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Physical Activity Energy Expenditure of Adolescents in India

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Physical activity (PA) has rarely been quantified in adolescent populations undergoing economic transition; therefore relationships with disease still remain uncertain. This study assessed whether absolute PA energy expenditure (PAEE), PAEE/kg, and PAEE/kg_{FFM} could be accurately estimated using accelerometry and a questionnaire in Indian adolescents and how these values compared to those of other populations. PAEE was assessed using doubly labeled water (DLW) in 30 adolescents from Chennai, India, over seven consecutive days, simultaneous with the measurement of PA using accelerometry and a previous-week recall questionnaire. Accelerometry counts (regression analysis) and questionnaire data were used to estimate PAEE; estimates were cross-validated using the Bland–Altman method. Accelerometry data and DLW-derived PAEE were visually compared to values from four North American and European populations. For boys, 49% of the variance in DLW-derived PAEE was explained with an equation including accelerometry counts and fat-free mass (FFM). Questionnaire-derived estimates did not contribute to the explained variance in DLW-derived PAEE. The group-level PA of these Indian adolescents was successfully assessed using accelerometry, but not questionnaire. DLW-derived PAEE/kg_{FFM} (mean (s.d.): 53.0 (27.5) kJ/kg_{FFM}/day) was lower in this group than other adolescent populations in Europe and similar to those in North America. Additionally, four boys and none of the girls accumulated ≥60 min/day of accelerometry-derived moderate intensity activity, indicating low levels of PAEE and PA in these adolescents. Further research is necessary to investigate the association between PA and health outcomes in Indian adolescents.

Obesity (2010) **18,** 2212–2219. doi:10.1038/oby.2010.4

INTRODUCTION

The observed magnitude of the relationship between physical activity (PA) and health varies considerably, especially in children (1); this is largely due to the difficulties of making accurate assessments of PA energy expenditure (PAEE) and patterns of PA in large populations. PA and PAEE are highly variable between individuals and need to be accurately measured to establish the relationship with health outcomes (2,3).

The accurate measurement of total EE (TEE) in free-living situations is possible with the doubly labeled water (DLW) method but it has limited utility in large epidemiological studies due to the high costs involved. Consequently, sample sizes are usually small, especially for those studies in the developing world (4–11). No Asian populations were included in a recent review of EE estimates of children and adolescents obtained by the DLW technique (12). Over 60% of the World's population lives in Asia and there is a lack of available data regarding adolescent health behaviors in this area. It is timely to begin accurately assessing population levels of PA, and subsequently the association with health outcomes in Indian adolescents.

Although accelerometry has rarely been used in countries transitioning to a western lifestyle (12), the measurement of body movement, such as with accelerometry has been used to assess PAEE in children and adolescents in developed countries (13,14). Accelerometers have potential for use in these countries as they are relatively simple and robust devices. Questionnaires have so far been the only PA assessment method of choice in countries undergoing lifestyle transition (15–19), but most are unable to adequately assess PAEE (20).

This study aimed to determine whether the free-living PAEE of Indian adolescents can be accurately estimated using accelerometry and a previous-week recall PA questionnaire; methods that may be applicable to large-scale studies. Additionally, we examined whether PA assessed in these Indian adolescents is comparable to that from other populations.

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Received 30 July 2008; accepted 5 January 2010; published online 4 February 2010. doi:10.1038/oby.2010.4

METHODS AND PROCEDURES

Participants

Volunteers were a convenience sample of 30 adolescents, 15 boys and 15 girls, who were recruited from two urban schools in Chennai, India, through an ongoing study (21). The volunteers were fully informed of the study details in their first language and provided verbal consent and a parent provided written informed consent for their participation in the study, which was approved by the local research ethics committee (Chennai). Data were collected in late October 2005 during the Monsoon season; school was cancelled for 1 day during the measurement period due to heavy rain.

Anthropometry and body composition

The volunteers were visited at school where body weight was measured to the nearest 0.2 kg using calibrated scales (Tanita TBF-531) and height was measured to the nearest 0.1 cm using a calibrated height measure, in light clothing and without shoes and socks. Body composition was determined using resistance (Ω) which was assessed using a standard bioimpedance technique (Bodystat, Isle of Man, UK). This device is suitable for use in large field-based studies and has shown to be a reasonably valid (22) and reliable (23) measure of body composition. Total body water and fat-free mass (FFM) were calculated using the impedance index (height^2/resistance), according to equations published in a similar South Asian population using the same bioimpedance device (24). Fat mass was calculated as body weight − FFM and body fat percentage as (fat mass/body weight) × 100.

