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

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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 ± SD) who were of standard body mass index (BMI) 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 activity predicted 45% of the variance in DEE, AEE and PAL 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.

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.

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 (Westterterp & 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…
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 indicates 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 an average 3 hours each day and also spent an average of 40 minutes per day working in the fields (Larsen et al., 2004; Onywere 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 accelerometer. 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 from the back-extrapolated intercept using elimination curves (Djafarian et al., 2010) and the dilution space evaluated 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.

**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 H₂O¹⁸ and 0.12 g H₂O 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 H₂O¹⁸ (Speakman et al., 1990) and H₂O (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

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### Table 1. Descriptive characteristics of subjects.

<table>
<thead>
<tr>
<th></th>
<th>All</th>
<th>Females</th>
<th>Males</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>30</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>41 ± 9 [24.5–57]</td>
<td>43 ± 8 [28–57]</td>
<td>39 ± 10* [25–53]</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>16.4 ± 1.9 [14–22]</td>
<td>17 ± 2 [15–22]</td>
<td>16 ± 1* [14–18]</td>
</tr>
<tr>
<td>BMI z-score</td>
<td>-1.06 [−3.29–0.67]</td>
<td>-0.6 [−1.62–0.67]</td>
<td>-1.64* [−3.29–0.5]</td>
</tr>
<tr>
<td>Distance to school (km)</td>
<td>7.5 ± 3.0 [0.8–13.4]</td>
<td>6 ± 3 [0.8–10]</td>
<td>8.9 ± 3* [3.2–13.4]</td>
</tr>
<tr>
<td>BMR (MJ/day)</td>
<td>5.3 ± 0.6 [4.3–6.5]</td>
<td>5.2 ± 0.4 [4.5–5.8]</td>
<td>5.4 ± 0.7 [4.3–6.5]</td>
</tr>
<tr>
<td>DEE (MJ/day)</td>
<td>12.2 ± 3.5 [7–20.7]</td>
<td>12.6 ± 3.6 [7.7–20.7]</td>
<td>11.8 ± 3.4 [7.0–18.4]</td>
</tr>
<tr>
<td>AEE (MJ/day)</td>
<td>5.7 ± 3.0 [1.5–13.1]</td>
<td>6.2 ± 3.1 [2.1–13.1]</td>
<td>5.2 ± 2.9 [1.5–10.3]</td>
</tr>
<tr>
<td>PAL</td>
<td>2.3 ± 0.6 [1.4–3.8]</td>
<td>2.4 ± 0.6 [1.6–3.8]</td>
<td>2.2 ± 0.5 [1.4–3.2]</td>
</tr>
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</table>

*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.
where BMI 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 × DEE − BMR (Westerterp, 2003). PAL is calculated as 0.9 × 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: ≤100 CPM, light: >100 and <2296 CPM, moderate: ≥2296 and <4012 CPM and vigorous physical activity: ≥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...
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

**Discussion**

This study objectively assessed sedentary behaviour and physical activity patterns in relation to DEE and its components using body mass and physical activity assessed by accelerometry. 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.
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 (Ponter 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 (Bénédicte 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 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.

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Declaration of interest

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

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