counts correlated with time spent in sedentary, light and moderate activities and EE from parental diaries.

Our major strength was the use of accelerometers which record the intensity and duration, and thus the pattern of physical activity. Diaries provided a cheap and the most effective tool to compare the activity pattern in habitual conditions. One of the major limitations was the non-availability of a 'gold standard' for validating actigraphs for total activity. As we did not assign any values to the missing times, it is possible that we have missed important activity data, and the impact of excluding this time in our analysis would increase as the duration of missing data increased.

We chose actigraphs because of their small size, non-intrusion in free-living conditions, good evidence of validity and acceptability for long-term use in other populations(12). We explored their utility

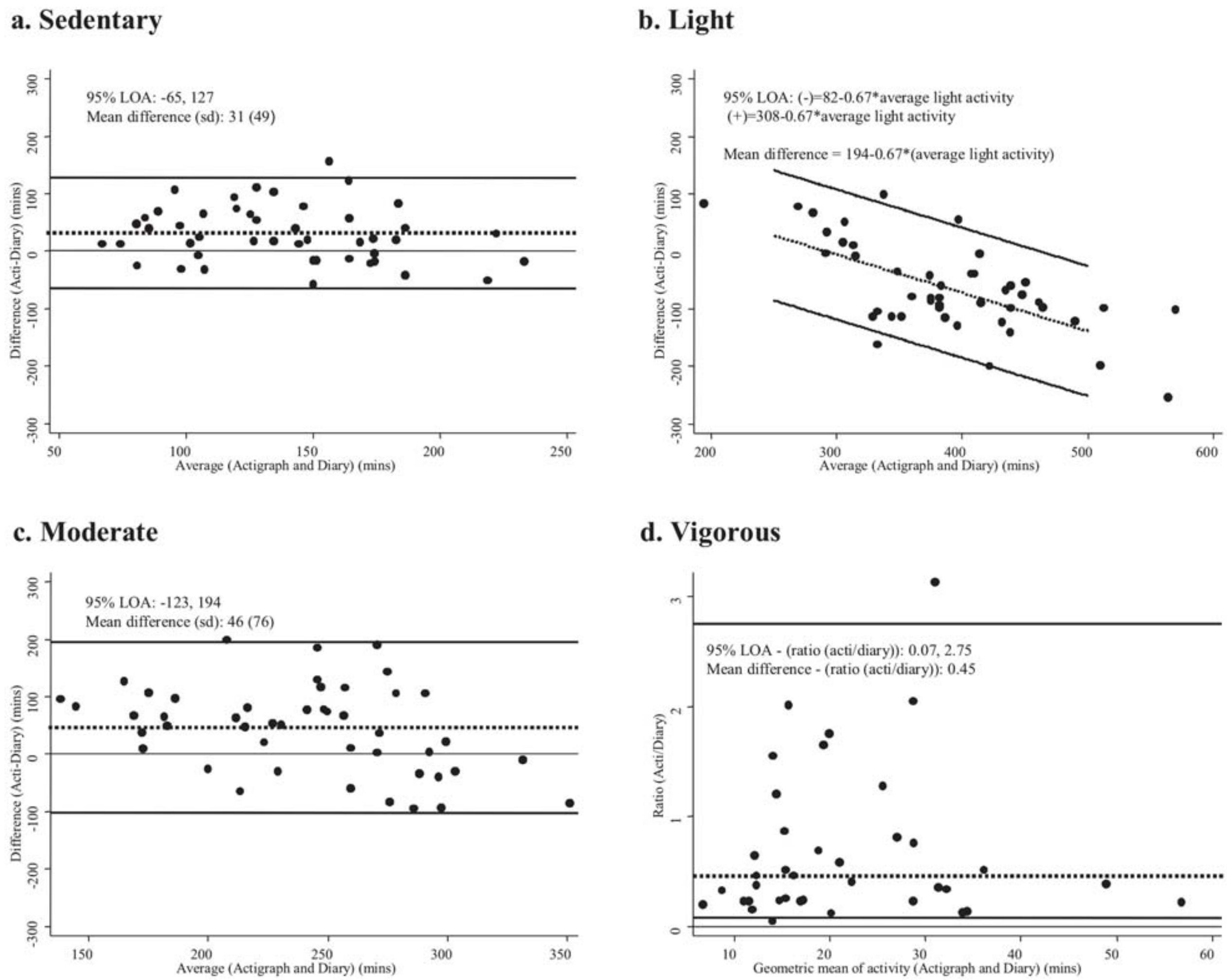

Fig.1 *Bland-Altman plots showing limits of agreement for average minutes per day spent at each activity level as measured by the Actigraph and activity diaries. For sedentary and moderate activities, the difference between Actigraph and diary-derived values, represented by the dotted line, were constant across the whole range of activity time (plots a and c). For light activity (plot b), the difference between the two methods increased as activity level increased; hence the difference is expressed as an equation, using the multiple of the activity level. For vigorous activity (plot d), the variables required log transformation. By definition, this results in limits of agreement that are on a multiplicative scale when the logged variables are back-transformed, and the difference between the two logged values becomes the ratio of the two back-transformed values.*

for the first time in pre-pubertal children in India. About 95% of children wore them for ≥4 days, the recommended period for assessing habitual activity(13), as compared to 65% of diaries with representative data. Total counts were lower than those reported from other populations(6,14-17). Children spent less than 20 minutes in vigorous intensity activities. A review suggests that Asian children in the UK are less active than white