International Journal of Sports Physiology and Performance, 2012, 7, 92-102

Kenyan and Ethiopian Distance Runners: What Makes Them So Good?

Randall L. Wilber and Yannis P. Pitsiladis

Since the 1968 Mexico City Olympics, Kenyan and Ethiopian runners have dominated the middle- and long-distance events in athletics and have exhibited comparable dominance in international cross-country and road-racing competition. Several factors have been proposed to explain the extraordinary success of the Kenyan and Ethiopian distance runners, including (1) genetic predisposition, (2) development of a high maximal oxygen uptake as a result of extensive walking and running at an early age, (3) relatively high hemoglobin and hematocrit, (4) development of good metabolic "economy/efficiency" based on somatotype and lower limb characteristics, (5) favorable skeletal-muscle-fiber composition and oxidative enzyme profile, (6) traditional Kenyan/Ethiopian diet, (7) living and training at altitude, and (8) motivation to achieve economic success. Some of these factors have been examined objectively in the laboratory and field, whereas others have been evaluated from an observational perspective. The purpose of this article is to present the current data relative to factors that potentially contribute to the unprecedented success of Kenyan and Ethiopian distance runners, including recent studies that examined potential links between Kenyan and Ethiopian genotype characteristics and elite running performance. In general, it appears that Kenyan and Ethiopian distance-running success is not based on a unique genetic or physiological characteristic. Rather, it appears to be the result of favorable somatotypical characteristics lending to exceptional biomechanical and metabolic economy/efficiency; chronic exposure to altitude in combination with moderate-volume, high-intensity training (live high + train high), and a strong psychological motivation to succeed athletically for the purpose of economic and social advancement.

Keywords*:* endurance performance, East African runners, genetic factors

The 1968 Mexico City Olympics was the first of several Olympic Games in which the middle- and long-distance events in men's athletics were dominated by countries from East Africa, in particular Kenya and Ethiopia. Kenya and Ethiopia participated in the Olympics for the first time in 1956, when they sent small groups of runners and boxers to the Melbourne Olympic Games. Ethiopia won its first Olympic medal in athletics in 1960, when Abebe Bikila won the marathon at the Rome Olympic Games, an accomplishment he duplicated 4 years later in the Tokyo Olympics. Kenya won its first Olympic medal in athletics in 1964, when Wilson Kiprugut won a bronze medal in the 800-m event at the Tokyo Olympic Games. Four years later, at the 1968 Mexico City Olympics, the Kenyan men emerged as a dominant world power in distance running when they won 7 medals, led by the performance of Kipchoge "Kip" Keino, who won a gold medal in the 1500-m run and a silver medal in the 5000-m run. In total, the Kenyan male distance runners won 3 gold, 3 silver, and 1 bronze medal in Mexico City in events ranging from 800 to 10,000 m. Ethiopia's Mamo Wolde won the marathon in the Mexico City Olympics and also earned a silver medal in the 10,000-m run. Despite the fact that Kenya and Ethiopia did not participate in the 1976 Olympic Games for political reasons, no other nation has attained their level of success in Olympic middle- and long-distance running over the past 40 years (Figure 1). Over the past decade, Kenyan and Ethiopian women have followed a similar path to success in athletics. In addition, the Kenyans and Ethiopians have dominated the International Association of Athletics Federations (IAAF) World Cross-Country Championships, as well as major international road races and marathons, since the 1990s.

Wilber is with the Athlete Performance Laboratory, United States Olympic Committee, Colorado Springs, CO. Pitsiladis is with the Institute of Cardiovascular and Medical Sciences, University of Glasgow, Glasgow, UK.

Genetic Factors

Middle- and long-distance runners from Ethiopia and Kenya hold over 90% of all-time world records and current top-10 positions in world-event rankings. Moreover, these successful athletes come from localized ethnic subgroups within their respective countries.[1,2] The Arsi region of Ethiopia contains roughly 5% of the Ethio-

