Training and Bioenergetic Characteristics in Elite Male and Female Kenyan Runners

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ABSTRACT

BILLAT, V., P.-M. LEPRETRE, A.-M. HEUGAS, M.-H. LAURENCE, D. SALIM, and J. P. KORALSZTEIN. Training and Bioenergetic Characteristics in Elite Male and Female Kenyan Runners. *Med. Sci. Sports Exerc.*, Vol. 35, No. 2, pp. 297–304, 2003. **Purpose:** This study compares the training characteristics and the physical profiles of top-class male and female Kenyan long-distance runners. **Method:** The subjects were 20 elite Kenyan runners: 13 men (10-km performance time: 10-km performance time of 28 min, 36 s ± 18 s) and 7 women (32 min, 32 s ± 65 s). The male runners were separated into high-speed training runners (HST: $N = 6$) and low-speed training runners (LST: $N = 7$) depending on whether they train at speeds equal or higher than those associated with the maximal oxygen uptake (v$\dot{V}O_{2max}$). All but one woman were high-speed training runners (female HST: $N = 6$). Subjects performed an incremental test on a 400-m track to determine $\dot{V}O_{2max}$, v$\dot{V}O_{2max}$, and the velocity at the lactate threshold (vLT). **Results:** Within each gender among the HST group, 10-km performance time was inversely correlated with v$\dot{V}O_{2max}$ (rho = −0.86, $P = 0.05$, and rho = −0.95, $P = 0.03$, for men and women, respectively). HST male runners had a higher $\dot{V}O_{2max}$, a lower (but not significantly) fraction of v$\dot{V}O_{2max}$ (F$\dot{V}O_{2max}$) at the lactate threshold, and a higher energy cost of running (ECR). Among men, the weekly training distance at v$\dot{V}O_{2max}$ explained 59% of the variance of v$\dot{V}O_{2max}$, and v$\dot{V}O_{2max}$ explained 52% of the variance of 10-km performance time. Kenyan women had a high $\dot{V}O_{2max}$ and F$\dot{V}O_{2max}$ at vLT that was lower than their male HST counterparts. ECR was not significantly different between genders. **Conclusion:** The velocity at the $\dot{V}O_{2max}$ is the main factor predicting the variance of the 10-km performance both in men and women, and high-intensity training contributes to this higher $\dot{V}O_{2max}$ among men. **Key Words:** AFRICA, $\dot{V}O_{2MAX}$, OXYGEN UPTAKE, RUNNING, PERFORMANCE

East Africa is currently producing a multitude of elite middle- and long-distance runners. No one doubts that a combination of genetics, training, environment, lifestyle, and social factors is involved (15,19). Several studies have examined the difference in physiological determinants of long-distance performance (10-km to marathon) in highly trained Caucasians and African runners. Bösch et al. (8) have reported that African long-distance runners raced at a higher percentage of maximal oxygen uptake ($\dot{V}O_{2max}$) when they performed on a treadmill a marathon at 87% of their best marathon time. Coetzer et al. (9), through extrapolating race $\dot{V}O_2$ from the $\dot{V}O_2$ versus treadmill speed relationship, have reported that African runners raced 10 km at a higher percentage of their $\dot{V}O_{2max}$ than Caucasian runners. Weston et al. (29) demonstrated that African 10-km runners have twice the time to exhaustion at 92% of peak treadmill velocity (i.e., 107% of their speed over 10 km as the peak velocity was 116.3% of the speed over 10 km). The higher fractional utilization of $\dot{V}O_{2max}$ at 10-km race pace was recently confirmed by Weston et al. (30) in African runners having the same 10-km performance time as Caucasian runners (around 32 min).

Velocity at the lactate threshold, $\dot{V}O_{2max}$, and the energy cost of running (ECR) have been reported to be key factors in performance for 10 km and more generally for long-distance running (11,16). The velocity associated with $\dot{V}O_{2max}$ (v$\dot{V}O_{2max}$), depending on both $\dot{V}O_{2max}$ and ECR, has been reported to be highly predictive for middle- and long-distance running in male and female subjects (4,5,13,18,21,23).

Kenyan women are starting to have some success on the international circuit. However, there are no available data on their physical characteristics. Previously, Tegla Loroupe was the most famous since she won The New York City

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Marathon in 1994 and holds the world record marathon in less than 2 h 21 min. Recently, a Kenyan woman (Catherine Ndereba) broke the marathon world record in Chicago, finishing in less than 2 h 20 min (2 h 18 min 47 s, hence running the 42.195 km at a pace slightly faster than 3 min 18 $s \cdot km^{-1}$, i.e., 5 min 34 $s \cdot mile^{-1}$ pace (18.2 $km \cdot h^{-1}$), and she won the New York City Marathon. Assuming that in elite female runners a marathon is run at about 85% of $v\dot{V}O_{2max}$ (7), these performances would mean that she has a $v\dot{V}O_{2max}$ not far from 21 $km \cdot h^{-1}$.

Even at a high level of performance, most of female Kenyan runners are still working and are not fully sports professional. Hence, they train fewer kilometers with fewer training sessions per week but at a higher intensity than men. Therefore, to compare energetic characteristics of female Kenyan runners versus their male counterparts, it may be significant to take into account differences in the type of training. Several studies have compared physiological characteristics between Caucasians and African runners (8,9,26,27,29,30). However, no studies have focused on the impact of the type of training on the physiological factors affecting performance among elite Kenyan runners. As for most of the elite runners, the type of training used by Kenyan runners depends on the training methods used by their coach. There are two methods. First, the quantitative approach, which we will call the "slow-speed training" (3 times per day) using tempo training at the lactate threshold and long-interval training (4 × 2000 m) at an intermediate velocity between vLT and $v\dot{V}O_{2max}$ (vΔ50) (3,12). The second method ("fast-speed training"), which is less used in men and more often in women, is the qualitative approach with fewer weekly kilometers run but including one or two weekly sessions at and above the velocity associated with $\dot{V}O_{2max}$, in addition to the long-interval training (3,6).