or other non-Asian children(18). Alternatively, parents might have curtailed children's activities to facilitate diary recording. Reduced outdoor spaces, increased television viewing, and fierce academic competition reduce activity levels in Indian children(5). Decreased activity behavior due to fetal programming(19), and the 'low muscle-high adipose' Indian body composition may be the other explanations. Gender difference was not evident in our cohort. Earlier studies have observed lower activities in girls than boys during pubertal(20), and pre-pubertal years(15,16), though others observed no differences in pre-pubertal children(21). Our study may have been underpowered to identify sex differences. Alternatively, the boys may have little

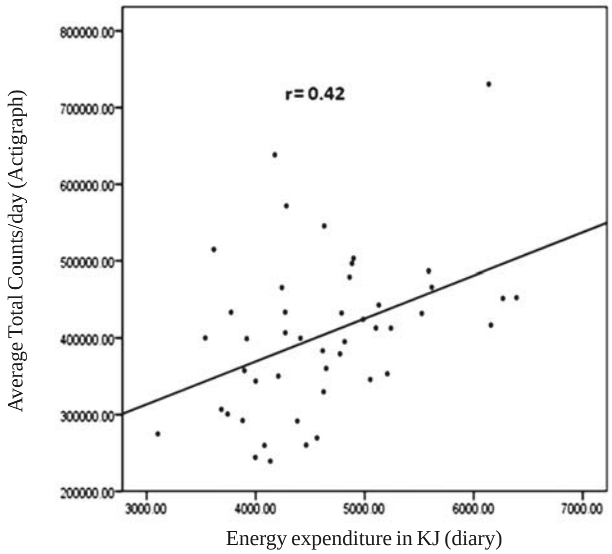

FIG. 2 *Scatterplot illustrating the correlation between Actigraph counts, and wake-time energy expenditure calculated using diaries.*

scope to be active in this urban setting, thus children of both sexes spend their leisure time in sedentary activities.

Our main purpose was to test the use of accelerometer-derived activity in categorizing children as sedentary or active. Using a simple exercise, we derived counts representing different activity levels for our population. Counts increased linearly with the intensity of the structured activities. Significant correlations with the diaries suggested that the Actigraph was measuring activity similarly to another commonly-used field tool. Both methods were consistent in mapping the duration of sedentary, light and moderate activities similarly, even on day-to-day observations. Poor correlations were observed for day-6 sedentary activities. The children with 6 days of monitoring were fewer than for other days. Parents may have become less observant towards the end, though we do not know why it did not affect other activities. Correlations were poor with vigorous activities. Accelerometers may not capture higher intensity activities effectively; they underestimate activities that do not involve much body displacement such as cycling(22). Alternatively, diaries may be unreliable, incomplete and biased; subject recalls/diaries tend to overestimate time spent in higher intensity activities(23).