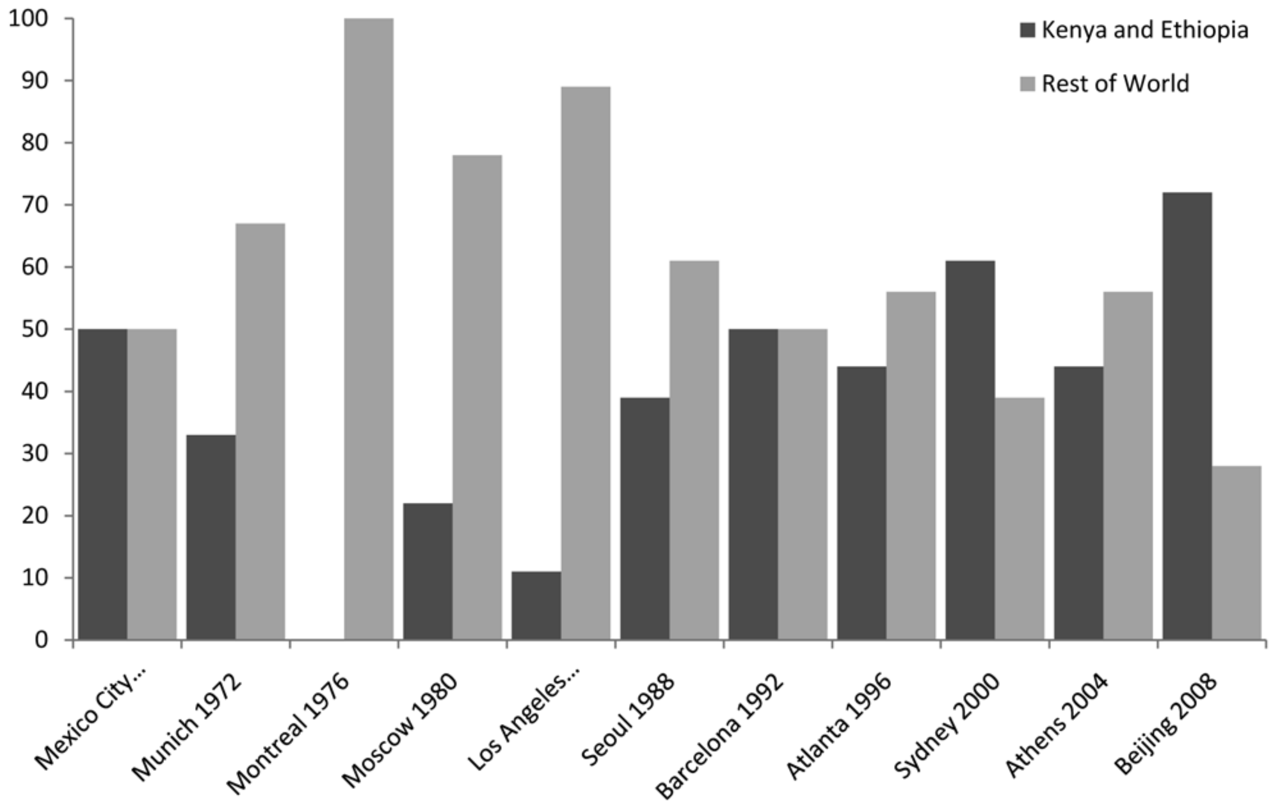

Figure 1 — Comparison of the number of medals won by Kenya and Ethiopia versus rest of world in men's middle- and long-distance events (800 m to marathon) in Olympic Games from Mexico City 1968 to Beijing 2008.

pian population but accounted for 14 of the 23 distance runners selected for the country's 2008 Olympic team. Similarly, the Kalenjin tribe of Kenya has less than 0.1% of the world's population, yet members of this tribe have together won nearly 50 Olympic medals in middle- and long-distance events. It is not surprising, therefore, that this remarkable geographical clustering has provoked assertions in the literature that Kenyans and Ethiopians have the "proper genes" for distance running.[3] Despite such assertions' having arguable theoretical underpinnings, one must identify the genes that are responsible for the phenomenal success of the East Africans in distance running to justify regarding this phenomenon as genetically mediated. In order to investigate the East African running phenomenon, a first study[2,4,5] involved 114 endurance runners from the Ethiopian junior- and senior-level national athletics teams (32 women, 82 men), 315 controls from the general Ethiopian population (34 women, 281 men), 93 controls from the Arsi region of Ethiopia (13 women, 80 men), and 38 sprint- and power-event athletes from the Ethiopian national athletics team (20 women, 18 men). A similar approach was taken in a subsequent study[6] that involved recruiting 291 elite Kenyan endurance athletes (232 men, 59 women) and 85 control subjects (40 men, 45 women). Seventy of the athletes (59 men, 11 women) had competed internationally representing Kenya. Of the 70, 42 had won Olympic, World, or Commonwealth medals; had a top-3 finish in an international marathon or equivalent road race; or have been ranked in the top 50 runners in the world in their event. Other athletes, classified as national, had competed at national level in Kenya (N = 221, 173 men, 48 women). All athletes had competed in distances from 3000 m to the marathon, in which the energy source is predominantly aerobic. Control subjects were students from Kenyatta University and were representative of the Kenyan population in their geographical distribution throughout Kenya.[1] These 2 East African cohorts provide a unique opportunity to study the genetics of East African runners and to discover performance genes.

