Aerobic Capacity, Activity Levels and Daily Energy Expenditure in Male and Female Adolescents of the Kenyan Nandi Sub-Group

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Abstract

The relative importance of genetic and socio-cultural influences contributing to the success of east Africans in endurance athletics remains unknown in part because the pre-training phenotype of this population remains incompletely assessed. Here cardiopulmonary fitness, physical activity levels, distance travelled to school and daily energy expenditure in 15 habitually active male (13.9±1.6 years) and 15 habitually active female (13.9±1.2) adolescents from a rural Nandi primary school are assessed. Aerobic capacity (VO₂ max) was evaluated during two maximal discontinuous incremental exercise tests; physical activity using accelerometry combined with a global positioning system; and energy expenditure using the doubly labelled water method. The VO₂ max of the male and female adolescents were 73.9±5.7 ml kg⁻¹ min⁻¹ and 61.5±6.3 ml kg⁻¹ min⁻¹, respectively. Total time spent in sedentary, light, moderate and vigorous physical activities per day was 406±63 min (50% of total monitored time), 244±56 min (30%), 75±18 min (9%) and 82±30 min (10%). Average total daily distance travelled to and from school was 7.5±3.0 km (0.8–13.4 km). Mean daily energy expenditure, activity-induced energy expenditure and physical activity level was 12.2±3.4 MJ day⁻¹, 5.4±3.0 MJ day⁻¹ and 2.2±0.6. 70.6% of the variation in VO₂ max was explained by sex (partial R² = 54.7%) and body mass index (partial R² = 15.9%). Energy expenditure and physical activity variables did not predict variation in VO₂ max once sex had been accounted for. The highly active and energy-demanding lifestyle of rural Kenyan adolescents may account for their exceptional aerobic fitness and collectively prime them for later training and athletic success.


Introduction

The success of east African athletes in middle- and long-distance running over the past 40 years raises many questions about why and how this region has produced so many successful runners in endurance events ranging from 800 m to the marathon. As is also the case in Ethiopia [1], the majority of Kenya’s national and international athletes originate from the same geographical district of the country - in the case of Kenya the altitudinous Rift Valley Province - and belong to the same ethnic group - the Nilotic Kalenjin [2]. Among the Kalenjin, the Nandi sub-group have a particularly rich heritage of producing national and international athletes despite accounting for less than 3% (just under one million) of the Kenyan population [2,3,4]. Proposed explanations for the phenomenal success of Kenyan runners include genetic, environmental, cultural, socioeconomic, lifestyle and training factors [for reviews see [3,4,5,6,7]]. It is widely accepted that some varied combination of these factors contributes to the success of these athletes, but efforts to investigate, let alone partition the variance, is challenging because sporting success is influenced by both polygenic and environmental factors - some physical and some socioeconomic and cultural.

In terms of physiological factors, maximal oxygen uptake (VO₂ max), running economy and fractional utilisation of VO₂ max are considered critical factors for endurance running performance [3,9]. Comparisons of Kenyan and European runners have found that both groups have very high but similar VO₂ max values, but that African runners tend to have a lower oxygen cost of running and therefore a superior running economy [9]. A key question is whether the aforementioned differences between east African and European athletes result from training, or from “naturally” superior running economy in east Africans [10]. Previous studies in untrained (no formal or taught athletic training) Kenyan adolescents have yielded disparate findings. In one study, sedentary male adolescents from Kenya had mean VO₂ max values (47.1±1.3 ml kg⁻¹ min⁻¹) [9] comparable to their European counterparts (51.6±5.1 ml kg⁻¹ min⁻¹) [11];
whereas, the more physically active Kenyan adolescents had significantly higher values than the sedentary group (62.0 ± 2.4 ml kg⁻¹ min⁻¹; [9]). Similar studies by Larsen et al. [12] also found associations between higher levels of physical activity and superior VO₂max in male Kenyan adolescents, but with VO₂max values that were not significantly different from comparable Caucasian populations (mean VO₂max of less active individuals 50.2 ml kg⁻¹ min⁻¹ vs. 55.1 ml kg⁻¹ min⁻¹ of more active individuals). As has been observed with Kenyan athletes, the running economy of untrained Kenyan boys (range 179–246 ml kg⁻¹ km⁻¹) tends to be superior to that reported for untrained Caucasian boys of the same age [12]. The aerobic capacities of untrained Kenyan girls have not been previously reported.