Table IV CROSS-TABULATION OF NUMBER OF STUDY CHILDREN ACCORDING TO THIRDS OF TOTAL COUNTS AND ENERGY EXPENDITURE

		Thirds of Energy Expenditure (diary) kJ		
		Lowest	Middle	Highest
Thirds of total counts (Actigraph)	Lowest	9 (19.6%)	4 (8.7%)	2 (4.3%)
	Middle	4 (8.7%)	7 (15.2%)	5 (10.9%)
	Highest	2 (4.3%)	5 (10.9%)	8 (17.4%)

Values given are N (%); k=0.28, P=0.007.

There was moderate agreement (r=0.4, κ=0.3) between total counts and EE calculated from diaries; >50% of the children were placed in comparable activity tertiles by both methods, while <10% were grossly miscategorized. Though few, studies in children validating Actigraphs using free-living TEE and Physical Activity Level (PAL) measured from doubly-labeled water (DLW) method have shown significant correlations (r=0.3 to 0.8)(12), comparable with our findings. In a study from the USA validating parents' records using PARs (METs) derived from Actigraph data, hour-specific correlations ranged from '0.0' to '0.4'(13). Exact agreement would not be expected, because accelerometers measure body movement, while diaries were used to estimate EE, which is dependent on body mass, and published PAR values are derived for adults rather than children.

The Bland-Altman analysis, which tests absolute agreement between methods, showed poor agreement. Without using a 'gold-standard' method, we could not assess the merits of one tool over the other. Since diaries recorded activity every 15 minutes, and the Actigraphs every minute, the latter may have detected different intensities during any given 15-minute period while the diaries recognized only one intensity. This may explain why bias increased with the duration of the activity.

Lower counts were associated with higher adiposity in our children. Studies among Western children have shown inverse associations between physical activity, and adiposity and other cardio-vascular risk markers(6,7). Some have also shown

WHAT IS ALREADY KNOWN?

- Accelerometers give a valid measure of physical activity in Western children. Lower activity correlates with higher adiposity and cardiovascular risk factors.

WHAT THIS STUDY ADDS?

- Accelerometers are well-tolerated in pre-pubertal Indian children, and give useful measures of total activity and activity patterns.

positive associations with fat-free mass suggesting that children with higher lean/muscle mass are either fitter and thus more active, or that physically active children develop higher lean mass.

In conclusion, describing activity levels is a first-step towards reducing sedentary behaviour, and adiposity, in India's transitioning population. We showed that in children from a developing population with low awareness of and exposure to physical activity, high compliance can be achieved for accelerometer use, and that these monitors were useful in characterizing children's activity levels. Accelerometers have limitations, and care is required in the interpretation of the data they generate. We now plan to use accelerometers to examine the determinants of physical activity behaviour and test interventions aimed at increasing physical activity in the wider cohort of children.

ACKNOWLEDGMENTS

We thank Jayakumar, Geetha, Chachyamma, Saroja, Tony Onslow, Kiran and Jane Pearce for their contributions, and Dr Ulf Ekelund, MRC Epidemiology Unit, Cambridge, UK, for providing the data reduction programme and for his help and advice. We thank Sneha-India for its support.

Contributions: GVK, SRV, ICM, SAW, CHDF: conceived and designed the study; GVK, SRV, SS, SCK acquired the data; GVK, CHDF drafted the article; GVK, ICM, AKW, SAW, PJC, DJF, CHDF: analyzed and interpreted data. All authors revised the manuscript critically for important intellectual content; and approved the final version to be published. CHDF will act as the guarantor of the study.

Funding: Parthenon Trust, Switzerland, Wellcome Trust, UK, Medical Research Council, UK.

Competing interests: None stated.

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