Mitochondrial DNA Research

The first approach adopted was to investigate the genetic ancestry of the elite East African runners using the uniparentally inherited genetic marker mitochondrial DNA (mtDNA). mtDNA provides a unique opportunity to explore the matriline of select groups. It is passed entirely matrilineally and accumulates mutations along the maternal genealogy, and given the relatively rapid mutation rate of mtDNA compared with the nuclear genome,[7] it is possible to create detailed phylogenies to explore the matrilineal relatedness of people in addition to phenotypes of interest. Grouping particular haplotypes creates easily comparable units of genealogical information with useful levels of predictability. When found in other parts of the world, these haplogroups can be used as indicators of recent migration.[8] A simplified version of an mtDNA phylogeny is shown in Figure 2. When this approach was applied to the unique cohorts of Ethiopian[5] and Kenyan[9] distance runners, those elite runners were not restricted to 1 area of the tree—results revealed a wide distribution, similar to their respective general populations and in contrast to the concept that these runners are a genetically distinct group as defined by mtDNA. Therefore, the mtDNA haplogroup diversity found in both Ethiopian and Kenya runners does not support a role for mtDNA polymorphisms in their success. It can be seen from Figure 2 that some of the elite athletes share a more recent common mtDNA ancestor with many Europeans. This finding does not support the hypothesis that the Ethiopian or indeed Kenyan population, from which the athletes are drawn, has remained genetically isolated in East Africa but shows that it has undergone migration events and subsequent admixture during the development of the species. This opposes the possibility that these elite athletes have maintained and further developed the ancestral endurance phenotype through having remained isolated in the East African highlands. It is likely that population movements within Africa as recently as a few thousand years ago contributed to the peopling of East Africa, through the eastern path of the Bantu migrations. However, linguistic data show that Bantu languages are absent in Ethiopia[2] but frequent in Kenya,[1] indicating that the neighboring regions may have been subject to widely different patterns of migration. The mtDNA haplogroup data from the Kenyan population and Kenyan runners[9] are very different from those found in Ethiopia and show a lower frequency of Eurasian haplogroups M and R; these haplogroups are present at a frequency of 10% in Kenya compared with 45% in Ethiopia (Figure 2). It is interesting to note that these 2 regions that share success in distance running have such different ancestral contributions to their gene pool. In contrast to the Ethiopian cohort, in which no differences in mtDNA haplogroup distribution were found between athletes and con-