Therefore, this study examined a cohort of male and female adolescents from South Nandi – a rural district of the Kenyan Rift Valley Province responsible for producing many elite Kenyan endurance runners. The study aims were to objectively measure cardiopulmonary fitness, as well as to quantify physical activity endurance runners. The study aims were to objectively measure VO₂max in male Kenyan adolescents, but with VO₂max values that were not significantly different from comparable Caucasian populations (mean VO₂max of less active individuals 50.2 ml kg⁻¹ min⁻¹ vs. 55.1 ml kg⁻¹ min⁻¹ of more active individuals).

Materials and Methods

Ethics Statement

Both children and parent(s) gave verbal informed consent to participate in the study, which was approved by the Institutional Research Ethics Committee, Moi University, Eldoret, Kenya. This was achieved and witnessed by the principle investigators (Dr. Alexander Gibson, Mr. Robert Ojiambo – who spoke the local dialect – and Dr. Yannis Pitsiladis) with the help of the children’s teachers to provide information and answer questions. Written informed consent was not collected from parents due to illiteracy. Agreement by verbal consent was documented next to each child’s name. This process was in line with the approval received from the local ethics committee.

Participants

Thirty Kenyan children known by the games teacher to have good cardiopulmonary fitness levels were selected to take part in the study. None of the subjects took part in formal or taught athletic training but all were habitually active. All commuted to and from school five days a week, four times a day (once in the morning, home and back for lunch, then home again in the evening, as was customary) over very undulating terrain. This was completed on foot, as always, with a mixture of walking and running. The number of participants was based on previous related studies as well as budget constraints given the use of the relatively expensive doubly labelled water method to objectively assess DEE. All testing took place at an altitude of approximately 2400 m. The mean ambient temperature during testing was 22.5 ± 1.8°C and mean relative humidity 55.9 ± 8.8%.

Exercise Testing

Subjects performed two identical maximal running tests on an outdoor running track. The track was constructed to traditional 400 m track dimensions with the accepted constraints and imperfections of doing so in rural Kenya. As such the track, surfaced primarily with irregular tree bark chip, contained significant undulations (≤ 5% gradient) especially around the bends. A discontinuous incremental protocol involving three-minute bouts of exercise followed by three-minute bouts of active recovery was used. Such protocols are generally well tolerated by children and typically produce reliable and valid VO₂max data [16,17]. Running speed was controlled by having subjects run on the outside of a cyclist on a pushbike using a calibrated speedometer. This method was considered safer for the adolescents involved but meant that they would have to run faster on each bend to keep pace with the bike on the inside. Variance in pace was also an accepted limitation under the constraints of the track and pacing strategy. For accurate measurement of running activity levels of the study population was unknown. The local guide was also blind to the specific aims and objectives of the study when identifying the school and study population. Key physical characteristics of the subjects are summarized in Table 1. In the present study focus on the indicators of cardiopulmonary fitness including VO₂max in this highly active cohort is made and findings related to the Kenyan running phenomenon. This data was generated as part of a much larger project involving a unique group of adolescents. The relationships between physical activity, energy demands and adiposity indices of this cohort in relation to obesity and the concept of an energy expenditure ceiling are described in detail elsewhere [14]. Selected pupils at this school (including some of the pupils investigated in the present study) participated in a study investigating the foot strike patterns and collision forces of these habitually barefoot pupils [12].

Experimental Design

The age of each subject was reported in years. Height was measured to the nearest 1 cm and mass to the nearest 100 g. Each child completed two maximal exercise tests as well as a week of simultaneous assessment of physical activity levels and DEE using accelerometry and doubly labelled water. Distance travelled to school (by running and walking) was objectively measured using a global positioning system (GPS) device (Timex Trainer V, Timex Group, Connecticut, USA). Each exercise test was separated by at least 7 days and did not occur during the period of assessment of activity levels and DEE. All testing took place at an altitude of approximately 2400 m. The mean ambient temperature during testing was 22.5 ± 1.8°C and mean relative humidity 55.9 ± 8.8%.

