Annals of Human Biology
Journal of the Society for the Study of Human Biology

http://informahealthcare.com/ahb
ISSN: 0301-4460 (print), 1464-5033 (electronic)

Ann Hum Biol, 2013; 40(4): 318–323
 DOI: 10.3109/03014460.2013.775344

informa healthcare

RESEARCH PAPER

Free-living physical activity and energy expenditure of rural children and adolescents in the Nandi region of Kenya

Robert Ojiambo[1,2], Alexander R. Gibson[1], Kenn Konstabel[1,3,4], Daniel E. Lieberman[5], John R. Speakman[6], John J. Reilly[7], and Yannis P. Pitsiladis[1,2]

[1]College of Medical, Veterinary and Life Sciences, Institute of Cardiovascular and Medical Sciences, University of Glasgow, Glasgow, UK, [2]Department of Medical Physiology, Moi University, Eldoret, Kenya, [3]National Institute for Health Development, Tallinn, Estonia, [4]Institute of Psychology, University of Tartu, Estonia, [5]Harvard University, Cambridge, MA, USA, [6]Institute of Biological and Environmental Science, Aberdeen University, Aberdeen, UK, and [7]Physical Activity for Health Group, School of Psychological Science and Health, University of Strathclyde, Glasgow, UK

Abstract

Purpose: To examine the relationship between physical activity and energy demands in children and adolescents with highly active lifestyles.
Methods: Physical activity patterns of 30 rural Kenyan children and adolescents (14 ± 1 years, mean $\pm$ SD) with median body mass index (BMI) *z*-score $= -1.06$ [-3.29–0.67] median [range] were assessed by accelerometry over 1 week. Daily energy expenditure (DEE), activity-induced energy expenditure (AEE) and physical activity level (PAL) were simultaneously determined using doubly-labelled water (DLW). Active commuting to school was assessed by global positioning system.
Results: Mean DEE, AEE and PAL were 12.2 ± 3.4, 5.7 ± 3.0 MJ/day and 2.3 ± 0.6, respectively. A model combining body mass, average accelerometer counts per minute and time in light activities predicted 45% of the variance in DEE ($p < 0.05$) with a standard error of DEE estimate of 2.7 MJ/day. Furthermore, AEE accounted for ~47% of DEE. Distance to school was not related to variation in DEE, AEE or PAL and there was no association between active commuting and adiposity.
Conclusion: High physical activity levels were associated with much higher levels of energy expenditure than observed in Western societies. These results oppose the concept of physical activity being stable and constrained in humans.

Keywords

Accelerometry, activitystat hypothesis, doubly labelled water, physical activity

History

Received 4 September 2012
Revised 23 November 2012
Accepted 7 February 2013
Published online 9 July 2013

Introduction

Western societies have experienced an obesity epidemic over the past 40 years, with over 25% of the population of many societies currently classed as obese (body mass index (BMI) >30) and an additional 40–45% overweight (BMI > 25) (Flegal et al., 2010; Onis et al., 2010; Wang & Lobstein, 2006). Obesity is a condition caused by prolonged energy imbalance where energy intake exceeds energy expenditure (Tappy et al., 2003). Whether this energy imbalance is a consequence of elevated food consumption or reduced physical activity remains a matter of intense debate. Physical activity patterns have changed substantially over the time course of the epidemic. Sedentary leisure time activities such as television viewing and computer use have increased enormously relative to the 1950s (Dollman et al., 2005). Whether these trends in physical activity have been sufficient to impact on energy expenditure is uncertain. Some argue that there has been no reduction in the level of energy expenditure in adults between the 1980s and present day in Western societies (Westerterp and Speakman 2008) and estimates of the difference in energy intake and expenditure necessary to drive the obesity epidemic suggest that this difference can be entirely accounted for by changes in food consumption rather than energy expenditure (Hall 2010; Swinburn et al., 2009). Measurements of energy expenditure in rural communities that are at a stage of economic development similar to what preceded the obesity epidemic reveal similar energy demands to those of Western societies (Luke et al., 2009; Westerterp & Speakman, 2008), despite the widespread perception of higher levels of physical activity in individuals residing in rural communities. For example, a recent assessment of total energy expenditure (TEE) in the Hadza hunter-gatherers in Tanzania did not reveal higher energy demands than Western populations and this observation challenges the view that restricted energy expenditure is the primary cause of obesity in developed countries (Pontzer et al., 2012). The finding that energy expenditure in rural communities could be in line with Western populations may reflect, in part at least, the characteristic periods of vigorous activity being compensated by prolonged periods spent in low levels of physical activity at other times of the day, which defines the 'activitystat' hypothesis first proposed by

Correspondence: Dr Yannis P. Pitsiladis, College of Medical, Veterinary and Life Sciences, Institute of Cardiovascular and Medical Sciences, University of Glasgow, West Medical Building, Glasgow G12 8QQ, UK. E-mail: yannis.pitsiladis@glasgow.ac.uk

Table 1. Descriptive characteristics of subjects.