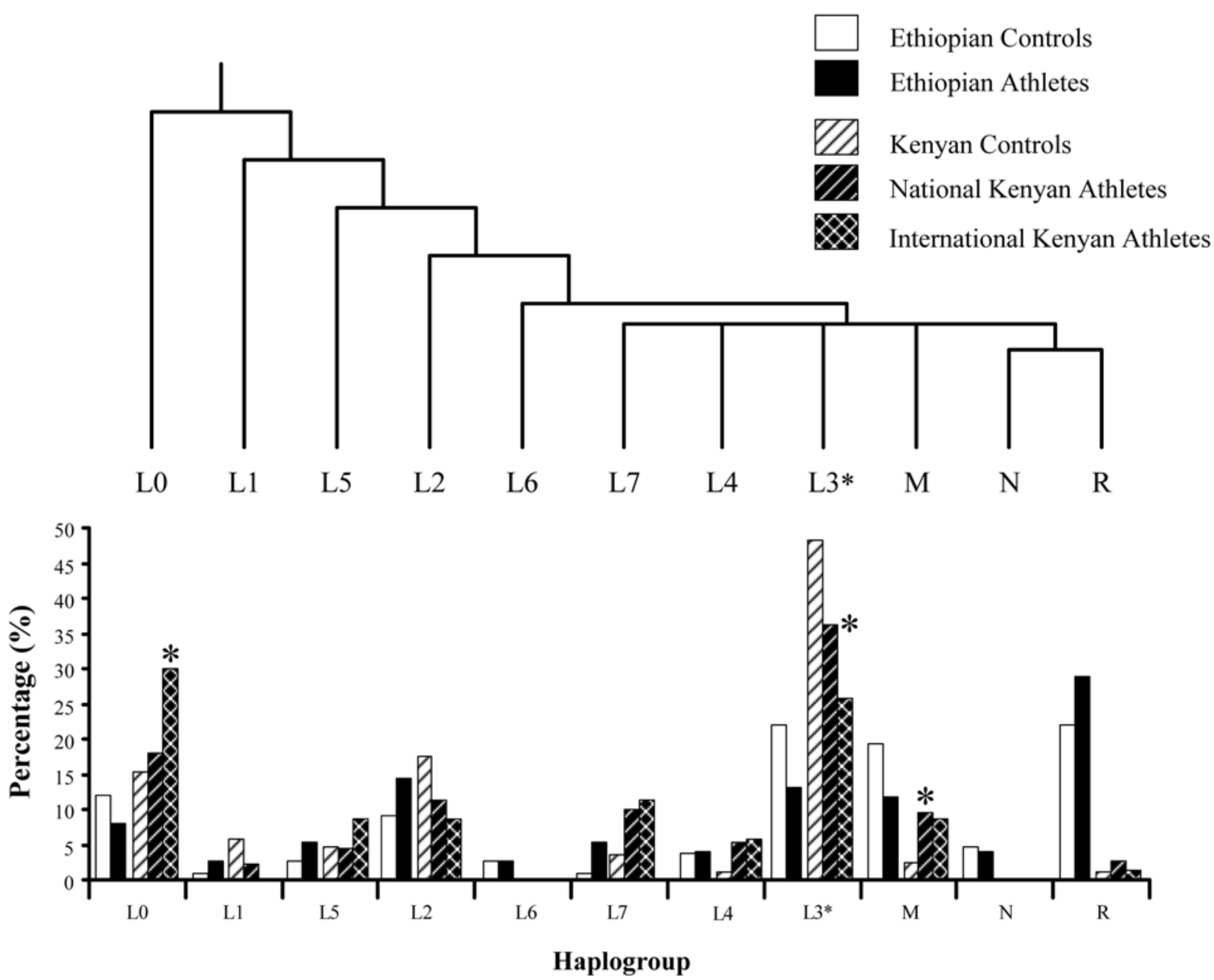

Figure 2 — Mitochondrial tree and haplogroup (ie, major branches on the family tree of *Homo sapiens*) distributions of Kenyan and Ethiopian athletes and controls. Reproduced by permission from Scott et al. *Med Sci Sports Exerc*. 2009;41:123–128.

trols, international athletes from Kenya displayed an excess of L0 haplogroups and a dearth of L3* haplogroups (Figure 2). National athletes from Kenya also showed differences from controls when each haplogroup was compared with the sum of all others, exhibiting an excess of M haplogroups (Figure 2). The association of mtDNA haplogroups L0 and M with Kenyan athlete status may suggest that these haplogroups contain polymorphisms that influence some aspect of endurance performance or its trainability but cannot explain the Kenyan running phenomenon.

Y-Chromosome Research

The idea that the elite East African runners studied to date do not arise from a limited genetic isolate is further supported by the analysis of the Y-chromosome haplogroup distribution of the same Ethiopian cohort.[4] The Y chromosome can be considered the male equivalent of mtDNA. Ethiopian runners differ significantly in their Y-chromosome distribution from both the general population and that of the Arsi region,[4] which produces an excess of elite runners.[2] The finding that Y-chromosome haplogroups were associated with athlete status in Ethiopians suggests that either an element of Y-chromosome genetics is influencing athletic performance or the Y-chromosome haplogroup distributions were affected by population stratification (ie, the population from which the athletes originate has a distinct Y-chromosome distribution). However, the haplogroup distribution of the Arsi region did not differ from the rest of Ethiopia, suggesting that the observed associations were less likely to be a result of simple population stratification. Currently, these haplogroup frequencies are being assessed in the larger Kenyan cohort.[1] If the same haplogroups are found to be underrepresented or overrepresented, this would provide some evidence for a biological effect of the Y chromosome on running performance. However, despite the finding of a potential effect of the Y chromosome on endurance performance, results show levels of diversity similar to those found using mtDNA and reflecting that a significant number of the athletes trace part of their male ancestry to outside Africa at some time during the age of our species. Collectively, the findings from Y-chromosome and mtDNA studies do not provide any genetic evidence to support the biology of ethnic differences in sports performance.