Table 1. Summary of subject ages and anthropometric measures (height and mass).

<table>
<thead>
<tr>
<th>Sex</th>
<th>n</th>
<th>Age (years)</th>
<th>Mass (kg)</th>
<th>Height (cm)</th>
<th>BMI (kg · m⁻²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>15</td>
<td>13.9 ± 1.6</td>
<td>39.2 ± 9.2</td>
<td>157.6 ± 12.8</td>
<td>55.3 ± 1.4</td>
</tr>
<tr>
<td></td>
<td>10–16</td>
<td>24.5 ± 53.0</td>
<td>132.0 ± 173.0</td>
<td>36.8 ± 18.0</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>15</td>
<td>13.9 ± 1.2</td>
<td>42.2 ± 7.7</td>
<td>157.0 ± 8.6</td>
<td>17.0 ± 2.2</td>
</tr>
<tr>
<td></td>
<td>11–17</td>
<td>28.0 ± 57.0</td>
<td>134.5 ± 172.5</td>
<td>14.6 ± 22.0</td>
<td></td>
</tr>
</tbody>
</table>

Mean values ± SD and ranges are presented. doi:10.1371/journal.pone.0066552.t001
velocity, each subject also wore a GPS device (GPSPorts Systems, Fyshwick, Australia). Subsequent to a short warm up period and habituation to the equipment, subjects began with a three-minute walk at 6 km hr⁻¹. Subjects then went immediately into a slow jog at 8 km hr⁻¹ for three minutes before returning back to a three-minute walk at 6 km hr⁻¹. After each succeeding three-minute walking-rest bout, subjects then continued with a three-minute run that was 2 km hr⁻¹ faster than the previous attained speed until volitional exhaustion. The running test was terminated when the subject stopped or when the subject began to consistently fall behind the rear wheel of the bike despite verbal encouragement. Tests were considered acceptable if maximum heart rate was either ≥95% of the predicted value (220 minus age in years) or if the subject showed signs of intense effort including breathlessness, sweating, facial flushing, unsteady gait or difficulty maintaining pace as is customary in paediatric exercise testing [16].

Cardiopulmonary variables were measured continuously throughout each test. Breath-by-breath gas analysis was conducted using a validated portable indirect-calorimetry system connected to a facemask (Cosmed K4b², Cosmed, Italy). The gas analysis system was calibrated before and after each exercise test using ambient air and a gas of a known concentration (O₂ 16.0%, CO₂ 6.0%, BOC Kenya Ltd., Nairobi, Kenya), the turbine flow meter using a three litre syringe, and time-delay by an experimenter breathing synchronously into the device. The device was worn over the shoulders of each individual so that the battery and gas analyser lay on the anterior and posterior aspects of the child’s thorax, respectively. This device has been shown to yield accurate and repeatable measurements of rate of oxygen uptake (VO₂) and carbon dioxide elimination (VCO₂) [18,19] and has previously been used in a similar population with comparable methods and conditions [13]. Heart rate was recorded by the same device using a telemetric Polar heart rate monitor chest strap (Polar Electro OY, Kempele, Finland). The combined weight of the equipment carried by each child during testing was approximately 1200 g. The addition of up to 10% of total body mass to the trunk has been shown to be well tolerated without significantly affecting VO₂ [20] and therefore this additional weight was not incorporated in the study calculations.

Physical Activity Levels and Distance Travelled to School
Physical activity levels and patterns were objectively measured for 7 consecutive days during school term time using one of 10 ActiTrain uni-axial accelerometer (Firmware version 7.5.0, ActiGraph LLC, Pensacola, FL, USA) with similar previous levels of use. The device was attached to the right hip of each subject using an elasticized belt and adjusted to ensure a tight fit. Each child was instructed to wear the device at all times except when sleeping and when bathing. The recording epoch was set at 15 s and data reduction and analysis is described below. The monitoring of activity levels was considered acceptable if a minimum of 12 h of recordings took place per day for at least six days (to include at least one Saturday or Sunday). Distance travelled to school was measured on a single occasion by asking each child to wear the GPS device along their usual route to and from school during their lunch break. Data was then multiplied by two in order to reach the total distance travelled to and from school each day.