Therefore, the purpose of this study was 1) to test, in elite Kenyan runners, the gender effect on energetic factors of long-distance performance by comparing men with women by using the same training methods (high-speed training: HST); and 2) to appreciate the influence of the type of training, i.e., HST versus low-speed training (LST) by comparing men training with or without interval training sessions at and above $v\dot{V}O_{2max}$.

METHODS

Subjects

The subjects were 7 women and 13 men. We had a relatively small number of subject because we focused on high-level Kenyan runner men and women who are on the international race circuit, which are few in number. All of them finished in the first 30 finishers of the Kenyan Cross-Country Championship 2002 and in the first 15 for women (the best man was 16th and the best woman was 3rd). The small sample sizes ($N = 6$ and 7 for each gender and group of training) have the effect of tending to overestimate the size of population differences, because the only group differences that are likely to be detected are large ones. All the subjects belonged to the Gusii, also called Kisii, tribal group (from the city of Kisii in the Western Highlands, at 1000–1800 m of altitude). In this place were born several excellent runners who are among the world's best (e.g., Yobes Ondieki, a 5,000- and 10,000-m world record holder in the 1990s, who is now a trainer). The experiments were carried out at sea level (in Europe) in April; approximately 2 wk of the European circuit had recent races of 8 km for women and 12 km for men.

The subjects trained 10–16 times per week (120–200 km). Before participation in this study, all subjects provided voluntary written informed consent in accordance with the guidelines of the Ethical Committee of University of Paris.

Experimental Design

Between 10:00 and 13:00, the subjects performed an incremental test until exhaustion on a synthetic 400-m track in a climate of 19–22°C without wind ($<2\ m \cdot s^{-1}$, anemometer, Windwatch, Alba, Silva, Sweden). For 2 d before the test, subjects were asked to carry out light training, i.e., 60 min at a pace in which they could easily converse. They were also asked to refrain from food or beverages containing caffeine before testing. They drank no coffee; however, they drank black Kenyan tea but with a lot of warm milk 3 h before the test, as is usual before their hard morning training. Runners followed a pacing cyclist moving at the required velocity. The cyclist received audio cues via a Walkman; the cue rhythm determined the speed needed to cover 20 m. Visual marks were set at 20-m intervals along the track (inside the first lane). The velocity was checked using a GPS system (Cosmed, Rome, Italy).

This test was performed to determine $\dot{V}O_{2max}$, the velocity associated with $\dot{V}O_{2max}$ ($v\dot{V}O_{2max}$), and the running velocity at the lactate threshold (vLT) (4) (Table 1). vLT was defined as the speed at which an increase in lactate concentration corresponding to 1 $mmol \cdot L^{-1}$ occurs between 3.5 and 5 $mmol \cdot L^{-1}$ (1), and vLT was determined by two independent experimenters. From these velocities, an intermediate velocity was calculated between the velocity at vLT and $v\dot{V}O_{2max}$, the so-called vΔ50, which is usually used for long interval training (3,12). Blood was collected by the experimenters placed on the track according the stage's speed and duration of the protocol (see below). For instance, men started at a speed equal to 16 $km \cdot h^{-1}$ for 3 min, covering a distance of 800 m (2 laps). The experimenters did not move on the track. For every further stage, the runners increased their velocity by 1 $km \cdot h^{-1}$ and covered 50 m more than during previous stage. When they ran 3 min at 17 $km \cdot h^{-1}$, they covered 850 m, 900 m at 18 $km \cdot h^{-1}$, 950 m at 19 $km \cdot h^{-1}$, and 1000 m at 20 $km \cdot h^{-1}$.

ECR was defined as the ratio between the oxygen consumption ($mL \cdot min^{-1} \cdot kg^{-1}$) and the running speed ($m \cdot min^{-1}$) (13). To be sure that ECR was accurately estimated by oxygen consumption, ECR was calculated from a sublactate threshold running speed (i.e., at vLT − 1 $km \cdot h^{-1}$).

TABLE 1. Physiological factors for 10-km performance time among HST and LST, and HST male and female runners.