Candidate-Gene Research

The candidate-gene approach was the next approach to be applied to the 2 East African cohorts. This method requires a prior hypothesis that the genetic polymorphisms of interest are causal variants or in strong linkage disequilibrium with a causal variant. To date, only 2 candidate genes for human performance have been extensively investigated in East African athletes.[5,6,10,11] The first was the angiotensin-converting enzyme (ACE) gene: the most studied of the candidate genes for human performance in which an insertion polymorphism (I) is associated with lower levels of circulating and tissue ACE than the deletion (D).[12] The ACE gene has been associated with a number of aspects of human performance.[13] In general, the I allele has been associated with endurance performance, and the D allele, with power performance. The ACE I allele has also been associated with altitude tolerance,[14] making it an ideal candidate gene to investigate in East African runners, given the suggestion that the altitude at which these athletes live and train may largely account for their success. As such, ACE I/D genotype frequencies were tested in Kenyan[6] and Ethiopian[11] runners relative to the general populations. Based on previous findings,[13] it may have been expected that the elite runners would show an excess of the I allele. However, no significant differences were found in I/D genotype frequencies between runners and their respective general populations.[6,11] Different levels of linkage disequilibrium (the nonrandom association of alleles) in Africans and whites led to testing of an additional, potentially causal variant (A22982G). However, no significant differences in A22982G genotype frequencies were found between runners and their respective general populations.[6,11] Indeed, 29% of Kenyan controls and only 17% of international Kenyan athletes had the putatively advantageous AA genotype (always found in concert with II in whites) for endurance performance. Although controversy over the influence of ACE genotype on endurance performance continues, these studies did not support a role for ACE-gene variation in explaining the East African distance-running phenomenon.

The only other extensively studied gene in elite East African runners is the alpha-actinin-3 (ACTN3) gene.[10] ACTN3 has been associated with elite physical performance[16] and found at widely differing frequencies in different populations.[17] In particular, a strong association has been found between the gene variant of ACTN3 called R577× and elite athlete status in white Australian populations, with the alpha-actinin-3-deficient XX genotype being present at a lower frequency in sprint and power athletes and at slightly higher frequency in elite female endurance athletes, relative to controls.[16] However, there was no evidence for an association between the R577× polymorphism and endurance performance in East African runners,[10] suggesting that ACTN3 deficiency is not a major determinant of East African running success. In summary, genotyping 2 of the key candidate genes for human performance in 2 cohorts comprising the world's most successful endurance athletes finds these genes not to be a significant determinant of their success. Whether other nuclear variants can help explain such phenomena remains to be determined. However, the extraordinary achievements of certain populations in sporting success must rely on the successful integration of a number of physiological, biochemical, and biomechanical systems, which themselves are the product of a multitude of contributors. The success of these athletes is unlikely, therefore, to be the result of a single gene polymorphism[18]; rather, it is likely that elite athletes rely on the presence of a combination of advantageous genotypes.

Future Genetic Research

It is accepted that there will be many interacting genes involved in elite running performance, and hence it is timely that genetic research has moved to the genomics era, that is, the simultaneous testing of multiple genes. As the cost of using such whole-genome methods becomes more affordable, new approaches and technologies are being applied to these unique East African cohorts to search the whole human genome instead of studying single genes. While it is this author's (Y.P.) contention that the East African running phenomenon is not a genetically mediated phenomenon on the basis of the data reviewed here and elsewhere,[19–21] whole-genome studies are currently underway to establish the definitive evidence.[22] These studies are envisaged to discover performance genes essential for world-class performances such as those typical of the East African runners but also possessed by world-class distance runners worldwide.