Daily Energy Expenditure
Doubly labelled water was used for the objective assessment of DEE over the same seven days used to quantify physical activity levels. Doubly labelled water was supplied by the Energetics Research Group, part of the Institute of Biological and Environmental Sciences at the University of Aberdeen, (Aberdeen, UK) where subsequent analysis was also completed. The protocol involved the oral consumption of doubly labelled water with 0.13 g H₂O¹⁸ and 0.12 g D₂O per kg body mass [21]. Urine samples were collected from each subject prior to dosing and every day thereafter, morning and evening, for 7 consecutive days. Samples were then frozen in duplicate, along with local water samples, prior to analysis by mass spectrometry. Equation A6 of Schoeller et al. [22] was used to evaluate dilution space and to estimate the rate of carbon dioxide production from the differential disappearance of the 2 isotopes based on multi-point elimination curves. This was converted to an estimate of energy expenditure using the Weir equation [23]. The Schofield equations [24], based on age and gender, height and body mass, were used to predict basal metabolic rate (BMR) for this calculation. DEE, activity-associated energy expenditure (AEE; 0.9 X TEE – BMR) and physical activity level (PAL; TEE/BMR) are reported.

Analysis and Statistics
Accurate running speeds were calculated by averaging GPS data across each three minute running bout for each child (data not included). Cardiopulmonary variables from the last 30 s of each exercise bout were edited by removing data values that fell outside of three standard deviations from the mean (indicating ‘false’ breaths often caused by an interruption to the breathing cycle such as coughing or swallowing) and averaged and plotted on the same axes. The VO₂max reported was determined from both tests by taking the highest congruent value that lay on linear plots of both incremental tests. The anaerobic threshold was determined by the V-slope method as described by Beaver et al. [25]. Running economy was calculated using the last 30 s of the 10 km h⁻¹ loaded exercise bout to allow comparison with Kenyan pupils measured by Larsen et al. [13]. For both anaerobic threshold and running economy the mean of the two test values was taken. Means, standard deviations and ranges are reported for each sex. Accelerometer data were analysed using algorithms developed in R (version R 2.9.0, R Foundation for Statistical Computing, Vienna, Austria; http://www.R-project.org). Briefly, R was programmed to re-integrate data collected in 15 s epochs to 60 s; edit the data to exclude periods where it was likely that the accelerometer was not being worn [26] and provide summary statistics. The output generated by R included: counts per day (CPD), total monitoring time, number of minutes spent in sedentary activity and in each physical activity intensity (i.e. light, moderate, vigorous and moderate to vigorous physical activity (MVPA)), as defined by the recommended [27] Evenson’s cut-points [28] and percentage of overall time spent in the specified activity level. The use of the Evenson cut-points are in line with recent recommendations by Trost et al. [27] who argue that these cut-points provide acceptable classification accuracy for the different physical activity intensities in children between 5 and 15 years of age.

Data is expressed as mean ± SD and range following a Shapiro-Wilk test of normality. Time spent in sedentary and vigorous activities was not normally distributed, however, time in light, moderate and MVPA was. The relative influence of sex, height, activity levels and patterns, distance travelled to school and DEE on VO₂max were assessed using a model comparison approach involving regression analysis on SPSS software (SPSS, Version 17.0, SPSS, Chicago, IL, USA). Significance was declared at p<0.05.
Table 2. $\dot{V}O_{2\max}$, anaerobic threshold and running economy in the 30 untrained Kenyan school children.