	All Mean ± SD [Range]	Females Mean ± SD [Range]	Males Mean ± SD [Range]
n	30	15	15
Age (years)	14 ± 1 [10–17]	14 ± 1 [11–17]	14 ± 2 [10–16]
Weight (kg)	41 ± 9 [24.5–57]	43 ± 8 [28–57]	39 ± 10* [25–53]
Height (cm)	157 ± 11 [132–175]	157 ± 9 [135–173]	158 ± 13 [132–175]
BMI (kg/m^2)	16.4 ± 1.9 [14–22]	17 ± 2 [15–22]	16 ± 1* [14–18]
BMI *z*-score	−1.06 [−3.29–0.67]	−0.6 [−1.62–0.67]	−1.64* [−3.29–−0.5]
Distance to school (km)	7.5 ± 3.0 [0.8–13.4]	6 ± 3 [0.8–10]	8.9 ± 3* [3.2–13.4]
BMR (MJ/day)	5.3 ± 0.6 [4.3–6.5]	5.2 ± 0.4 [4.5–5.8]	5.4 ± 0.7 [4.3–6.5]
DEE (MJ/day)	12.2 ± 3.5 [7–20.7]	12.6 ± 3.6 [7.7–20.7]	11.8 ± 3.4 [7.0–18.4]
AEE (MJ/day)	5.7 ± 3.0 [1.5–13.1]	6.2 ± 3.1 [2.1–13.1]	5.2 ± 2.9 [1.5–10.3]
PAL	2.3 ± 0.6 [1.4–3.8]	2.4 ± 0.6 [1.6–3.8]	2.2 ± 0.5 [1.4–3.2]

*Significant differences across gender ($p < 0.05$)
BMI, Basal metabolic rate; DEE, Daily energy expenditure; BMR, Basal metabolic rate; AEE, Activity-induced energy expenditure; PAL, Physical activity level.

Rowland (1998). Furthermore, although time spent watching television in the developed world has undoubtedly increased over the past decades, this increase may have occurred during a time slot in the early evening displacing other sedentary pursuits such as reading or listening to the radio. On the other hand, a recent systematic review of trends in energy expenditure in children and adolescents over the past 50 years indicate that absolute TEE has declined, but this decline is only evident after adjusting for the increase in body mass (BM) over the period of the review (Malina & Little, 2008). Another review of the trends in physical activity over the past 50 years in the US adults also revealed a decline in occupational-related energy expenditure which would account for the increase in BM in men and women (Church et al., 2011). Previous studies of Kenyan adolescents living in rural areas reveal highly physically active lifestyles, with subjects reporting that they walked or ran on average 3 hours each day and also spent an average of 40 minutes per day working in the fields (Larsen et al., 2004; Onywera et al., 2006). This high level of self-reported physical activity would be expected to result in high levels of daily energy expenditure (DEE), activity-induced energy expenditure (AEE) and physical activity level (PAL), but studies combining measurement of energy expenditure and physical activity have been scarce in such populations. Therefore, the aim of the current study was to objectively measure the characteristically high energy demands of a rural population of Kenyan children and adolescents using the doubly labelled water (DLW) technique combined with measuring physical activity levels and patterns by accelerometry. Our hypothesis was that these rural Kenyan children and adolescents would demonstrate higher levels of activity and energy expenditure than observed in Western societies. We also hypothesized that variation in energy expenditure within the cohort would be associated with differing levels of physical activity.