Criterion assessment

DLW (TEE and PAEE). The DLW technique was used to measure TEE and PAEE (**Figure 1**), DLW measurement occurred over seven consecutive days, simultaneous with accelerometry measurement and a previous-week recall questionnaire. Two predose urine samples were collected the day before the study started. On the first day of measurement, the volunteers drank a weighed DLW dose equivalent to 0.174 g $H_2{}^{18}O$ and 0.07 g ^2H_2O per kg of body weight, with the ^{18}O from a 10% normalized stock solution and the deuterium 99.98% sterility tested. All volunteers were instructed to provide their first postdose urine sample 24 h after DLW-dosing and then to provide one sample per day for the next 6 days. The volunteers were instructed to produce these samples at a similar time of day to their first sample and not to use the first void of the day (**Figure 1**, days 1–7). A 7-day sample collection was used to satisfy time constraints and the minimum number of days needed to produce a valid measurement of TEE by DLW (25); the sampling procedure used in this study was similar to that used previously (6). The urine samples were collected in 5 ml screw-top vials and refrigerated by volunteers until collection by the fieldworker. Samples were initially stored at −25 °C at the MV Hospital for Diabetes, Chennai, before being insulated and transported to the Medical Research Council Collaborative Centre for Human Nutrition Research, Cambridge, UK where the analysis of all samples was carried out by isotope ratio mass spectrometry (6). Standard equations (26) using Schoeller's estimation of CO_2 production (27) were used to calculate TEE, which normalizes $^2H/^{18}O$ space ratios to 1.04/1.01 = 1.03 (28,29). TEE was obtained from CO_2 production assuming a mix of carbohydrate, fat, and protein substrate oxidation (30) resulting in a respiratory quotient of 0.85.

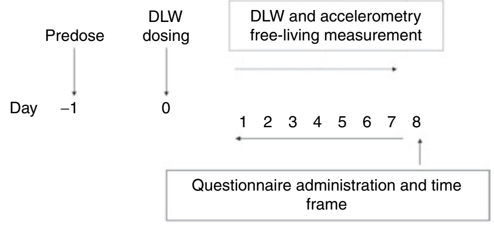

Figure 1 Timeline of measurements.

PAEE was calculated as PAEE = 0.9·measured TEE—predicted basal metabolic rate (BMR). BMR was predicted using age- and sex-specific equations: (boys: BMR = 0.068·weight + 0.57·height + 2.16 and girls: BMR = 0.035·weight + 1.95·height + 0.84) (31) and diet-induced thermogenesis was assumed to amount to 10% of TEE in all individuals (32). PAEE was expressed as absolute PAEE, PAEE/kg, and PAEE/kg_{FFM} to account for individual body size differences and due to the lack of consensus in the literature regarding the best way to normalize PAEE for body size (33–35). PA level (PAL) was also calculated to ease comparison with previously published values and calculated as TEE/BMR (36).

PA assessments

Accelerometry. PA was assessed using the GT1M Actigraph accelerometer (Actigraph LLC, Fort Walton Beach, FL). The Actigraph (formerly CSA/MTI) is probably the most commonly used accelerometer in PA research and has been shown to accurately assess EE in European children under free-living conditions (37,38). Volunteers were fitted with an Actigraph, which was worn for 7 days. The monitor was placed centrally on the hip, with the side of placement randomly assigned. The monitors were set to record acceleration and movement frequency at 5-s epochs, the shortest epoch allowing for seven consecutive days of continuous measurement. The volunteers were asked to wear the monitors during waking hours and to remove them while bathing, showering, and swimming.

The Actigraph data were processed using a custom-written program ("MAHUffe", available from www.mrc-epid.cam.ac.uk). This program allows batch analysis of Actigraph data from the original files (*.dat). Using this program, the 5-s data were reintegrated into 60-s data, but checked manually in a random sample. When 20 min of consecutive zeros were present in the accelerometry data, they were removed and it was assumed that the monitor was unworn at that time. Consequently, all days consisting of over 500 min of valid data were included in the analysis. Published thresholds (39) were used to estimate the time spent in different activity intensities. Sedentary activity was classed as <100 counts per minute (cpm) and light intensity activity as between 100 and 1,951 cpm. A lower threshold of 1,952 cpm was used to estimate time spent in moderate-to-vigorous PA (MVPA). Data from one volunteer was excluded due to insufficient days of wear and one due to monitor malfunction. Therefore, data from 28 volunteers was included in all subsequent analyses.