<table>
<thead>
<tr>
<th></th>
<th>$\dot{V}O_{2\max}$ ($\text{f} \cdot \text{min}^{-1}$)</th>
<th>$\dot{V}O_{2\max}$ (mL kg$^{-1}$ min$^{-1}$)</th>
<th>$\dot{V}O_{2\max}$ (mL kg$^{-1}$ km$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\dot{V}O_{2\max}$ ($\text{f} \cdot \text{min}^{-1}$)</td>
<td>$\dot{V}O_{2\max}$ (mL kg$^{-1}$ min$^{-1}$)</td>
<td>$\dot{V}O_{2\max}$ (mL kg$^{-0.75}$ min$^{-1}$)</td>
</tr>
<tr>
<td>Boys</td>
<td>2.88 ± 0.64</td>
<td>73.9 ± 5.7</td>
<td>183.8 ± 15.0</td>
</tr>
<tr>
<td></td>
<td>1.97 ± 0.02</td>
<td>63.9 ± 8.16</td>
<td>157.3 ± 213.6</td>
</tr>
<tr>
<td>Girls</td>
<td>2.61 ± 0.31</td>
<td>61.5 ± 6.63</td>
<td>156.4 ± 10.7</td>
</tr>
<tr>
<td></td>
<td>1.93 ± 0.06</td>
<td>47.9 ± 68.9</td>
<td>131.6 ± 170.3</td>
</tr>
</tbody>
</table>

Mean running velocity recorded by GPS (expected) were: boys averaged 73.9 ± 5.0 km hr$^{-1}$, girls averaged 61.5 ± 6.3 km hr$^{-1}$, and therefore BMI was used as our best-fit model. Hence 70.6% of the variance in $\dot{V}O_{2\max}$ was explained by sex (p<0.001). Height, mass and BMI significantly predicted 81.1%, 15.0% and 15.9% of the variance respectively. Height and mass were highly correlated (R$^2$ = 0.06) and therefore BMI was used as our best-fit model. Hence 70.6% of the variance in $\dot{V}O_{2\max}$ was shared with sex and BMI. The standard error of the estimate (SEE) of $\dot{V}O_{2\max}$ in this model was 4.8 ml kg$^{-1}$ min$^{-1}$ or 7.1% of the mean $\dot{V}O_{2\max}$ (Table 4). Energy expenditure and physical activity variables, including daily distance travelled to school, did not contribute to improvements in this model.

Comparison between Boys and Girls

Boys achieved significantly higher $\dot{V}O_{2\max}$ values, were significantly more active and travelled greater distances to school than the girls, however, no significant difference in energy expenditure variables were observed between genders (data not included) and there were no correlations between inter-individual variation in $\dot{V}O_{2\max}$ and energy expenditure and physical activity variables after accounting for gender.