Materials and methods

Subjects

A sample of 30 rural Kenyan children and adolescents (15 male, 15 female), mean age 14 ± 1 year, were recruited for this study (Table 1). Due to the high levels of illiteracy in rural Kenyan villages, verbal informed consent was sought from the study participants in line with the ethical approval received for the study by the Institutional Research Ethics Committee (IREC), Moi University, Eldoret, Kenya. This approval required parent(s)/guardian(s) to provide verbal informed consent based on the low literacy levels anticipated in this population. In addition, subjects were required to personally assent to participate in the study. It was made clear to the young participants that they were free to withdraw from the study at any stage without the need to provide any explanation. Height was measured in all subjects to the nearest 0.1 cm using a portable stadiometer (Somatometre Model SE V91, Seca, Birmingham, UK) and BM measured to the nearest 0.1 kg using portable weighing scales (Seca, Model 761, Vogel and Halke, Hamburg, Germany) and used to calculate BMI. In addition, BMI *z*-scores were calculated relative to the World Health Organization (WHO) reference data (WHO, 2007a,b).

Assessment of daily energy expenditure, activity-induced energy expenditure and physical activity level

DEE was measured over 7 days under free-living conditions using the DLW technique (Speakman, 1997). Baseline urine samples were collected before oral dosing with 0.15 g H_2O^{18} and 0.12 g ^2H_2O per kg BM. The following day, subjects provided two timed urine samples (morning and evening). This was repeated over the 7-day urine collection period. Urine samples were stored at −4 °C in cryogenically stable tubes until analysis by isotope ratio mass spectrometry. Samples were analysed in duplicate for H_2O^{18} (Speakman et al., 1990) and ^2H_2O (Speakman & Krol, 2005). Carbon dioxide production rate was estimated from the differential disappearance of the two isotopes based on multi-point elimination curves (Djafarian et al., 2010) and the dilution space evaluated from the back-extrapolated intercept using equation A6 of Schoeller et al. (1986) and was converted to energy expenditure using the Weir (1949) equation.

Prediction of basal metabolic rate (BMR) and estimation of AEE and PAL

The Henry (2005) equations based on gender, age and BM were used to predict BMR for subjects aged 10–18 years as described below:

$$\text{BMR (MJ/day)} = 0.0769\ \text{BM} + 2.43\ \text{(males)}$$
$$\text{BMR (MJ/day)} = 0.0465\ \text{BM} + 3.18\ \text{(females)}$$

where BM is body mass in kilograms. These equations have been identified as those showing the best agreement with measured BMR in children and adolescents (Henry, 2005). The predicted BMR was subsequently used to estimate AEE and PAL. AEE is the energy expenditure associated with muscular contractions involved in body movements and maintenance of posture and is the most variable component of DEE expressed as $= 0.9 \times \text{DEE} - \text{BMR}$ (Westerterp, 2003). PAL is calculated as $0.9 \times \text{DEE/BMR}$ (Westerterp, 2003).

Physical activity assessment

Free-living daily physical activity levels and patterns were quantified using the ActiTrainer uni-axial accelerometer (ActiGraph LLC, Pensacola, FL) with the recording epoch set at 15 seconds. Subjects wore the accelerometer for the same 7 consecutive days during school term time, during which DLW measurements took place. Accelerometers were mounted on the right hip of each subject using an elasticized belt and adjusted to ensure close contact with the body. Each subject was instructed to wear the accelerometer at all times except when bathing, swimming and sleeping. Subjects were simultaneously fitted with either a Timex trainer V 1.3.36 (Timex Group, USA) or GPSports Team AMS Release 1.2.1.12 (Fyshwick, Australia) global positioning system (GPS) devices during their travel from home to school to obtain daily distance travelled to school.

Accelerometer data reduction

Accelerometer data were analysed using algorithms developed in R (R Development Core Team, 2011). A set of add-on functions to R was developed that allowed R to automatically read in the accelerometer raw files, edit the data for excluding the likely non-wearing periods and compute daily summary statistics. Two rules were used for excluding data: (a) all negative counts were replaced by missing data code and (b) periods of 20 minutes or more consecutive zero counts were replaced by missing data code prior to further analysis, as recommended by Treuth et al. (2003), who found that this period of inactivity was inconsistent with monitor wear. The output generated by R included the total volume of physical activity expressed as the average accelerometer counts per minute (CPM) over the monitoring period; the number of minutes spent sedentary and in each physical activity intensity as defined by the Evenson (2008) cut-points. These are sedentary: $\leq$100 CPM, light: >100 and <2296 CPM, moderate: >2296 and <4012 CPM and vigorous physical activity: $\geq$4012 CPM. In addition, moderate-to-vigorous activity (MVPA) was calculated by combining moderate and vigorous categories (i.e. >2296 CPM) and the percentage of overall time spent in the specified activity level. A minimum of 12 hours of monitoring per day for at least 6 days including at least 1 weekend day was considered acceptable for evaluation of physical activity and sedentary time.