Questionnaire

The Youth Physical Activity Questionnaire (available at www.mrc-epid.cam.ac.uk) and previously validated in white youth (40) is based on the Children's Leisure Activities Study Survey (41) and prompts volunteers to self-report the mode, frequency and duration of PA and sedentary activities in different domains, including school time and leisure time over the past 7 days. This questionnaire lists specific activities with volunteers requested to enter the frequency and duration of each activity for both week and weekend days. This questionnaire was adapted by including three extra activities known to be commonly carried out by Indian adolescents. The questionnaire was administered the day after the last urine sample for the DLW measurement was collected (**Figure 1**; day 8), therefore the past 7-day time frame of recall matched the DLW and accelerometry measurements (**Figure 1**; days 1–7). One volunteer did not complete the questionnaire.

Frequency and duration of listed physical activities were reported and these activities were assigned a MET value according to published values (42). Metabolic equivalents (MET)-minutes were calculated as follows: duration × frequency × MET-intensity. An estimate of PAEE/kg was derived from the questionnaire, using a similar method to that described previously (43). It was assumed that 1 MET is equivalent to an oxygen consumption rate of 4.00 ml/kg/min (44). The oxygen energy equivalent was assumed to be 20.9 J/ml and the formula used to estimate PAEE/kg from the questionnaire data was: PAEE/kg (kJ/kg/day) = reported time × (0.0209 × MET equivalent) × (total MET·min/total time frame) (40,43).

Statistical analysis

Differences in anthropometric variables, PA and EE between genders were assessed using Student's *t*-tests.

The estimates of absolute PAEE (kJ/day), PAEE/kg (kJ/kg/day) and PAEE/kg$_{FFM}$ (kJ/kg$_{FFM}$/day) from the multiple regression equations including accelerometer counts were cross-validated using the Jack-knife approach ("leave-one-out"). Predictions were generated with an equation derived from all individuals except for one for whom an estimate was generated, and then this was repeated for all individuals (45). Collectively these estimates were then compared to the criterion (i.e., DLW) using Student's *t*-tests. The Bland–Altman method was then used to assess the degree of agreement between methods over the range of PAEE (kJ/day), PAEE/kg (kJ/kg/day) and PAEE/kg$_{FFM}$ (kJ/kg$_{FFM}$/day) measured in this study. The difference (estimation error) between predicted (derived using accelerometry and FFM) and criterion values of absolute PAEE was calculated (predicted—criterion) and then plotted against the mean of both methods (46).

The predictive ability of the questionnaire to estimate absolute PAEE in this group was firstly assessed by comparing questionnaire-predicted PAEE with doubly labeled water-derived PAEE using student's *t*-tests. Linear regression analysis was then used to determine the amount of variance of the criterion values explained by the questionnaire-derived estimate. The degree of agreement between these methods over the range of EEs measured in this study was assessed using the Bland–Altman method. The difference between methods (predicted—measured) was plotted against the mean of both methods (46).

DLW-derived PAEE and accelerometry-derived PA values were visually compared to other previously published worldwide values. Due to the methodological differences between studies, values were tabulated and not statistically compared.

Multiple regression analysis was used to predict absolute PAEE, PAEE/kg and PAEE/kg$_{FFM}$ from accelerometer counts (cpm). A threshold of $P < 0.05$ was used, below which, results were deemed statistically significant. Analysis was carried out using Stata 10.0 (Statacorp, College Station, TX).

RESULTS

Volunteer characteristics, including EE variables, are displayed in **Table 1**. Boys were significantly taller ($P < 0.001$) and had a higher FFM ($P = 0.003$) than the girls. Conversely, the girls had a higher BMI and fat mass ($P = 0.02$ and $P = 0.002$) than the boys. EE estimated using the DLW method and also accelerometry-derived values did not significantly differ between boys and girls. The mean EE values estimated from DLW and accelerometry did not differ for any of the models tested, mean bias and *P* values for each of these comparisons are shown in **Table 2**. The boys carried out a mean of 42.9 min of accelerometry-derived MVPA per day whereas the girls carried out a mean of 32.3 min ($P = 0.12$). Only four boys and no girls carried out a mean of at least 60 min/day of accelerometry-derived MVPA over the measurement period. There were no significant differences between boys and girls for sedentary and light intensity activity.

The regression equations derived for the prediction of absolute PAEE, PAEE/kg and PAEE/kg$_{FFM}$ using activity counts, for the whole sample and stratified by gender are displayed in **Table 2**. According to the R^2 values, 49% of the variance in DLW-derived absolute PAEE can be explained by the equation including activity counts and FFM for boys but only 6% for the girls. Examination of this regression model indicated that accelerometer counts contributed 31% additional variance

Table 1 Volunteer characteristics, displayed as mean (s.d.)