Discussion

In this study, 15 Kenyan boys and 15 Kenyan girls completed two maximal exercise tests on an undulating outdoor running
and DEE of each child were also objectively measured. Both male
determined. The activity levels, daily distance travelled to school
ventilatory anaerobic threshold and running economy were
reviews see [29,30]). Nevertheless,
subject selection procedures and exercise protocols and signifi-
track. On both occasions, aerobic variables including VO\textsubscript{2}\text{max},
ventilatory anaerobic threshold and running economy were
determined. The activity levels, daily distance travelled to school
and village boys (16.6 years, n = 19). The village boys had a mean
VO\textsubscript{2}\text{max} of 55.1 ml kg\textsuperscript{-1} min\textsuperscript{-1} and the town boys averaged
50.2 ml kg\textsuperscript{-1} min\textsuperscript{-1} [12]. Similar findings and conclusions were
published by Larsen et al., in 2005 [13] when comparing Nandi
town and village boys. The VO\textsubscript{2}\text{max} values of the sedentary boys
reported by these authors were similar to those of European
populations (50.3 ml kg\textsuperscript{-1} min\textsuperscript{-1}; [13]), whereas the active village
boys demonstrated a VO\textsubscript{2}\text{max} that was approximately 10% higher
(56.0 ml kg\textsuperscript{-1} min\textsuperscript{-1}; [13]) [11,31,32,33]. Average
VO\textsubscript{2}\text{max} reported in European populations for ages between
10.2 and 16.3 years are between 47.2 and 60.0 ml kg\textsuperscript{-1} min\textsuperscript{-1}
for boys and 36.9 and 53.6 ml kg\textsuperscript{-1} min\textsuperscript{-1} for girls [31,33,34,35].
Similar ranges have been reported in American and Chinese
cohorts [36,37]. Even trained, high-achieving distance runners of
similar ages in the USA [38] did not achieve the high values
attained in the present sample of Kenyan adolescents. The
VO\textsubscript{2}\text{max} values of the present study are even more remarkable if
one considers that these adolescents were tested at an altitude of
approximately 2400 m. The differences in VO\textsubscript{2}\text{max} observed in
our study and those previously reported in male, Kenyan
adolescents [12,13,9] may be due, in part at least, to the fact
that the earlier studies used motorised treadmills to elicit maximal
aerobic capacity. Despite efforts to achieve familiarity with
treadmill running, treadmill running is particularly foreign in
these rural populations and can therefore attenuate maximal
values. Our high VO\textsubscript{2}\text{max} values may also partially reflect the
very low body mass of the subjects tested in this study (Table 1).
The implications of low body mass and scaling VO\textsubscript{2}\text{max} to body
mass to achieve a size-free variable is subject to considerable
debate in the literature [39,40] and therefore outside the scope of
the present paper. VO\textsubscript{2}\text{max} values have thus been presented as
absolute values; as a ratio standard, per kilogram of body mass (ml.
kg\textsuperscript{-1} min\textsuperscript{-1}) and using allometric scaling, bodymass\textsuperscript{0.75} (ml kg\textsuperscript{-1.75} min\textsuperscript{-1}) to allow comparison with the relevant literature. Whilst no
relationship between activity levels, energy expenditure and
VO\textsubscript{2}\text{max} has been demonstrated in this population, as will be
more fully discussed, this cohort was very active as is demonstrated
in their high CPM and PAL values as well as some of the distances
commuted to and from school. Whilst no formal or taught exercise
took place, to label the group untrained would be misleading.
Although the previous studies in Kenya [9,12,13] did not measure
activity levels and daily energy expenditure, as this study has, some
of the differences in results may be as a result of a more active
population measured here whose ‘training’, with no specific goal,
was in the context of a challenging daily commute to and from school.

### Table 3. Daily physical activity, total daily distance travelled to school and daily energy expenditure characteristics in the 30 untrained Kenyan school children.

<table>
<thead>
<tr>
<th></th>
<th>Mean ± SD</th>
<th>[range]</th>
</tr>
</thead>
<tbody>
<tr>
<td>kCPD</td>
<td>932±204</td>
<td>[664–1484]</td>
</tr>
<tr>
<td>CPM</td>
<td>1148±244</td>
<td>[809–1843]</td>
</tr>
<tr>
<td>Sedentary (min)</td>
<td>406±63</td>
<td>[328–561]</td>
</tr>
<tr>
<td>Light (min)</td>
<td>244±56</td>
<td>[132–354]</td>
</tr>
<tr>
<td>Moderate (min)</td>
<td>75±18</td>
<td>[43–113]</td>
</tr>
<tr>
<td>Vigorous (min)</td>
<td>82±30</td>
<td>[32–153]</td>
</tr>
<tr>
<td>MVPA (min)</td>
<td>156±33</td>
<td>[109-234]</td>
</tr>
<tr>
<td>% time sedentary</td>
<td>50</td>
<td>[39–67]</td>
</tr>
<tr>
<td>% time light</td>
<td>30</td>
<td>[17–42]</td>
</tr>
<tr>
<td>% time moderate</td>
<td>9</td>
<td>[5–17]</td>
</tr>
<tr>
<td>% time vigorous</td>
<td>10</td>
<td>[4–19]</td>
</tr>
<tr>
<td>% time MVPA</td>
<td>19</td>
<td>[14–30]</td>
</tr>
<tr>
<td>Daily distance to school (km)</td>
<td>7.5±3.0</td>
<td>[0.8–13.4]</td>
</tr>
<tr>
<td>TEE (MJ d\textsuperscript{-1})</td>
<td>12.2±3.4</td>
<td>[7–20.7]</td>
</tr>
<tr>
<td>PAL</td>
<td>2.2±0.6</td>
<td>[1.3–3.5]</td>
</tr>
<tr>
<td>REE (MJ d\textsuperscript{-1})</td>
<td>5.6±0.6</td>
<td>[4.4–6.8]</td>
</tr>
<tr>
<td>AEE (MJ d\textsuperscript{-1})</td>
<td>5.4±3.0</td>
<td>[1.2–12.7]</td>
</tr>
</tbody>
</table>

kCPD - kilo counts per day.
CPM - Counts per day.
MVPA - Moderate to vigorous physical activity.
TEE - Total energy expenditure.
PAL - Physical activity level.
REE - Resting energy expenditure.
AEE - Activity-associated energy expenditure.