Physiological and Socioeconomic Factors

In addition to genetic factors, several physiological and socioeconomic factors have been proposed to explain the extraordinary success of the Kenyan and Ethiopian distance runners. Some of these factors have been examined objectively in the laboratory and field, whereas others have been evaluated from an observational perspective. In addition, some of these factors (eg, total hemoglobin mass) may be secondary to living and training at moderate altitude (2000–2500 m), where the Kalenjin (Kenya) and Arsi (Ethiopia) tribes that produce great runners have resided for millennia. It should be noted that there are relatively more data and information on the Kenyan distance runners than on the Ethiopians. This is primarily due to political, cultural, and socioeconomic factors in Ethiopia that have limited the opportunities for data-based research and general observation of training methodology.

Maximal Oxygen Uptake

It has been postulated that the Kenyan and Ethiopian distance runners develop a high maximal oxygen uptake (VO_{2max}) as a result of extensive walking and running from an early age, which ultimately contributes to exceptional endurance-running performance later in life. Onywera et al[1] reported that 86% of Kenyan international-level runners used running (vs walking or vehicle transport) as their main method of travel to school when they were children (Figure 3[a]). In comparison, only 23% of nonathletic Kenyan control subjects indicated that they had run to school as children. Similar results were seen in Ethiopia, where 68% of elite marathon runners reported that they had used running (vs walking or vehicle transport) as their primary method of travel to school when they were children, compared with 24% of Ethiopian nonathletic control subjects[2] (Figure 3[b]). In the elite Ethiopian marathon group, 73% indicated that the average total distance run to and from school was between 5 and 20 km. However, it is not clear whether this type of robust running background at an early age has an effect on VO_{2max} that distinguishes the running performance of Kenyan and Ethiopian athletes. In an early study conducted by Saltin et al,[23] VO_{2max} was not significantly different between elite Kenyan versus elite Scandinavian distance runners, whether measured at sea level (Kenyans 79.9, Scandinavians 79.2 $mL \cdot kg^{-1} \cdot min^{-1}$) or 2100 m (Kenyans 66.3, Scandinavians 67.3 $mL \cdot kg^{-1} \cdot min^{-1}$). More recently, this finding was confirmed when it was reported that the VO_{2max} of elite male Kenyan distance runners (71.5 $mL \cdot kg^{-1} \cdot min^{-1}$) was not different versus elite male German distance runners (70.7 $mL \cdot kg^{-1} \cdot min^{-1}$).[24] Note that although VO_{2max} was similar between the elite Kenyan and German athletes, the Kenyans' personal best time in the 10,000-m run (average 28:29 [min:s], n = 10) was over 2 minutes faster than that of their German counterparts (average 30:39, n = 11).[24] Thus, it appears that elite Kenyan and Ethiopian runners do not have any specific advantage over non-Kenyan elite runners in terms of VO_{2max} despite clear differences in performance.

Hematological Profile

There are minimal data regarding the hematological profiles of elite Kenyan and Ethiopian distance runners, and those studies are difficult to compare due to inconsistent methodology and design.[24,25] Moore et al[25] reported a relatively high hemoglobin concentration (flow cytometry) and hematocrit in 41 elite male Kenyan distance runners who were native to the Rift Valley (2000–2500 m). The mean hemoglobin concentration and hematocrit were 16.4 g/dL and 49%, respectively, and nearly 25% of these athletes had a hemoglobin concentration above 17.0 g/dL and hematocrit above 50%.[25] A recent investigation compared 10 elite male Kenyan distance runners (10,000-m personal best 28:29 [min:s]) who were native to Eldoret, Kenya (2100 m), and 11 elite male German distance runners (10,000-m personal best 30:39) who were sea-level natives.[24] When measured in Kenya (Nairobi, 1660 m) approximately 12 hours after subjects had left Eldoret, hemoglobin concentration (photometric analysis) was 16.1 g/dL, which was not significantly different ($P > .05$) from the German runners (15.2 g/dL).[24] When measured at sea level (Bayreuth, Germany, 340 m) approximately 26 to 30 hours after the subjects had left Eldoret, total hemoglobin mass (CO rebreathing) was not different between the Kenyan athletes (14.2 g/kg) and German athletes (14.0 g/kg).[24] Similarly, there were no differences in total blood volume between the Kenyan runners (101.9 mL/kg) and German runners (99.6 mL/kg).[24] Based on these inconsistent study designs and methodologies for measuring erythropoietic parameters, it is not possible to draw definitive conclusions as to whether the hematological profile of Kenyan distance runners is a distinct factor contributing to their success on