Statistical analysis

Descriptive statistics included calculation of means, standard deviation and range following a Shapiro-Wilk test of normality. Time spent sedentary and in vigorous activities was not normally distributed. Differences between gender groups for physical characteristics and energy expenditure measurements were tested by one-way ANOVA. To identify the factors that may be associated with DEE and objectively measured physical activity and sedentary time in the present study, total amount of physical activity (as evaluated by CPM), sedentary time and physical activity intensity (time in light; moderate, vigorous and MVPA) were assessed by hierarchical nested regression analysis. The regression models for DEE, AEE and PAL included BM and physical activity parameters as independent variables. In addition, the relationship between indices of adiposity (i.e. BMI and BMI *z*-score) and DEE or distance to school (active commuting) was examined by regression analysis. A minimum sample size of 31 subjects was considered appropriate for multiple regression analysis with three predictors, an effect size of 0.33 and power level of 0.7 at declared significance of $p < 0.05$. Statistical computations were performed using the software packages SPSS, Version 17.0 (SPSS, Inc., Chicago, IL) and R version 2.9.0 (2011).

Results

Descriptive characteristics including anthropometrics and average daily distance travelled to school (active commuting); DEE, AEE and PAL are summarized in Table 1. All subjects were monitored by uni-axial accelerometry for a daily average of 14 ± 4 hours with an average CPM of 1148 ± 244 (Table 2). Girls had significantly ($p < 0.05$) higher BMI-z scores compared to boys, i.e. -0.6 (-1.62–0.67) vs -1.55 (-3.29–-0.5); median (range) for girls vs boys, respectively). On the other hand, boys engaged in significantly ($p < 0.05$) more physical activity compared to girls (mean CPM: 1264 ± 268 vs 1032 ± 152, respectively). In addition, boys travelled significantly ($p < 0.05$) greater distances to school daily compared to girls (8.9 ± 2.8 vs 6.2 ± 2.6 km, respectively (Tables 1 and 2)). However, there was no significant difference between DEE or any of the DEE components between boys and girls (Table 1).

Relationship between physical activity, energy expenditure and indices of adiposity

Mean DEE, AEE and PAL for Kenyan children and adolescents was 12.2 ± 3.5 MJ/day, 5.7 ± 3.0 MJ/day and 2.3 ± 0.6, respectively (Table 2). Twenty-one per cent of the variance in DEE could be predicted by BM ($p < 0.05$). A model combining BM and CPM predicted 33% of the variance in DEE ($p < 0.05$). A model combining BM, CPM and time engaged in light activities predicted 45% of the variance in DEE ($p < 0.05$) (Table 3). The standard error (SE) of DEE estimates for the models ranged from 2.7–3.2 MJ/day or 21–26% of the average DEE (Table 3). A model combining BM and CPM predicted 22% of the variance in AEE ($p < 0.05$). In addition, a model combining BM, CPM and time engaged in light activities predicted 39% of the variance in AEE ($p < 0.05$). The SE of AEE estimate ranged from

Table 2. Descriptive characteristics of subjects.

	All Mean ± SD [Range]	Females Mean ± SD [Range]	Males Mean ± SD [Range]
Count per minute	1148 ± 244 [809–1843]	1032 ± 152 [809–1304]	1264 ± 268* [883–1843]
Sedentary (min)	406 [328–561]	409 [339–538]	404 [328–561]
Light (min)	244 ± 56 [132–354]	271 ± 49 [169–354]	218 ± 50* [132–298]
Moderate (min)	82 ± 30 [32–153]	77 ± 11 [57–102]	100 ± 28 [67–153]
Vigorous (min)	75 [43–113]	63 [32–92]	73* [43–113]
MVPA (min)	156 ± 33 [109–234]	140 ± 25 [109–193]	173 ± 34* [131–234]
% time sedentary	51 [39–67]	50 [39–63]	51 [39–67]
% time light	30 [17–42]	33 [20–42]	27 [17–36]
% time moderate	10 [4–19]	9 [7–13]	12* [8–19]
% time vigorous	9 [5–17]	8 [4–11]	10 [5–17]
% time MVPA	19 [14–30]	17 [14–24]	22 [16–30]

*Significant differences across gender ($p < 0.05$).
MVPA, Moderate-to-Vigorous Physical activity; min, Minutes.