	Boys ($n = 13$)	Girls ($n = 15$)	Total ($n = 28$)	*P* value
Age (years)	15.9 (0.3)	15.7 (0.75)	15.8 (0.59)	0.37
Weight (kg)	46.1 (7.1)	49.4 (12.5)	47.9 (10.3)	0.41
Height (cm)	162.4 (5.6)	153.5 (6.9)	157.6 (7.7)	0.001
BMI	17.4 (2.6)	20.8 (4.2)	19.3 (3.9)	0.02
Fat mass (kg) (BIA)	6.7 (5.3)	15.5 (7.8)	11.3 (8.0)	0.002
Fat mass (kg) (DLW)	7.2 (5.2)	15.5 (7.8)	11.5 (7.8)	0.002
FFM (kg) (BIA)	39.0 (6.1)	33.9 (5.8)	36.3 (6.4)	0.003
FFM (kg)	39.0 (5.8)	33.9 (5.8)	36.4 (6.3)	0.02
Body fat percentage (%) (BIA)	14.3 (10.0)	29.8 (8.7)	22.3 (12.1)	<0.001
Body fat percentage (%) (DLW)	15.2 (9.7)	29.9 (8.7)	22.8 (11.7)	<0.001
BMR (kJ/day)	6,143.5 (521.6)	5,639.7 (694.7)	5,873.6 (660.8)	0.04
Doubly labeled water-derived values				
TEE (kJ/day)	9,287.2 (1,455.0)	8,433.4 (1,725.0)	8,829.8 (1,634.5)	0.17
PAEE (kJ/kg$_{FFM}$/day)	51.2 (26.3)	54.8 (29.4)	53.0 (27.5)	0.74
Accelerometry-derived values				
Sedentary (min)	466.3 (85.2)	495.5 (61.3)	481.9 (73.5)	0.30
Light activity (min)	247.4 (69.0)	281.3 (75.3)	265.6 (73.2)	0.23
MVPA (min)	42.9 (22.8)	32.3 (11.1)	37.2 (18.0)	0.12
Average daily cpm	364.6 (121.5)	314.4 (66.6)	337.7 (97.5)	0.18

P values; for the difference between genders.
cpm, accelerometry counts per minute; BIA, estimate derived from bioelectrical impedance; BMR, predicted basal metabolic rate; DLW, estimate derived from isotope dilution; FFM, fat-free mass; MVPA, moderate-to-vigorous physical activity; PAEE, physical activity energy expenditure; TEE, total energy expenditure.

Table 2 Presentation of equation and cross validation of PAEE assessed using activity counts, or a questionnaire in comparison with PAEE estimated from the DLW method