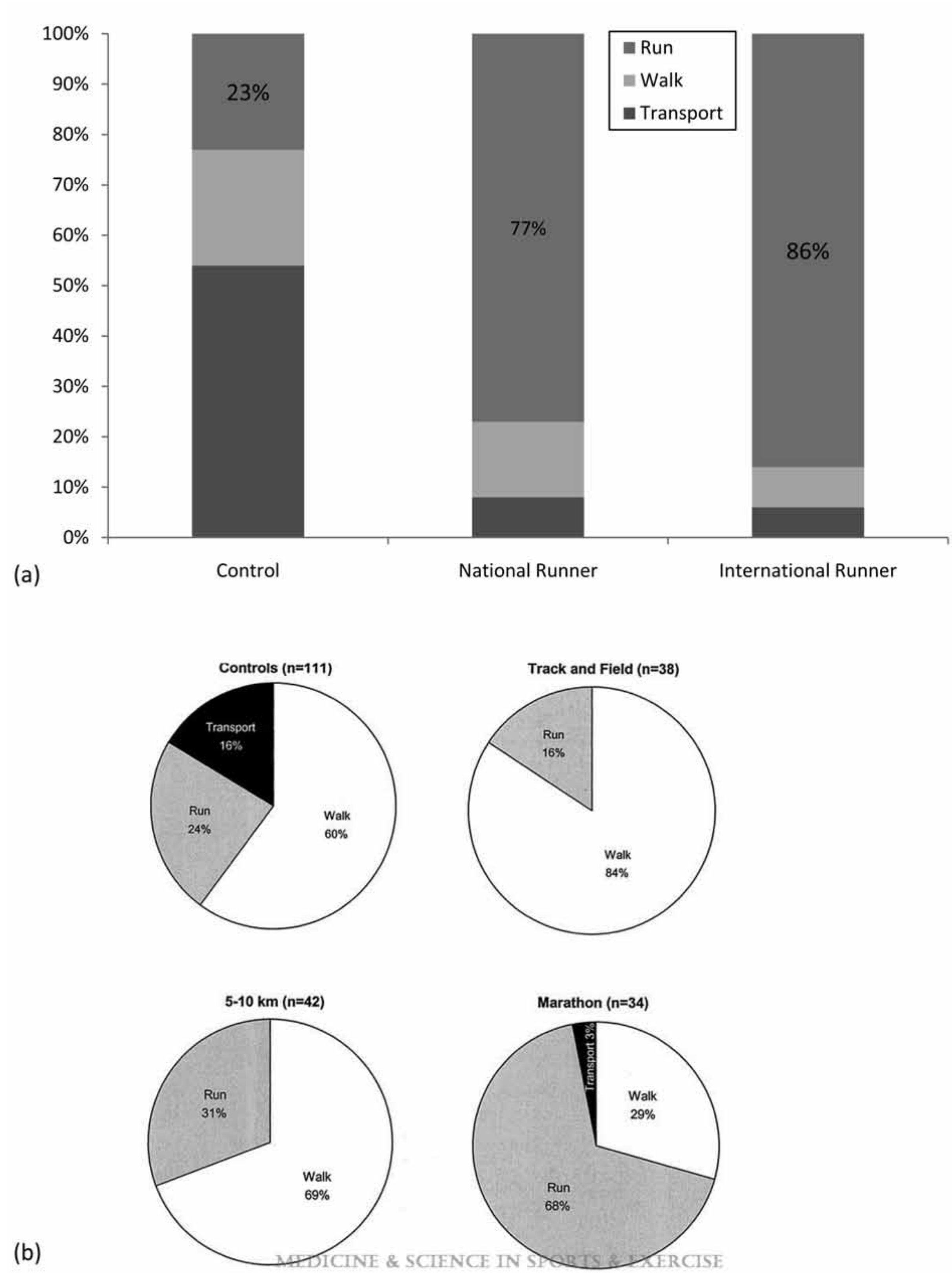

Figure 3 — Percentage of elite runners from (a) Kenya and (b) Ethiopia who ran to school as youngsters versus walking or vehicle transport. Data from (a) reproduced by permission from Onywera et al. *J Sports Sci*. 2006;24:415–422. (b) Reproduced by permission from Scott et al. *Med Sci Sports Exerc.* 2003;35:1727–1732.

the track and roads. However, this is clearly an intriguing area, and additional research is warranted. In terms of the Ethiopian distance runners, to our knowledge there are no data to support or refute that hemoglobin and total blood volume are uniquely different from other elite running populations.