Table 3. Daily energy expenditure (DEE), activity-induced energy expenditure (AEE) and physical activity level (PAL) prediction models using body mass and physical activity assessed by accelerometry.

Model	R^2	Δr^2	p	SEE	% SEE mean
DEE					
BM	21%		0.012	3.2 MJ/day	26
BM + CPM	33%	12%	0.005	3.0 MJ/day	25
BM + Light	29%	8%	0.001	3.1 MJ/day	25
BM + CPM + Light	45%	24%	0.001	2.7 MJ/day	22
AEE					
BM	10%		0.100	2.9 MJ/day	51
BM + CPM	22%	12%	0.040	2.7 MJ/day	47
BM + Light	24%	14%	0.030	2.7 MJ/day	47
BM + CPM + Light	39%	29%	0.004	2.5 MJ/day	44
PAL					
BM	3%		0.320	0.6	26
BM + CPM	12%	9%	0.180	0.6	26
BM + Light	21%	18%	0.040	0.6	26
BM + CPM + Light	34%	31%	0.012	0.5	22

CPM, Average accelerometer counts per minute; Light, Time spent engaged in Light activities; BM, Body mass; SEE, Standard Error of Estimate; Δr^2, change in R^2 relative to the first model containing body mass as the single predictor.

2.5–2.9 MJ/day or 44–51% of the average AEE (Table 3). On the other hand, 3% of the variance in PAL could be predicted by BM. A model combining BM and CPM predicted 12% of the variance in PAL; however, both models were not statistically significant ($p > 0.05$). A model combining BM, CPM and time engaged in light activities predicted 34% of the variance in PAL; which was significant ($p < 0.05$) (Table 3). The SE of PAL estimate ranged from 0.5–0.6 or 22–26% of the average PAL (Table 3). Furthermore, there was no association between variation in distance travelled to school and DEE, AEE or PAL. On the other hand, there were moderate negative correlations between BMI-*z* scores and CPM ($r = -0.6$; $p = 0.001$), vigorous activity ($r = -0.53$; $p = 0.03$) and MVPA ($r = -0.57$; $p = 0.01$). In contrast, there was no association between BMI-*z* scores and active commuting ($p = 0.96$).

Discussion

This study objectively assessed sedentary behaviour and physical activity patterns in relation to DEE and its components in a sample of Kenyan children and adolescents. The results from the present study indicate that boys had higher engagement in physical activity compared to girls. Surprisingly, there was no significant difference in DEE or any of its components across gender. This finding could be attributable to the fact that girls were significantly heavier than boys and thus differences in BM masked the effects of greater engagement in physical activity on the comparative energy expenditure profiles between boys and girls. On the other hand, habitual physical activity in Kenyan adolescents was very high compared to levels previously reported in American children (Kwon et al., 2011). Despite these high activity levels, the absolute DEE from our lean subjects was comparable to levels observed in obese American children, primarily because of the high BMR observed in these obese subjects (Treuth et al. 1998). This finding is consistent with the recent data from Hadza hunter-gatherers in Tanzania where similar DEE values were reported to a Western population but Westerners had higher BMR compared to the Hadza (Pontzer et al., 2012). Therefore, AEE must account for a greater percentage of DEE in the Hadza compared to Westerners. AEE accounted for ~47% of DEE in our cohort compared to only 26% in obese US children (Treuth et al., 1998). Consequently, absolute DEE may appear similar between hunter-gatherers, agrarian and post-industrialized societies and lead to the erroneous conclusions that energy expenditure has a limited role in the secular trends of obesity in the West (Pontzer et al., 2012), but components of DEE (i.e. AEE and BMR) are very different and thus the role of altered AEE/PAL in fuelling adiposity needs to be further explored. In the present study, Kenyan children and adolescents had a mean absolute PAL of 2.3, which was higher than levels reported for this age group in industrialized countries (Table 4). This finding appears to contradict the observation

Table 4. Comparisons of estimated physical activity levels (PAL) in Kenyan children and adolescents with estimates in post-industrial societies.