Factors	Effect of Type of Training among Men		*P* HST vs LST among Men	Gender Effect Women vs. Men Both Group Being HST Runners		*P* Women vs Men among HST
	HST	LST		Men	Women	
Age (yr)	26.5 ± 3.6	27.4 ± 4.1	*0.61*	26.5 ± 3.6	26.3 ± 3.4	*0.81*
Weight (kg)	53.8 ± 4.7	56.7 ± 3.7	*0.28*	53.8 ± 4.7	47.8 ± 3.5	*0.04*
Height (cm)	170 ± 4	173 ± 4	*0.17*	170 ± 4	168 ± 2	*0.10*
Fat mass (% body mass)	6.6 ± 1.1	7.4 ± 0.8	*0.17*	6.6 ± 1.1	16.0 ± 6.6	*0.01*
Age of starting running training (yr)	15.2 ± 1.8	15.4 ± 1.5	*0.76*	15.2 ± 1.8	15.3 ± 1.0	*0.80*
10-km PT (min, s)	28 min 15 s ± 15 s	28 min 54 s ± 33 s	*0.03*	28 min 15 s ± 15 s	32 min 22 s ± 35 s	*0.01*
10-km velocity ($km \cdot h^{-1}$)	21.2 ± 0.2	20.8 ± 0.4	*0.03*	21.2 ± 0.2	18.4 ± 0.3	*0.01*
10-km velocity (% $v\dot{V}O_{2peak}$)	93.8 ± 1.9	95.9 ± 1.9	*0.06*	93.8 ± 1.9	92.6 ± 0.9	*0.42*
$\dot{V}O_{2max}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	78.4 ± 2.1	74.7 ± 2.6	*0.03*	78.4 ± 2.1	68.6 ± 1.1	*0.01*
$v\dot{V}O_{2max}$ ($km \cdot h^{-1}$)	22.7 ± 0.6	21.6 ± 0.4	*0.01*	22.7 ± 0.6	19.9 ± 0.4	*0.01*
vLT ($km \cdot h^{-1}$)	20.2 ± 0.4	19.9 ± 0.4	*0.17*	20.2 ± 0.4	16.8 ± 0.8	*0.01*
$v\Delta50$ ($km \cdot h^{-1}$)	21.4 ± 0.4	20.8 ± 0.4	*0.01*	21.4 ± 0.4	18.3 ± 0.5	*0.01*
$F\dot{V}O_{2max}$ (%vLT)	88.9 ± 2.5	91.8 ± 1.2	*0.08*	88.9 ± 2.5	84.5 ± 2.8	*0.01*
ECR ($mL \cdot kg^{-1} \cdot km^{-1}$)	214 ± 6	203 ± 8	*0.01*	214 ± 6	208 ± 14	*0.14*

10-km PT:10-km performance time; $v\Delta50$, the intermediate velocity between vLT and $v\dot{V}O_{2max}$.

Data Collection Procedures

Protocol of $\dot{V}O_{2max}$ and $v\dot{V}O_{2max}$ determination. The initial speed was set at 14 and 16 $km \cdot h^{-1}$ for women and men, respectively, and was increased by 1 $km \cdot h^{-1}$ every 3 min. Each stage was separated by a 30-s rest during which a capillary blood sample was obtained from the fingertip and analyzed for lactate concentration (Lactate Pro LT, Arkray Inc., Kyoto, Japan) (25). Measurement of $\dot{V}O_2$ was performed throughout each test using a telemetric system weighing 0.7 kg, which was worn on the back and abdomen (K4b2, Cosmed) (20). Expired gases were measured, breath by breath, and averaged every 30 s. The response times of the oxygen and CO_2 analyzers are less than 120 ms to reach 90% of the flow sample. The ventilation range of the flow meter is from 0 to 300 $L \cdot min^{-1}$. The time delay of the gas analyzer (time necessary for the gas to transit through the sampling line before being analyzed) is about 500 ms. This time delay is automatically measured and is considered in the calculations when a delay calibration procedure is performed according to the manufacturer's specifications. The algorithms used in the K4b2 have been developed according to Beaver et al. (2). Before each test, the O_2 analysis system was calibrated using ambient air, whose partial O_2 composition was assumed to be 20.9% and a gas of known CO_2 concentration (5%) (K4b2 instruction manual). The calibration of the turbine flow meter of the K4b2 was performed with a 3-L syringe (Quinton Instruments, Seattle, WA). In this incremental protocol, $\dot{V}O_{2max}$ was defined as the highest $\dot{V}O_2$ obtained in a 30 s-interval, and $v\dot{V}O_{2max}$ was defined as the lowest running speed maintained for more than 1 min that elicited $\dot{V}O_{2max}$ (4). A plateau of $\dot{V}O_2$ was identified if the $\dot{V}O_2$ of the latest stage was not greater than the previous one by 1.75 $mL \cdot kg^{-1} \cdot min^{-1}$ because 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$ corresponds to the normal increase of $\dot{V}O_2$ for a 1 $km \cdot h^{-1}$ speed increment. $\dot{V}O_{2max}$ was defined as the highest 30-s oxygen uptake value reached during this incremental test with a respiratory exchange ratio greater than 1.0 (RER = $\dot{V}CO_2/\dot{V}O_2$), blood lactate greater than 8 mM, and a peak HR at least equal to 90% of the age-predicted maximum. When subjects did not reach a $\dot{V}O_2$ plateau, we considered that it was a $\dot{V}O_{2peak}$ rather than $\dot{V}O_{2max}$. However, for an easier reading, we have used the acronym $\dot{V}O_{2max}$ for all the subjects. If during the last stage, an athlete achieved $\dot{V}O_{2max}$ that was not sustained for at least 1 min, the speed during the previous stage was recorded as his $v\dot{V}O_{2max}$. If this velocity, which resulted in fatigue, was only sustained for $\geq$ 1 min and $<$ 2 min, then $v\dot{V}O_{2max}$ was considered to be equal to the velocity during the previous stage plus the half velocity increase between the last two stages, i.e., $1\ km \cdot h^{-1}/2 = 0.5\ km \cdot h^{-1}$ (17).

Data Analyses

Anthropometry. Height and weight were measured. Five skinfold measurements were made (triceps, biceps, suprailiac, subscapular, and mid-thigh) and percent body fat calculated using the formula of Durnin and Womersley (14).