Mean values ± SD and ranges are given.
doi:10.1371/journal.pone.0066552.t003

### Table 4. VO\textsubscript{2}\text{max} prediction models.

<table>
<thead>
<tr>
<th>Dependent</th>
<th>Independent variable</th>
<th>Coefficient variable</th>
<th>P</th>
<th>Partial R\textsuperscript{2}</th>
<th>R\textsuperscript{2}</th>
<th>SE(ml kg\textsuperscript{-1} min\textsuperscript{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO\textsubscript{2}\text{max}</td>
<td>Intercept</td>
<td>86.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sex</td>
<td>9.06</td>
<td>&lt;0.001</td>
<td>54.7%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BMI</td>
<td>-1.98</td>
<td>&lt;0.001</td>
<td>15.9%</td>
<td>70.6%</td>
<td>4.83</td>
</tr>
</tbody>
</table>

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The anaerobic threshold of the subjects in this study occurred at a high percentage of their $\text{VO}_{2\text{max}}$. On average the anaerobic threshold of the boys occurred at 51.5±3.7 ml kg$^{-1}$ min$^{-1}$ or 70.0±6.5% of their $\text{VO}_{2\text{max}}$. In the girls the same threshold occurred at 46.9±6.6 ml kg$^{-1}$ min$^{-1}$ or 75.2±5.3% of their $\text{VO}_{2\text{max}}$. Compared to European adolescents, the anaerobic thresholds reported here are also high. In untrained Belgian adolescents between the ages of 10 and 17 years, anaerobic thresholds ranged between 57.9 and 67.6% of their $\text{VO}_{2\text{max}}$ for males and 53.8 to 67.8% for females [41]. These high percentages of $\text{VO}_{2\text{max}}$ may reflect the higher physical activity and DEE levels of our subjects. One study in an adult population found that this threshold occurs at 61.6% of their $\text{VO}_{2\text{max}}$ in untrained individuals and 68.8% $\text{VO}_{2\text{max}}$ in trained [42].

The mean running economy recorded for boys and girls in the current study was 270.7±21.0 and 256.7±29.3 ml kg$^{-1}$ km$^{-1}$, respectively. The boys in Larsen et al. [12] paper had a mean running economy of 221.1±17.9 ml kg$^{-1}$ km$^{-1}$ and were therefore more efficient runners than this sample. This may be accounted for by two study limitations. The first being the undulating nature of the outdoor running track used in the present study and the second, the varying nature of running speed as reflected in the recorded GPS. Such variations in gradient and running velocity will have resulted in failure to maintain exact work rates and may partially account for the lower running economy observed in our tests. Our subjects also had a lower mean age (13.9 vs. 16.6 years) and a wider range of ages (10–16 years) than previous studies [34].

The differences observed between the Kenyan village adolescents and their urban and European peers in previous studies has often been attributed to greater physical activity level observed in the rural population, especially regular walking and running in the Kenyan and Ethiopian environment. Such differences might be expected because the physical activity patterns of most children and adolescents are typically sporadic and short in nature and, therefore, may not contribute to improvements in aerobic fitness if indeed causality exists [31]. The effect of lifestyle factors such as physical activity on developmental changes in aerobic power may also be confounded by neglecting to account for changes secondary to the processes of growth, development and maturational increase in mass or exacerbation of external influences. Additionally, previous studies have not always used such objective measures of physical activity and aerobic parameters that accelerometry and indirect calorimetry afford.