Study	Mean age	n	PAL	Country
Bandini et al. (1990)	15	14	1.88	US
Davies et al. (1991)	15	12	1.85	UK
Bratteby et al. (1997)	15	25	1.93	Sweden
This study (2012)	14	30	2.29	Kenya

by Malina & Little (2008) that mean PALs for adolescents of 14–18 years have not changed appreciably over time. However, these authors also report higher PALs in contemporary hunter-gatherers and agriculturalists than in affluent industrialized populations, which is consistent with our findings in rural Kenyan children and adolescents and in the Hadza hunter-gatherers (Pontzer et al., 2012). On the other hand, examination of the activity-time budget indicated that Kenyan adolescents spent ∼49% of the monitored time engaged in light, moderate and vigorous intensity physical activities, while engagement in vigorous activity was 9% of the monitored time or on average 75 minutes per day. As hypothesized, engagement in vigorous intensity physical activity is substantially higher than levels previously reported in a free-living US cohort using the Evenson cut-points (Kwon et al., 2011). This high engagement in physical activity was associated with a comparatively high AEE (i.e. 47% of DEE). The high AEE and PAL observed in our cohort are contrary to the 'activitystat' hypothesis proposed by Rowland (1998). Evidence favouring the 'activitystat' hypothesis includes studies where enhanced physical activity is compensated by inactivity later in the day (Metcalf et al., 2004; Wilkin et al., 2006). According to the 'activitystat' hypothesis, an increase in physical activity cannot displace inactivity since physical activity is under biological control and, therefore, highly consistent across different cultures and environments (Rowlands, 2009). In contrast to this idea, Baggett et al. (2010) found that each additional minute of MVPA was associated with 1.85 minutes less inactivity on the same day, suggesting that increased physical activity can displace inactivity. This observation and the fairly wide inter-individual variability in physical activity found in the present study favour the environment and culture over any biological constraint in determining habitual physical activity levels in children and adolescents.

Recent evidence indicates that levels of habitual physical activity of children and adolescents earlier in the century were greater compared with contemporary youth in post-industrial societies (Malina & Little, 2008), which is consistent with our previous findings in rural vs urban adolescents in Kenya (Ojiambo et al., 2012). In that study (Ojiambo et al., 2012), all the rural adolescents engaged in active transport to school (i.e. ran or walked to school), whereas half of the urban adolescents used motorized transport to get to school. In addition, other than physically active play, rural adolescents consistently reported spending part of their ''leisure time'' (defined as time away from school) engaged in physically active household chores. For example, subjects reported activities such as fetching water from distant streams and fetching firewood, gardening and running involved in cattle herding. In contrast, the urban sample studied either did not report such activities or reported these activities very infrequently. The urban subjects reported that they spent their leisure time pursuing largely sedentary activities such as studying, watching television and listening to the radio. The differences in reported physical activity profiles between rural and urban adolescents are an indication of the distinct socio-economic and built environments between these two groups. Rural areas in Kenya do not have modern amenities such as mains electricity or piped water and schools are located remotely from villages, which may help explain the more active lifestyle in the rural group in our previous study (Ojiambo et al., 2012). On the other hand, urban schools and households are served with modern necessities such as piped water and mains electricity with accessible roads and frequent motorized transportation. Consequently, urban adolescents might be expected to spend less of their leisure time engaged in such physically active chores (Ojiambo et al., 2012). In traditional poor societies whose economy is based on human labour, basic needs such as food are satisfied through investment in occupational physical activity (Bénéfice et al., 2001). Furthermore, active commuting to school appears to be the principal mode of transport in rural Kenyan school children (Larsen et al., 2004; Ojiambo et al., 2012; Onywera et al., 2006). Therefore, it was anticipated that variations in DEE would be largely the result of variations in physical activity. However, volume of physical activity (CPM) and time spent engaged in light activities were the only significant predictors of DEE, AEE and PAL. On the other hand, time engaged in moderate, vigorous and MVPA were not significant predictors of DEE, AEE or PAL.

Physical inactivity is implicated in the recent worldwide obesity epidemic (WHO, 2000). In fact, it has been previously reported that active commuting (a proxy of physical activity) is inversely related to obesity and has been suggested to explain the differences in global obesity prevalence rates (Bassett et al., 2008). However, there was no association between active commuting and either energy expenditure or indices of adiposity in this sample. This difference could be attributable to the fact that we quantified the commuting distances objectively by GPS rather than using questionnaires as was conducted in the study by Bassett et al. (2008). Conversely, indices of physical activity (i.e. CPM and time in vigorous and MVPA) were negatively correlated with indices of adiposity and consistent with our earlier findings (Ojiambo et al., 2012).