Training log analysis. The final 8 wk of specific training before the 10-km trials were analyzed from the subjects training log, which was usually a diary. Five runners did not have a training book. In addition, the runner was asked to describe his or her typical week, that information being used for the runners who did not have a training diary. Two of the subjects without training diaries belonged to the fast training group. The three other ones were in the long training group. This information was confirmed by the subjects having a training book and who trained with them. Training sessions were classified according to their velocity and duration: long run of more 90 min $<$ vLT, runs = vLT; = $v\Delta50$; = $v\dot{V}O_{2max}$; $>$ $v\dot{V}O_{2max}$. The total weekly distance and number of sessions run were also reported. The number of daily training sessions was calculated by averaging the weekly training session number by seven.

The two types of training. The division between the two types of training was based on the presence of HST. Runners who trained at speeds $\geq$ $v\Delta50$, which is the intermediate velocity between the velocity at $v\dot{V}O_{2max}$, were classified as HST and the others as LST. The first type of training used so called "tempo training" at vLT (30–45

TABLE 2. Maximal and submaximal physiological responses measured in the incremental test among high level and low speed training group (HST vs LST) and HST male and female runners.

Factors	Effect of Type of Training among Men		*P* HST vs LST among Men	Gender Effect Females vs. Males		*P* Women vs Men among HST
	HST ($N = 6$)	LST ($N = 7$)		Men ($N = 6$)	Women ($N = 6$)	
HR_{max} (beats·min^{-1})	186 ± 5	187 ± 6	*0.72*	186 ± 5	185 ± 7	*0.69*
HR at vLT (beats·min^{-1})	177 ± 4	177 ± 7	*0.66*	177 ± 4	169 ± 5	*0.01*
[L] peak (mM)	10.4 ± 1.8	9.3 ± 2.0	*0.32*	10.4 ± 1.8	9.1 ± 0.9	*0.15*
[L] peak at vLT (mM)	4.3 ± 0.6	3.9 ± 0.8	*0.28*	4.3 ± 0.6	4.0 ± 0.6	*0.52*
RER_{max}	1.03 ± 0.03	1.05 ± 0.04	*0.38*	1.03 ± 0.03	1.04 ± 0.04	*0.37*
No. of subjects having reached a $\dot{V}O_2$ plateau at the end of incremental test (*N* yes/*N* no)	5	3	—	5	5	—

HR, heart rate; vLT, velocity at the lactate threshold; [L], blood lactate concentration; RER, rate of expiratory ratio.

min) and long-interval training session at vΔ50. There is a great diversity of training methods in Kenya. Kenyans are often trained by foreign coaches (Tegla Loroupe is trained by a German coach who uses the so-called tempo training at vLT (28)). Tempo training as defined by Daniels (10) is a steady 20-min run at approximately 86–88% of $\dot{V}O_{2max}$, or 90% of $v\dot{V}O_{2max}$ or maximum HR. This approximates the lactate threshold velocity, depending on the runner's characteristics. LST men trained at 15% of their training volume by using tempo training at vLT. Tempo training is by far the most popular form of training in Kenya, with runs of between 45 and 70 min. In addition, Tegla Loroupe (as our LST group) ran long-interval training (6 × 1 mile: 1609 m with a rest of 200- to 400-m jog in between) at an intermediate speed between her velocity over 3,000 m and 10,000 m. The second type of training, HST, involves less volume per week (< 160 km and < 130 km for men and women, respectively) and two interval trainings (10–20 × 400–600 m) or above at $v\dot{V}O_{2max}$ (7 × 200 m at 120% of $v\dot{V}O_{2max}$). The other interval training session is performed at vΔ50 (10 × 1000 or 5 ×2000 m). vΔ50 is close to the specific 10-km velocity. The HST men were, as with their LST runner counterparts, full-time runners. However, they had different coaches using interval training at $v\dot{V}O_{2max}$, rather than tempo training at vLT or long-interval training at vΔ50 very close to the 10-km pace. The male and female groups each contained six high-speed runners. As women had only one low-speed runner (7 for men), the influence of gender could not be evaluated in LST runners. Therefore, the influence of the type of training was studied in men only and the gender effect in HST runners only. All the women trained using HST. One of the reasons for this could be social. Indeed, except the top female runners (such as Tegla Loroupe, who is the best world performer over 20 km in 1 h 05 min 26 s), women often train alone because they have both professional and familial work. The majority of the women studied in that present study trained once per day and not on Sunday (for church and family). They chose to train at HST and carried out interval training at and above $v\dot{V}O_{2max}$ rather than tempo training at vLT.

Statistical Analysis

The nonparametric Mann and Whitney test was used to compare groups of type of training (HST vs LST) in men and the gender among HST runners. Correlations between energetic parameters and marathon performance time for each of the group were determined using the Spearman rank correlation coefficient. Results are presented as mean ± SD. Statistical significance was set at $P < 0.05$.

RESULTS

Anthropometric individual characteristics are given in Table 1. In men, different groups of training had similar anthropometric characteristics. History of training (when training was started and years of experience) was not different between the training and gender groups (Table 1).

The intermediate velocity between $v\dot{V}O_{2max}$ and vLT (so-called vΔ50) was not significantly different from the 10-km speed, whatever the gender or the type training (Table 1) ($P = 0.87$, 0.25, 0.87 for, respectively, the HST, LST, and female groups).