Sub group	Variable predicted	Equation	R^2	Criterion value	Predicted value	Mean bias (s.d.) *P* value	95% CI	RMSE (% of criterion)	Error correlation[a]
Accelerometry-derived estimates									
Boys (n = 13)	$\text{PAEE/kg}_{\text{FFM}}$	0.127 × cpm + 4.82	0.29	51.19 (24.77)	50.99 (15.26)	−0.19 (24.77) $P = 0.98$	−15.16, 14.77	46.49	−0.53 ($P = 0.06$)
Girls (n = 15)	$\text{PAEE/kg}_{\text{FFM}}$	0.054 × cpm + 37.87	0.06	54.78 (29.36)	55.12 (5.40)	0.35 (33.69) $P = 0.97$	−18.31, 19.01	59.42	−0.97 ($P < 0.001$)
All (n = 28)	$\text{PAEE/kg}_{\text{FFM}}$	0.11 × cpm − 9.0·sex + 20.8	0.07	53.11 (27.53)	53.08 (10.30)	−0.03 (28.26) $P = 0.99$	−11.0, 10.93	52.25	−0.76 ($P < 0.001$)
Boys (n = 13)	PAEE/kg	0.12 × cpm + 5.30	0.25	49.46 (25.51)	49.20 (14.61)	−0.26 (25.51) $P = 0.97$	−15.68, 15.16	49.56	−0.56 ($P = 0.05$)
Girls (n = 15)	PAEE/kg	0.035 × cpm + 28.85	0.06	39.87 (21.31)	40.24 (3.94)	0.36 (24.64) $P = 0.96$	−13.28, 14.01	59.72	−0.98 ($P < 0.001$)
All (n = 28)	PAEE/kg	0.10 × cpm + 4.6·sex + 8.81	0.13	44.32 (23.87)	44.28 (10.41)	−0.05 (23.94) $P = 0.99$	−9.33, 9.23	53.05	−0.69 ($P < 0.001$)
Boys (n = 13)	PAEE	4.93 × cpm + 442.7	0.18	2,239.19 (1,204.32)	2,228.11 (596.58)	−11.08 (1,223.64) $P = 0.97$	−750.52, 728.35	52.51	−0.62 ($P = 0.03$)
Girls (n = 15)	PAEE	1.68 × cpm + 1,429.9	0.07	1,959.52 (1,148.14)	1,967.98 (198.72)	8.46 (1,319.44) $P = 0.98$	−722.22, 739.14	65.10	−0.98 ($P < 0.001$)
All (n = 28)	PAEE	4.19 × cpm + 675.2	0.09	2,089.37 (1,161.17)	2,082.93 (402.51)	−6.43 (1,177.06) $P = 0.98$	−462.85, 449.98	55.32	−0.79 ($P < 0.001$)
Boys (n = 13)	PAEE	8.4 × cpm + 144.48·FFM − 6,208.86	0.49	2,239.19 (1,204.32)	2,228.18 (887.48)	−11.02 (949.04) $P = 0.97$	−584.51, 562.48	40.72	−0.37 ($P = 0.21$)
Girls (n = 15)	PAEE	0.63 × cpm + 98.08·FFM − 1,147.70	0.10	1,959.52 (1,148.14)	2,041.43 (862.10)	81.91 (1,481.79) $P = 0.83$	−738.68, 902.50	73.18	−0.28 ($P = 0.31$)
All (n = 28)	PAEE	5.60 × cpm + 101.02·FFM − 771.9·sex − 2,797.1	0.25	2,089.37 (1,161.17)	2,117.61 (759.94)	28.24 (1,170.80) $P = 0.90$	−425.75, 482.23	55.04	−0.42 ($P = 0.03$)
Boys (n = 13)	PAEE	5.17 × cpm + 15.92·weight − 379.31	0.11	2,239.19 (1,204.32)	2,414.51 (930.97)	175.32 (1,530.01) $P = 0.69$	−749.26, 1,099.90	66.11	−0.25 ($P = 0.41$)
Girls (n = 15)	PAEE	1.29 × cpm + 34.88·weight − 169.27	0.01	1,959.52 (1,148.14)	1,989.00 (664.90)	29.49 (1,447.31) $P = 0.94$	−772.01, 830.98	71.37	−0.51 ($P = 0.05$)
All (n = 28)	PAEE	4.33 × cpm + 29.2·weight + 158.9·sex − 844.01	0.09	2,089.4 (1,161.17)	2,102.0 (586.46)	12.62 (1,264.09) $P = 0.96$	−477.55, 502.78	59.41	−0.59 ($P < 0.001$)
Questionnaire-derived estimates									
Boys (n = 12)	PAEE		0.08	2,349.2 (1,187.7)	2,888.3 (1,837.3)	539.2 (2,323.1) $P = 0.44$	−936.9, 2,015.2	97.42	0.41 ($P = 0.18$)
Girls (n = 14)	PAEE		0.08	1,990.5 (1,185.0)	681.7 (526.0)	−1,308.78 (1,096.3) $P < 0.001$	−1,941.8, −675.8	84.50	−0.70 ($P = 0.005$)
All (n = 26)	PAEE		0.03	2,156.04 (1,970.31)	1,700.16 (1,699.31)	−455.88 (1,970.31) $P = 0.25$	−1,251.70, 399.95	92.07	0.35 ($P = 0.08$)

Values in $\text{kJ/kg}_{\text{FFM}}$/day for $\text{PAEE/kg}_{\text{FFM}}$; kJ/kg/day for PAEE/kg, and kJ/day for PAEE.

95% CI, 95% confidence interval; cpm, mean daily accelerometer counts per minute; mean bias, (predicted-criterion); PAEE, physical activity energy expenditure; RMSE, root mean square error.

[a] Correlation of Bland–Altman plots.