This study had several limitations. It is unclear how the the relationship between physical activity and energy expenditure may generalize in other settings since the present findings may be sample- or device-specific or may be limited to the Evenson threshold cut-points for sedentary behaviour and physical activity used in the current study. Further enquiry is therefore warranted using different accelerometer devices and cut-points in other free-living populations to determine the consistency of our findings. In addition, there was wide variability in physical activity and energy expenditure parameters; a post-hoc sample size calculation to determine the required sample size to obtain statistical power of 0.8, with three predictors and an effect size of 0.33 for a multiple regression analysis indicated a minimum sample of 37 subjects and therefore this study was slightly under-powered, thus other potentially significant relationships may have been missed.

In conclusion, objectively assessed physical activity indicates that Kenyan adolescents are very active and have high DEE, AEE and PAL values; a reflection of the active 'rural African' way of life. This finding opposes the idea that physical activity is a relatively stable and constrained physiological phenomenon in humans. Furthermore, physical activity was a significant predictor of DEE, AEE and PAL.

However, there was no association between active commuting and DEE, AEE and PAL or indices of adiposity in Kenyan adolescents.

Acknowledgements

We sincerely thank all the study participants for donating their time to facilitate this study. This study was partially supported by grants No. 7060 from the Estonian Science Foundation and no. SF0940006s12 from the Estonian Research council.

Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

References

Baggett CD, Stevens J, Catellier DJ, Evenson KR, McMurray RG, He K, Treuth MS. 2010. Compensation or displacement of physical activity in middle-school girls: the Trial of Activity for Adolescent Girls. Int J Obes 34:1193–9.

Bandini LG, Schoeller DA, Dietz WH. 1990. Energy expenditure in obese and non-obese adolescents. Pediat Res 27:198–202.

Bassett DR, Pucher J, Buehler R, Thompson DL, Crouter SE. 2008. Walking, cycling, and obesity rates in Europe, North America and Australia. J Phys Activ Health 5:795–814.

Bénéfice E, Garnier D, Ndiaye G. 2001. High levels of habitual physical activity in West African adolescent girls and relationship to maturation, growth and nutritional status: results from a 3-year prospective study. Am J Hum Bio 13:808–20.

Bratteby LE, Sandhagen B, Fan H, Samuelson G. 1997. A 7-day activity diary for assessment of daily energy expenditure validated by the doubly labeled water method in adolescents. Eur J Clin Nutr 51: 585–91.

Church TS, Thomas DM, Tudor-Locke C, Katzmarzyk PT, Earnest CP, Rodarte RQ, Martin CK, et al. 2011. Trends over 5 decades in U.S. occupation-related physical activity and their associations with obesity. PLoS One 6:e19657.

Davies PS, Livingstone MBE, Prentice AM, Coward WA, Jagger SE, Stewart C, Strain JJ, Whitehead RG. 1991. Total energy expenditure during childhood and adolescence. Proc Nutr Soc 50:14A.

Djafarian K, Jackson DM, Milne E, Roger P, Speakman JR. 2010. Doubly-labeled water: multi- and two-point methods in young children. Int J Pediatr Obes 5:102–10.

Dollman J, Norton K, Norton L. 2005. Evidence for secular trends in children's physical activity behaviour. Br J Sport Med 39:892–7.

Evenson KR, Cattellier D, Gill K, Ondrak K, McMurray RG. 2008. Calibration of two objective measures of PA for children. J Sports Sci 26:1557–65.

Flegal KM, Caroll MD, Ogden CL, Curtin LR. 2010. Prevalence and trends in obesity among US adults, 1999-2008. JAMA 303:235–41.

Hall KD. 2010. Mathematical modelling of energy expenditure during tissue deposition. Br J Nutr 104:4–7.

Henry CJK. 2005. Basal metabolic rate studies in humans: measurement and development of new equations. Public Health Nutr 8:1133–52.

Kwon S, Janz KF, Burns TL, Levy SM. 2011. Association between Light-Intensity Physical Activity and Adiposity in Childhood. Pediatr Exerc Sci 23:218–29.

Larsen HB, Chistensen DL, Nolan T, Søndergaard H. 2004. Body dimensions, exercise capacity and physical activity levels of adolescent Nandi boys in Western Kenya. Ann Hum Biol 31:159–73.

Luke A, Douglas LR, Ebersole K, Durazo-Arvizu RA, Cao G, Schoeller DA, Adeyamo A, et al. 2009. Energy expenditure does not predict weight change in either Nigerian of African American women. Am J Clin Nutr 89:169–76.

Malina RM, Little BB. 2008. Physical activity: The Present in the context of the past. Am J Human Biol 20:373–91.