Gender Effect on Physiological Characteristics of Elite 10-km Kenyan Runners

Gender effect (female HST vs male HST). As expected, the height and weight of men were significantly greater and % body fat lower than in women (Table 1). All the HST runners reached a $\dot{V}O_2$ plateau, whatever the gender, except for one man and one woman (Table 2). In the HST runners group, women had significantly lower $\dot{V}O_{2max}$, $v\dot{V}O_{2max}$, and $F\dot{V}O_{2max}$ at vLT than their HST male counterparts ($P < 0.01$, Table 2). However, the ECR, even when expressed in mL·kg$^{-0.75}$·km^{-1}, was not significantly different between gender (546 ± 39 mL·kg$^{-0.75}$·km^{-1} vs 579 ± 20 mL·kg$^{-0.75}$·km^{-1}, for women and men, respectively, $P = 0.09$). In the same way, fractional utilization of $v\dot{V}O_{2max}$ at 10-km velocity was not significantly different between male and female runners (92.6 ± 0.8 vs 93.7 ± 1.9%, $P = 0.42$, for women and men, respectively). However, the difference in performance between men and women was not significantly explained by the difference in $\dot{V}O_{2max}$ (rho = 0.77, $P = 0.08$).

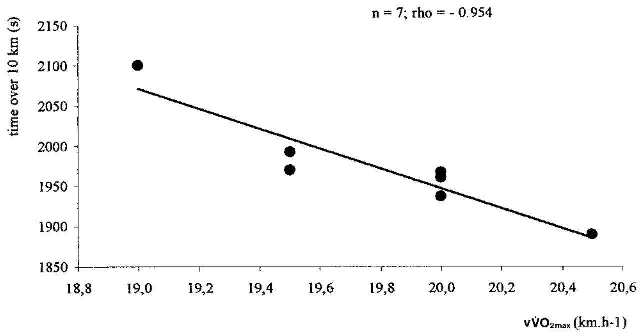

FIGURE 1—Relationship between the performance (time over 10 km in minutes) and v$\dot{V}O_{2max}$ in women.

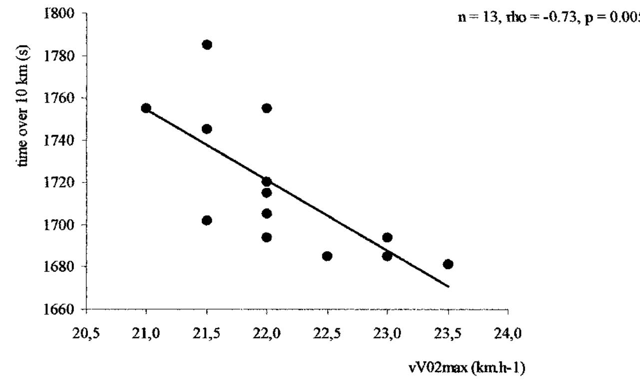

FIGURE 2—Relationship between the performance (time over 10 km in minutes) and v$\dot{V}O_{2max}$ in all the men. Four of the five best performers are in HST group.

Difference in Physiological Characteristics according Their Training Groups (Male HST vs Male LST)

HST male runners had significantly higher $\dot{V}O_{2max}$ and v$\dot{V}O_{2max}$ (78.4 ± 2.1 mL·kg^{-1}·min^{-1} vs 74.7 ± 2.6 mL·kg^{-1}·min^{-1}, $P = 0.03$ and 22.7 ± 0.6 mL·kg^{-1}·min^{-1} vs 21.6 ± 0.4 mL·kg^{-1}·min^{-1}, $P = 0.03$). However, whereas all the HST runners reached a $\dot{V}O_2$ plateau at the end of the incremental test, this was the case for only three of seven LST runners only (Table 2). The peak blood lactate reached at the end of the incremental test was not significantly different between HST and LST men (Table 2). For all the subjects, the RER was above 1.00 at the end of the incremental test (Table 2). HST runners ran faster for 10 km than the LST runners (28 min 15 s ± 15 s vs 28 min 54 s ± 33 s, $P = 0.02$), but this difference in performance was not correlated with the difference in $\dot{V}O_{2max}$ (rho = −0.61, $P = 0.17$) and of v$\dot{V}O_{2max}$ (rho = −0.66, $P = 0.51$).

HST runners had not significantly different ($P = 0.08$, Table 1) fraction of v$\dot{V}O_{2max}$ at the lactate threshold than LST runners (89.0 ± 2.5 vs 91.8 ± 1.2% of v$\dot{V}O_{2max}$ for HST and LST runners, respectively). This was similar to the fractional utilization of v$\dot{V}O_{2max}$ at their 10-km velocity (93.7 ± 1.9 vs 95.9 ± 1.9, $P = 0.06$ for HST and LST runners, respectively). HST runners were less economical than their LST counterparts, having a significant higher ECR at 19 km·h^{-1}, i.e., vLT − 1 km·h^{-1} (214 ± 6 vs 203 ± 8 mL·kg^{-1}·km^{-1}, $P = 0.01$).

Bioenergetic Predictors of Performance (Time for 10 km) in Men and Women

v$\dot{V}O_{2max}$ was the best predictor of 10-km performance in women ($N = 7$) (rho = −0.954, $P = 0.03$ for v$\dot{V}O_{2max}$ (Fig. 1). For men ($N = 13$), it was both and v$\dot{V}O_{2max}$ and vΔ50 (rho = −0.73, $P = 0.005$; rho = −0.77, $P = 0.007$) (Figs. 2 and 3). For women and men, the other bioenergetic characteristics were not correlated with 10-km performance. When, among the men, we consider separately the HST ($N = 6$) and LST ($N = 7$) groups, there was not a single predictor for performance in LST group, whereas v$\dot{V}O_{2max}$ remained well correlated with performance in the HST group (rho = −0.86, $P = 0.05$).