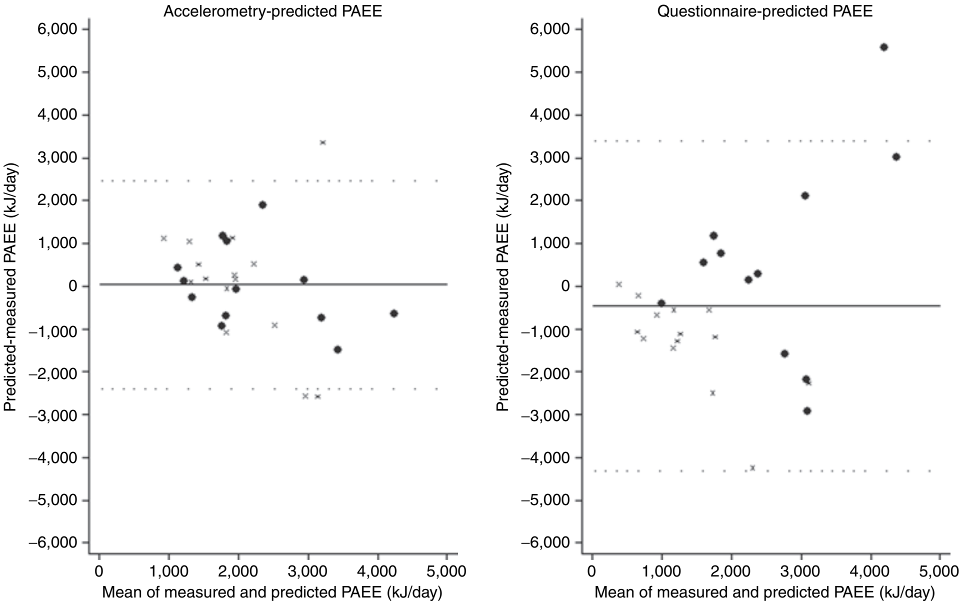

Figure 2 Bland–Altman plots of the difference (predicted-measured) against the mean of the predicted and criterion values for jack-knife cross-validation of PAEE (kJ/day) derived using activity counts and fat-free mass (left panel) and questionnaire-derived PAEE (kJ/day (right panel)) for boys (closed circles) and girls (cross symbols).

to the prediction of PAEE in boys above that explained only by FFM but didn't meaningfully change the explained variance for girls. For all equations, less variance in PAEE was explained for girls, compared to boys. The equation predicting absolute PAEE including accelerometer counts and body weight explained less variance than the equation including just cpm (11% vs. 18%) and also less than the equation including FFM (11% vs. 49%). After cross-validation, no significant differences were observed between group-level (mean) DLW-measured values and any of the accelerometry-predicted values (**Table 2**). Despite accuracy at the group-level the root mean square error ranged from 40.7 to 66.1% of the criterion value for boys and between 59.4 and 73.2% for girls. All Bland–Altman plots showed a negative correlation (**Table 2**; **Figure 1**), indicating underestimation by these equations at higher values of PAEE and consequently an over-estimation at lower values.

Questionnaire-derived PAEE and was significantly higher for boys than girls ($P = 0.01$) and was underestimated for the girls (mean bias −1,308.8 ± 1,096.3 kJ/day) and overestimated for the boys (mean bias 539.2 ± 2,323.1 kJ/day) as shown in **Table 2**. The questionnaire-derived value explained a small amount of the variance in DLW-derived absolute PAEE ($R^2 = 0.08$ for both boys and girls) (**Table 2**) and the group-level estimate for girls was significantly different from that measured by DLW ($P < 0.001$) but not for boys ($P = 0.25$). The root mean square error for the comparison between questionnaire- and DLW-derived PAEE was 97.4% of the criterion value for boys and 84.5% for girls. The questionnaire underestimated PAEE, and to a greater extent with increasing PAEE, as shown by the negative correlation between the difference of the methods and mean of the methods in the Bland–Altman plot (**Table 2**; **Figure 2**).

PA and EE values from this study are displayed alongside comparative data from European and North American adolescents in **Table 3**. The DLW- and accelerometry-derived PA data from these adolescents is lower than that from the European populations but similar to those from North America (47–52) (**Table 3**). Boys and girls in the current study carried out 43 and 32 min of MVPA, respectively, this was less than European boys (99 min) and girls (73 min) of a similar age (13) but comparable to slightly older rural Canadian boys (39 min) and girls (31 min) (52) and to 15 year-old healthy American adolescents (weekday values: boys = 51 min, girls = 26 min) (53). However, it should be noted that different intensity thresholds were used to determine time spent in MVPA in the different studies so these values are not directly comparable. The DLW-derived PAL values for boys and girls in this study were 1.52 and 1.49, respectively, these are lower than those for Swedish adolescents of a similar age (boys = 1.92 and girls = 1.78) and white American girls (1.82) (47), however, the PAL values are comparable with those of slightly younger African-American girls (1.50) (47).