Trowbridge et al. [32] reported a weak but significant relationship ($r^2 = 0.18; p<0.05$) between $\text{VO}_{2\text{max}}$ and activity related energy expenditure in young Caucasian Americans but not in African-Americans in the same age group. This difference may have been related to the intensity of exercise in which each population participates. Rutenfranz et al. [34] concluded that active children are 5–10% fitter than untrained children, findings mirrored by work completed in Kenya [9,12]. Larsen et al. [12] found a positive correlation between physical activity and $\text{VO}_{2\text{max}}$ ($r = 0.55$). In a more recent study, in which these two parameters were measured both quantitatively and accurately, 248 children of both sexes of mean age 9.8±0.6 years $\text{VO}_{2\text{max}}$ was weakly correlated with mean accelerometer counts ($r = 0.23$ in both sexes) and time spent in vigorous activity ($r = 0.32$ and 0.30) measured over four days using accelerometry and Trost cut-points [53]. The authors concluded that approximately 10% of the variability in $\text{VO}_{2\text{max}}$ was attributable to differences in both mean daily physical activity levels and time spent in vigorous physical activity [35]. Of course there is an inferred causality in these assumptions and perhaps fitter children are more active as a result of the increased capacity for physical activity.
However, running economy estimations may have been particularly affected by the undulating track surface and the non-consistent running speed as previously discussed. The authors also acknowledge that the portable indirect calorimetry system (Cosmed K4b², Cosmed, Italy) used is sometimes unreliable, particularly when using outdoors and in athletes required outdoors training and careful calibration. Whilst calibration was conducted frequently by accustomed users of the device and whilst the device had been validated by the team, indoor and outdoor, in the U.K. [18], the authors recognise that replication of results is needed to confirm the cardiorespiratory data. Notably, the introduction of an automatic, periodic recalibration during sampling has gone someway in an attempt to improve the reliability and validity of the device. In addition to this the authors acknowledge that the optimal accelerometer cut-point for measurement of MVPA remains to be established, and may vary between populations and between accelerometer models. While the error in estimation of MVPA is therefore unclear in the present study, a widely used accelerometer cut-point [23] was adopted and it is likely that any bias in measurement applied across the sample. Despite these potential sources of error neither effect the conclusions of this study and both must be considered in context of the potential pitfalls in the use of alternative methodology.

The generalisation of such data in this population is of course unknown without further study. Given previous published studies [9,12,13], it is unlikely that the study cohort is representative of adolescents in the South Nandi region of Kenya or indeed the wider east African region. Similar aerobic fitness and physical activity levels would be expected in other pupils of the school if tested; a reflection of the schools exceptional rural African setting (i.e. located close to the summit of Nandi Rock, at the end of and overlooking the escarpment). The school was not famed for developing athletes and no pupil took part in formal athletic training. Whilst some selection bias cannot be excluded, the school was identified without prior knowledge of the cardiopulmonary fitness and physical activity levels of the study population and blind to the aims and objectives of the study.

Conclusions

We describe a population of Kenyan adolescents of both sexes who have demonstrated an enormous capacity for physical activity. Physiological markers of cardiopulmonary fitness, activity levels, distance travelled daily to school and DEE were quantified. \( V_{\text{O2 max}} \) and anaerobic threshold are larger than previously documented in any paediatric population we are aware of. Activity levels and DEE are also exceptionally high. Whilst the relationship between physical activity and cardiopulmonary fitness remains incompletely understood, and whilst maturation and scaling issues complicate the picture, this data has demonstrated no correlation between activity levels, energy expenditure and \( V_{\text{O2 max}} \) within this group. However, when analysed in the context of other groups of adolescents previously studied the comparatively high \( V_{\text{O2 max}} \) and anaerobic threshold are mirrored by comparatively high measures of physical activity and energy expenditure. The highly active and energy demanding lifestyle of these children, correlated with their high physical fitness, may together prime them for later training and athletic success as well as permit the early identification of talent in this region.

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Author Contributions

Conceived and designed the experiments: YPP ARG RO JS. Performed the experiments: ARG RO YPP. Analyzed the data: ARG RO YPP JS YPP. Contributed reagents/materials/analysis tools: KK JS YPP. Wrote the paper: ARG RO DI JR JS YPP.

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