Training Characteristics of the Elite Kenyan 10-km Runners and Their Association with the 10-km Performance Gender Effect (HST Men vs HST Women)

Among the HST group, women trained significantly fewer weekly kilometers than their male counterparts (127 ± 8 vs 158 ± 13 km, $P < 0.03$) (Table 3). Women ran no kilometers at vLT, whereas men trained 6.3 ± 5.6% of the total distance training at vLT (10.8 ± 8.6 km). However, distances run at vΔ50 and v$\dot{V}O_{2max}$ were not significantly different among gender: 4.8 ± 5.5 vs 6.8 ± 3.8 km at v$\dot{V}O_{2max}$ for women and men ($P = 0.56$) and 10.0 ± 3.2 vs 7.8 ± 3.8 km at vΔ50 for women and men ($P = 0.32$). Considering the fact that women run less distance than men, women ran relatively more distance at these two high speeds added together (11.6 ± 3.4 vs 9.3 ± 1.3 for women and men respectively, $P = 0.05$) expressed in percentage of the total training distance. Among the HST male and female runners, no particular training characteristic was correlated significantly with 10-km performance time or with v$\dot{V}O_{2max}$.

Difference between Type of Training Groups (LST vs HST Men)

The LST male runners ran more weekly total distance (but not significantly) than their HST male counterparts

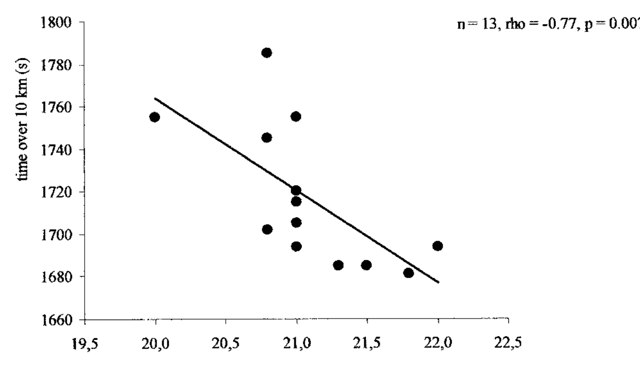

FIGURE 3—Relationship between the performance (time over 10 km in minutes) and vΔ50 in all the men. Four of the five best performers are in HST group.

TABLE 3. Training log among HST men and women runners and LST men runners; when the number is not specified, that means that all five runners did that type of training.

Training Factors	Effect of Type of Training among Men: HST ($N = 6$)	Effect of Type of Training among Men: LST ($N = 7$)	*P* HST vs LST among Men	Gender Effect Women vs. Men both HST Groups: Men ($N = 6$)	Gender Effect Women vs. Men both HST Groups: Women ($N = 6$)	*P* Men vs Women among HST Runners
Total weekly distance (km)	158 ± 19	174 ± 17	*0.01*	158 ± 19	127 ± 8	*0.03*
Weekly distance run at vLT (km)	10.8 ± 8.6 $N = 3$	25.4 ± 13.0 $N = 2$	*0.03*	10.8 ± 8.6 $N = 3$	0 ± 0 $N = 2$	*0.01*
Weekly distance run at vLT (% total weekly training distance)	6.9 ± 5.6 $N = 3$	14.4 ± 6.8 $N = 2$	*0.08*	6.9 ± 5.6 $N = 3$	0 ± 0 $N = 2$	*0.01*
Weekly distance run @ vΔ50 (km)	6.8 ± 3.8	2.4 ± 4.2 $N = 1$	*0.08*	7.8 ± 3.8	10.0 ± 3.0 $N = 4$	*0.32*
Weekly distance run @ vΔ50 (km) (% total weekly training distance)	4.3 ± 2.4	1.4 ± 6.8 $N = 2$	*0.06*	4.3 ± 2.4	3.6 ± 4.1 $N = 4$	*0.94*
Weekly distance run @ $v\dot{V}O_{2max}$ (km)	7.8 ± 3.8	0	*0.01*	6.8 ± 3.8	4.8 ± 5.5 $N = 4$	*0.56*
Weekly distance run @ $v\dot{V}O_{2max}$ (% total weekly training distance)	5.0 ± 2.6	0	*0.01*	5.0 ± 2.6	8.0 ± 2.8	*0.12*

(174 ± 17 vs 158 ± 13 km, $P = 0.38$; 2.4 ± 0.5 vs 2.5 ± 0.5 training sessions per day, $P = 0.75$). The LST runners ran significantly more distance at vLT (25.5 ± 13.0 vs 10.8 ± 8.6 km, $P = 0.03$) and almost significantly less at vΔ50 (2.4 ± 4.1 vs 6.8 ± 3.8 km, $P = 0.08$). The distance covered at $v\dot{V}O_{2max}$ determined 59% of the variance of $v\dot{V}O_{2max}$ ($R^2 = 0.591$, $P = 0.002$, $N = 13$) and was the only one characteristics entered in the stepwise regression predicting $v\dot{V}O_{2max}$ with training characteristics.

DISCUSSION

This study was the first to report: 1) physiological training characteristics and performance in elite Kenyan female long-distance runners and 2) to study the association between types of training, physical characteristics, and performance. However, we have to keep in mind that conclusions have been drawn on the basis of a cross-sectional study and the possibility that selective factors were at work that preselected athletes into either group on the basis of the very physiological variables that are then considered to have been the result of the differences in training. Because the study was not a randomized intervention trial, this possibility cannot be excluded. However, even if the only way to exclude preselection was to do a prospective randomized study, this would obviously be impossible in the real world of elite sport.