Metcalf B, Voss L, Jeffery A, Perkins J, Wilkin T. 2004. Physical activity cost of the school run: impact on school children of being driven to school. BMJ 329:832–3.

Ojiambo RM, Easton C, Casajus JA, Konstabel K, Thairu K, Anjila E, Reilly JJ, Pitsiladis YP. 2012. Effect of urbanisation on objectively measured physical activity levels, sedentary behaviour and indices of adiposity in Kenyan adolescents. J Phys Activ Health 9:115–23.

Onis M, Blössner M, Borgi E. 2010. Global prevalence and trends of overweight and obesity among preschool children. Am J Clin Nutr 92: 1257–64.

Onywera VO, Scott RA, Boit MK, Pitsiladis YP. 2006. Demographic characteristics of elite Kenyan endurance runners. J Sports Sci 24: 414–22.

Pontzer H, Raichlen DA, Wood BM, Mabulla AZ, Racette SB, Marlowe FW. 2012. Hunter gatherer energetics and human obesity. PLoS One 7:e40503.

R Development Core Team. 2011. R: a language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. ISBN 3-900051-07-0. Available online at: http://www.R-project.org/ (accessed June 27, 2013).

Rowland TW. 1998. The biological basis of physical activity. Med Sci Sports Exerc 30:392–9.

Rowlands AV. 2009. Methodological approaches for investigating the biological basis for physical activity in children. Pediatr Exerc Sci 21: 273–8.

Schoeller DA, Ravussin E, Schultz Y, Acheson KJ, Baertschi P, Jequier E. 1986. Energy expenditure by doubly-labeled water: validation in humans and proposed calculation. Am J Physiol 250:R823–30.

Speakman JR. 1997. Doubly-labelled water: theory and practice. London: Chapman and Hall.

Speakman JR, Krol E. 2005. Validation of the doubly-labelled water method in a small mammal. Physiol Biochem Zool 78:650–67.

Speakman JR, Nagy KA, Masman D, Mook WG, Poppitt SD, Strathearn GE, Racey PA. 1990. Interlaboratory comparison of different analytical techniques for the determination of O^{-18} abundance. Anal Chem 62:703–8.

Swinburn B, Sacks G, Ravussin E. 2009. Increased food energy supply is more than sufficient to explain the US epidemic of obesity. Am J Clin Nutr 90:1453–6.

Tappy L, Binnert C, Schneiter PH. 2003. Energy expenditure, physical activity and body-weight control. Proc Nutr Soc 62:663–6.

Treuth MS, Figueroa-Colon R, Hunter GR, Weinsier RL, Butte NF, Goran MI. 1998. Energy expenditure and physical fitness in overweight vs non-overweight prepubertal girls. Int J Obes 22:440–7.

Treuth MS, Sherwood N, Butte NF, McClanahan B, Obarzanek E, Zhou A, Ayers C, Adolph A, Jordan J, Jacobs DR, Rochon J. 2003. Validity and reliability of activity measures in African-American girls for GEMS. Med Sci Sports Exerc 35:532–9.

Wang Y, Lobstein T. 2006. Worldwide trends in childhood overweight and obesity. Int J Ped Obes 1:11–25.

Weir JB. 1949. New methods for calculating metabolic rate with special reference to protein metabolism. J Physiol 109:1–9.

Westerterp KR. 2003. Energy metabolism and body composition; general principles. Eur Resp Monogr 24:1–10.

Westerterp KR, Speakman JR. 2008. Physical activity energy expenditure has not declined since the 1980s and matches energy expenditures of wild mammals. Int J Obes 32:1256–63.

Wilkin TJ, Mallam KM, Metcalf BS, Jeffery AN, Voss LD. 2006. Variation in physical activity lies with the child, not his environment: evidence for an 'activitystat' in young children. Int J Obes (Lond) 30: 1050–5.

World Health Organization (WHO). 2000. 2007a. Obesity: preventing and managing the global epidemic (WHO Technical Report Series 894). BMI for age GIRLS; 5 to 19 years (z-scores). Geneva: World Health Organization. Available online at: http://www.who.int/growthef/bmifa_girls_5_19years_z.pdf (accessed January 30, 2010).

World Health Organization (WHO). 2007b. BMI for age BOYS; 5 to 19 years (z-scores) Geneva: World Health Organization. Available online at: http://www.who.int/growthef/bmifa_boys_5_19years_z.pdf (accessed January 30, 2010).