DISCUSSION

PA assessed by accelerometry but not by a previous 7-day recall questionnaire appears to be able to assess group-level PAEE in this study population. Furthermore, our data suggest low levels of PAEE and PA in these adolescents.

There was a lack of statistically significant gender differences for the DLW and accelerometer derived PAEE values which could be explained by our small sample size. However, all three methods used to assess PA indicated that girls were less active than boys in this study population despite not reaching statistical significance. This may be explained by sex differences in activity profiles between boys and girls in this population.

Table 3 Comparison of studies assessing physical activity and energy expenditure of adolescents

Studies using doubly labeled water

Study	Current study	Current study	Bratteby *et al.*, (51)	Bratteby *et al.*, (51)	Wong *et al.*, (47)	Wong *et al.*, (47)
Population	Urban Indian boys	Urban Indian girls	Swedish boys	Swedish girls	White American girls	African-American girls
Age (years)	15.9 (0.3)	15.7 (0.8)	15.0 (0.1)	15.0 (0.1)	13.6 (1.7)	13.4 (1.7)
n	13	15	25	25	40	41
Mean weight (kg)	46.1 (7.1)	49.4 (12.5)	61.3 (8.5)	58.4 (7.8)	53.2 (10.6)	57.5 (13.9)
PAEE (kJ/day)	3,154 (1,487)	2,803 (1,307)	6,760	4,690	5,313 (2,642)	3,382 (2,663)
PAEE (kJ/kg_{FFM}/day)	51.2 (26.3)	54.8 (29.4)	127.0[a]	113.1[a]	149.4[b]	88.4[b]
PAL	1.52 (0.2)	1.49 (0.2)	1.92 (0.19)	1.78 (0.21)	1.82	1.50

Studies using accelerometry

Study	Current study	Current study	Riddoch *et al.*, (13)	Riddoch *et al.*, (13)	Thompson *et al.*, (52)	Thompson *et al.*, (52)
Population	Urban Indian boys	Urban Indian girls	European boys	European girls	Rural Canadian boys	Rural Canadian girls
Age (years)	15.9 (0.3)	15.7 (0.8)	15.4 (0.5)	15.4 (0.6)	16.1 (0.5)	16.2 (0.5)
n	13	15	~500[c]	~500[c]	153	219
Average movement (cpm)	365 (122)	314 (67)	615 (228)	491 (163)	—	—
Minutes of MVPA	43 (23)[d]	32 (11)[d]	99 (45)[e]	73 (32)[e]	39.4[f]	31.0[f]
% > 60 min/day	31%	0%	82%	62%	—	—

Values are mean (s.d.) where available. For (50) doubly labeled water (DLW) derived values given with PAL calculated from DLW data as TEE/BMR. MVPA is moderate-to-vigorous physical activity.

cpm, accelerometry counts per minute; BMR, predicted basal metabolic rate; FFM, fat-free mass; MVPA, moderate-to-vigorous physical activity; PAEE, physical activity energy expenditure; TEE, total energy expenditure; —, data not available.

[a] Values calculated from total daily AEE (MJ) and FFM (kg) values (54). [b] Values calculated from EEPA (kcal/day) and FFM (kg) (50). [c] Numbers per group not given, 2,185 in total for both 9- and 15-year-old boys and girls. [d] Moderate-to-vigorous activity intensity threshold, 1,952 cpm. [e] 1,500 cpm. [f] Using age specific equations (37).

Visual examination of the self-reported questionnaire data suggested that the girls reported more light intensity activities such as household chores and no sports. In contrast, boys reported sports participation and no household chores.

Estimates from all accelerometry models predicting absolute PAEE, PAEE/kg or PAEE/kg_{FFM} using activity counts, were not significantly different from that measured using DLW. For all models, more variance was explained for boys than girls. As the correlation between PAEE and activity counts was lower for girls ($r = 0.10$) than boys ($r = 0.50$), this could be contributed to by less variation in the PAEE of the girls and differences in the types of activities carried out. The equation predicting absolute PAEE using accelerometry counts and FFM explained more variance than the equation including body weight. Body weight and fat mass alone explained no variance in PAEE ($R^2 = 0.0005$ and $R^2 = 0.04$, respectively), whereas FFM alone explained 10% of the variance in PAEE. Therefore the inclusion of weight reduced the explained variance of the model. Although the root mean square error was relatively large for all of these estimates, especially for girls, it was still substantially lower than that for the questionnaire-derived estimates. Systematic error was present in these accelerometry-derived estimates, specifically an over-estimation at lower EEs and underestimation at higher values. However, the explained variance of the prediction equations presented here are within the range of studies from western countries comparing accelerometry and DLW data in youth (37,38,54,55). However, it is unlikely that any accelerometry-derived prediction equation will adequately estimate free-living PAEE on an individual basis in any population (56). Nonetheless, this study suggests that accelerometry can be used to estimate absolute PAEE, PAEE/kg and PAEE/kg_{FFM} on a group level in larger epidemiological studies in this relatively unstudied population.