Physiological training characteristics and performance in elite Kenyan female long-distance runners. In opposition to men (5,7,9,26,27), Kenyan women had a weight that is comparable with that reported for Caucasian elite middle- and long-distance runners (5,7,18). Fat mass was not significantly different from values reported in literature in Caucasian elite long-distance runners, both in men and women (5,16,26,27). All the women reached a maximal $\dot{V}O_2$ plateau, and their $\dot{V}O_{2max}$ was similar to the highest measured in Caucasian women for the same level of performance in middle-distance running (16,18) but higher than in elite Caucasian female marathon runners (7). Kenyan 10-km elite women had a very high $v\dot{V}O_{2max}$, i.e., 20 $km \cdot h^{-1}$ on track, i.e., about 21 $km \cdot h^{-1}$ on level treadmill according to the air resistance which amounts to 8% of the total ECR at these velocities (24). All the women demonstrated a $F\dot{V}O_{2max}$ above 80% of $\dot{V}O_{2max}$ (84.5 ± 2.9), and this value is comparable to those reported in Caucasian long-distance runners (16), even in elite marathon runners previously tested in 2000 during the Olympic trials (7). $F\dot{V}O_{2max}$ obtained in women was significantly lower than in men undertaking the same type of training (HST). The fact that women did not train at vLT seemed to affect their endurance capacity. They trained at vΔ50, but this could not be effective in improving both $v\dot{V}O_{2max}$ $F\dot{V}O_{2max}$ at vLT, as reported in previous studies performed on regional runners (3). $v\dot{V}O_{2max}$ was the best predictor for 10-km performance in women. Comparing men and women at the same relative velocity without the use of allometric scaling of body weight to compare ECR and at the same high relative level of performance (Olympic minima), we found that Kenyan men and women did not have a significantly different ECR. This is in accordance with a recent study performed on elite marathon runners (7). In this present study, we measured ECR under conditions highly specific to the 10-km track pace. Both in men and women, ECR are in line with those measured on road in elite Caucasian marathon runners at their specific velocity over the marathon (7,11). Weston et al. (30) were the first to have measured the running economy of elite African runners at steady state (16.1 $km \cdot h^{-1}$) and to have matched the groups for body mass. They measured an ECR (we calculated it from the running economy at 16.1 $km \cdot h^{-1}$) equal to 187.5 and 190 $mLO_2 \cdot kg^{-1} \cdot km^{-1}$ for African and Caucasian athletes, respectively. The higher value obtained in that present study in male Kenyan long-distance runners was performed at 19 $km \cdot h^{-1}$ (vLT − 1 $km \cdot h^{-1}$) probably due to air resistance (24).

The association between types of training, physical characteristics, and performance. As in women, $\dot{V}O_{2max}$ in the men was not inordinately high as previously reported by one of the two studies of (male) Kenyans runners (26,27). Some men, the majority LST group, were unable to reach a maximal $\dot{V}O_2$ plateau. This could be due to the lack of training at high speed, which could contribute to a lack of muscular force needed to sustain high speed (22,23). However, we can assume that LST runners reached a $\dot{V}O_{2peak}$ considering their RER, blood lactate, and HR. In our study, the maximal blood lactate values were in the same range than in Coetzer et al.'s study (9) (i.e., around 9 mM). RER values at 22 $km \cdot h^{-1}$ (equivalent to 23 $km \cdot h^{-1}$ on a level treadmill) were around 1.04 and between those at 21 $km \cdot h^{-1}$ (1.01) and those at 24 $km \cdot h^{-1}$ (1.09). The highest values of $\dot{V}O_{2max}$ and $v\dot{V}O_{2max}$ were obtained in the HST male runners. It may be probable that the interval training run at and above $v\dot{V}O_{2max}$ could improve the aerobic potential of Type IIA muscle fibers, which could become more fatigue resistant. In the only study performed on elite African distance runners, Coetzer et al. (9) showed that elite black South African long-distance runners and white runners had no significant difference in $\dot{V}O_{2max}$ (71 $mL \cdot kg^{-1} \cdot min^{-1}$) but white South African middle-distance runners had a higher treadmill peak velocity (24.2 ± 1.0 vs 23.7 ± 1.3 $km \cdot h^{-1}$) according to the definition of Noakes et al. (22,23) using a 1-min stage incremental test. However, because of the difference of protocols between the present study and previous ones, we cannot compare the value of $v\dot{V}O_{2max}$ because this study was the first having reported speed measured on the track and not on a level or 3% of slope treadmill. The total (aerodynamic and nonaerodynamic) ECR ($mLO_2 \cdot kg^{-1} \cdot km^{-1}$) is probably higher on the track (24).

The fractional utilization of $v\dot{V}O_{2max}$ at the 10-km velocity in HST group (93.7 ± 1.9%) are of same order of magnitude (92%) than those reported by Coetzer et al. (9), this value being exceptional (13,16). However, considering the LST group they were still able to sustain a higher fraction of $v\dot{V}O_{2max}$ (96%) calculated at the 10-km speed. However, even if the fractional utilization of $v\dot{V}O_{2max}$ was significantly higher in LST that in HST groups, this factor was not a predictor for performance. The fact that the fractional utilization of $v\dot{V}O_{2max}$ differs with the type of training among Kenyans runners underlines the difficulty in comparing ethnic groups without matching the type of training. Only one previous study has quantified and analyzed the training characteristics of elite black long-distance runners (9). Coetzer et al. (9) reported that training type was different considering the higher average exercise training speed performed by black athletes compared with Caucasian. Indeed, this study (9) reported that runners trained 35.6 ± 17.7 vs 13.5 ± 7.1% of their weekly distance run above 80% of $\dot{V}O_{2max}$. However, the choice of 80% of $\dot{V}O_{2max}$ was rather low considering that a 10-km race is run at 92–93% of $\dot{V}O_{2max}$ with end laps at $\dot{V}O_{2max}$ (3,10). Furthermore, in Coetzer et al.'s (9) study both groups trained fewer kilometers than our subjects (90 and 80 $km \cdot wk^{-1}$), and considering their performances on 3 km and 5 km, it may be possible that they trained at a very high intensity (at or above $v\dot{V}O_{2max}$). The analysis of training might have compared the effective work at and above peak velocity, which could have been a significant determinant for performance, even for distance above 5 km, as already reported by Noakes et al. (23). We saw in the present study that the distance run at $v\dot{V}O_{2max}$ explained most of the variance in $v\dot{V}O_{2max}$.

The men who neither trained at $v\dot{V}O_{2max}$ and above have lower $\dot{V}O_{2max}$ and lower ECR and higher endurance at vLT (%$\dot{V}O_{2max}$ at vLT). $v\dot{V}O_{2max}$ was the best predictor for 10-km performance in women, whereas in men there was also $v\Delta50$. When the HST and LST groups were considered separately, $v\dot{V}O_{2max}$ remained the sole predictor for HST group, whereas there was no predictor for LST group. The present study showed that for the men $v\dot{V}O_{2max}$ and $v\Delta50$ were the primary factors explaining the variance in the 10-km performance among male runners. For the female and HST (male) groups, only $v\dot{V}O_{2max}$ was significantly correlated with performance. Noakes et al. (23) reported that for high-level male runners, peak treadmill running velocity during a progressive test was a better predictor of running performance for distances of 10–90 km or during a half marathon ($r = -0.93$ to $r = -0.83$) compared with $\dot{V}O_{2peak}$. The fact that $v\dot{V}O_{2max}$ predicts performance better than $\dot{V}O_{2max}$ did is due to the fact that $v\dot{V}O_{2max}$ integrates ECR in addition to $\dot{V}O_{2max}$. In addition, $v\Delta50$ takes into account vLT. We also showed in present study that v10 km was not significantly different from $v\Delta50$. Furthermore, this study suggests that male runners who trained faster (at or above $v\dot{V}O_{2max}$) had a greater $\dot{V}O_{2max}$ and $v\dot{V}O_{2max}$, a significantly higher ECR, and a value of $F\dot{V}O_{2max}$ that was not significantly different at the lactate threshold velocity. Indeed, in this group of male runners, those athletes who had the highest $\dot{V}O_{2max}$ were also those who had the highest ECR (7,22). More and more Kenyans athletes are trained by former Kenyan high-level runners who recommend the HST method. Indeed, one of the best current Kenyan runners, Yobes Ondieki, is one of these high-level runners. His personal training to set a world 10-km record was based on interval workouts run at slightly faster than world-record pace (28) (e.g., near $v\dot{V}O_{2max}$). He would cover a full 10 km during an interval workout, with short recoveries. The idea was to mimic the overall effort required for a world-record performance, while at the same time making record pace feel more comfortable as it would actually be a bit slower than interval-training pace. This kind of interval training had been already performed by a Finnish runner, Hannes Kolehmainen, a century ago, a pioneer of interval training (7). Now, Yobes Ondieki greatly influences the Kenyan way of training, in particular, the runners who are from Kissii (his native land) as are the runners of our HST group. Indeed, in this group, the key for performance has always been the intensity rather than the volume of training. Nowadays this rule applies even for elite marathon runners (7). The training speed not only ensures that the cardiovascular demand is at its maximum but also determines the generation of muscular force that can be determinant for performance (22,23). Even HST men used tempo training but to a lesser extent than the LST group. Therefore, it is often difficult to demarcate the category of training in men. This comes from the fact that they train collectively and that even some previously easy planned runs turn out to be a mini-competition in the last 45 min of a 1 h training run (28). However, it may be of prime interest to consider these diversities of training when physical characteristics are studied for comparison with Caucasian runners.

CONCLUSION

The present study showed that the type of training (LST vs HST) is associated with different physiological characteristics of Kenyan runners and that women have a high $v\dot{V}O_{2max}$ combined with an excellent ($80\%v\dot{V}O_{2max}$ at vLT) but lower endurance capacity than men having the same kind (HST) of training. LST runners had a higher endurance than HST men and a lower $v\dot{V}O_{2max}$. The cost of running was apparently not affected by gender or by the type of training. In men, the performance over 10 km was related to $v\dot{V}O_{2max}$ and $v\Delta50$, whereas it was related only to $v\dot{V}O_{2max}$ in women and men HST groups. However, this is a cross-sectional study and not a randomized intervention trial, and it must be acknowledged that there exists the possibility that the bioenergetic characteristics of the high- and low-intensity groups could be due to preselection, however unlikely this may seem. At least, the present study showed that female Kenyan elite runners trained less weekly distance than the men having the same (HST) type of training but had a high endurance associated with a high $\dot{V}O_{2max}$ and a medium ECR. We did not estimate the anaerobic power and capacity of these runners. Further studies considering the difference in performance between men and women are necessary to explain the difference in performance between gender in elite middle- and long-distance runners. However, no studies to date focused on the anaerobic characteristics at African and Caucasian high-level middle- and long-distance runners. In the present study, we only had the opportunity to do one test because the African athletes were in Europe to perform competition.

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