The PA questionnaire used in this study was unable to provide an accurate group-level estimate of PAEE. We have recently shown that this questionnaire accurately rank estimated PAEE in 16–17-year-old British adolescents but not in 12–13-year olds when compared to DLW-derived PAEE (40). This suggests that the validity of a questionnaire is dependent on the age of the population and the cultural setting in which it is employed (40). Questionnaire-predicted PAEE for girls, but not boys, was significantly different from the DLW-derived values at a group level and the root mean square error was very high at between 84 and 97% of the criterion value. Subsequently, this questionnaire did not contribute substantially to the explained variance in PAEE for either boys or girls and it appears that this questionnaire is not suitable for use in either boys or girls in this population. Although unlikely to explain these differences in questionnaire data between boys and girls, it is interesting that the majority of the girls in this study did not report any structured activities such as participation in different sports, which are more accurately assessed by questionnaire than lighter intensity activities (57). Consequently, this questionnaire may be more suitable to assess PA in more active adolescents. Error in the questionnaire-derived estimates may at least partly be explained by the interpolation and data manipulation necessary for the derivation of PAEE from this questionnaire. Similar findings have been reported previously and it appears difficult to accurately estimate PAEE in children and adolescents, even on a group level, using self-report methods (58). It is possible that another questionnaire, such as one with a shorter frame of recall may provide more accurate estimates of PAEE, but further study would be necessary to investigate this.

We were unable to find any comparative studies of healthy adolescents of a similar age and ethnic group reporting DLW- or accelerometry-derived PA values with which to statistically compare this data. However, the PA data from this study does appear to be lower than previously published European studies (13,51) and similar to those from North America (47,52,53), although due to differences in measurement methods and data presentation it was not possible to statistically test these differences (47–52). The mean of 37 min per day spent carrying out MVPA is substantially lower than the PA recommendation for young people of at least 60 min (59,60) with none of the girls and only four (31%) of the boys meeting this recommendation. Although the BMI of these adolescents was relatively comparable to data shown in a previous study of Indian adolescents from the same city (21) these results may not be generalizable to Indian adolescents as a whole. Future population based studies using objective measures of PA are needed to refute or confirm this.

The results from this study should be interpreted with some limitations in mind including the small sample size and the use of predicted BMR. The equations used to estimate BMR were derived in a white population (31). Error in these BMR estimates may have reduced the accuracy of predicted PAEE but there is a lack of specific BMR prediction equations for Indian adolescents. We acknowledge the unknown error possibly introduced by the standard equations used here as it is unlikely that a single set of equations can be used across all ethnicities and age groups (61). We also cannot rule out the possibility that the equations used overestimated the BMR of these adolescents, if so this would directly impact on all subsequent analyses including the low PAL and PAEE levels of this population. Some error may also have been introduced into the DLW estimates as some volunteers did deviate from the instructions regarding sample timing. However, the EE estimates were derived as 24 h averages and therefore lack of adherence to the sample collection protocol should not have substantially affected the results (62). We have no reason to believe that any differential bias was introduced at any stage, so we expect that any error would have led to a dilution of any association. Data was collected during the Monsoon season, and school was cancelled for one day during the study period due to heavy rain. As DLW-dosing occurred at the beginning of the study, data collection continued as planned during this time but it is possible that this could have contributed to the low PA levels of this group and we therefore cannot generalize our results to other seasons. To our knowledge this is the first study reporting objective PA data in an indigenous Asian Indian adolescent population, using a combination of accelerometry and the DLW method.

In conclusion, accelerometry but not a questionnaire appears to be able to assess group-level PA levels in this population, although not without error. Our data suggest that the EE and PA levels of these Indian adolescents are low but further studies are necessary to confirm this. It is important to more accurately assess population levels of PA and the association with health outcomes in Indian adolescents.

ACKNOWLEDGMENTS

The Medical Research Council, UK funded this study. We are grateful to Cheryl Chapman for assistance with data collection and thanks to all of the participating children.

DISCLOSURE

The authors declared no conflict of interest.

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