Metabolic Economy/Efficiency

Although both the Kenyans and Ethiopians excel at distance running, they differ in general somatotype. The Kenyans, particularly those from the tribes of the Great Rift Valley, have an ectomorphic somatotype characterized by long, slender legs that are typical of central and southern African tribes. The Ethiopians, in contrast, are generally more mesomorphic in somatotype and exhibit physical characteristics that are more reflective of northern Africa and include some European and Middle Eastern physical traits. The Ethiopians are generally more light-skinned than the Kenyans, are shorter, and have greater thigh circumference. There is some scientific evidence, as well as anecdotal observation, to support the notion that the ectomorphic somatotype of typical Kenyan runners allows them to be more mechanically efficient than their opponents. Larsen et al[26] studied the anthropometric characteristics of elite Kenyan distance runners and reported that they had longer legs (5% longer) than elite Scandinavian distance runners. In addition, the Kenyan runners had thinner/lighter calves (12% lighter) than the Scandinavian runners.[26] In support of this, Saltin et al[23] demonstrated that elite Kenyan distance runners were more metabolically economical than elite Scandinavian distance runners, particularly at race-pace running velocities. Thus, it appears that the innate ectomorphic somatotype of elite Kenyan runners may contribute in part to their success on the track and roads via enhanced biomechanical and metabolic efficiency. To our knowledge, biomechanical and metabolic efficiency have not been evaluated in Ethiopian distance runners.

Skeletal-Muscle-Fiber Composition and Oxidative-Enzyme Profile

It has been suggested that the success of the Kenyan and Ethiopian distance runners is based on skeletal-muscle-fiber characteristics and enzymatic capabilities that favor endurance activity. In a study done by Saltin et al[27] using muscle biopsy samples of the gastrocnemius and vastus lateralis, no difference was found in type I muscle-fiber percent between elite Kenyan runners (72.6%) and elite Scandinavian runners (67.7%). In addition, no difference was found in the citrate synthase activity of the Kenyans (71.9 $\mu mol \cdot min^{-1} \cdot g^{-1}$) versus Scandinavians (72.9 $\mu mol \cdot min^{-1} \cdot g^{-1}$). However, the Kenyan runners had a significantly higher ($P < .05$) activity for the enzyme hydroxylacyl-CoA dehydrogenase (HADH), which is a key enzyme involved in lipid-generated energy production. HADH activity for the Kenyans was 66.8 $\mu mol \cdot min^{-1} \cdot g^{-1}$, whereas for the Scandinavians it was 48.7 $\mu mol \cdot min^{-1} \cdot g^{-1}$.[27] Thus, it is possible that the Kenyan runners may be able to generate energy more efficiently from lipid-based sources than some of their competitors. Although this may provide the Kenyan runners with a slight advantage in relatively long-distance events (eg, half-marathon and marathon) in which lipid-based energy production is a factor, it does not explain their success in shorter-distance events (eg, 800 m, 1500 m, 3000-m steeplechase, 5000 m) in which lipid metabolism is less of a contributing factor to competitive success than glycolysis. At present, there is nothing to report in terms of skeletal-muscle-fiber characteristics and enzymatic activity among elite Ethiopian distance runners.

Traditional Kenyan/Ethiopian Diet

Onywera et al[28] have reported that the traditional Kenyan diet is composed of 10% protein, 13% fat, and 77% carbohydrate. This low-fat, high-carbohydrate diet has been consumed by Kenyan people for centuries, and its composition is consistent with research-based recommendations for endurance-sport athletes. The carbohydrate component of the Kenyan diet includes the staples of vegetables, fruit, rice, and unrefined sugar, along with the traditional Kenyan maize dish, *ugali,* which has a very high glycemic index. In addition, Kenyan runners drink traditional Kenyan tea immediately after training sessions and with their meals. This tea, called *chai,* also has a high glycemic index and serves as a Kenyan "energy drink" to effectively replenish glycogen stores in the critical period immediately post-training when GLUT-4 transport and insulin activity are optimal. Beis et al[29] recently reported that the traditional Ethiopian diet is composed of 13% protein, 23% fat, and 64% carbohydrate. Although still relatively high, the Ethiopian diet is approximately 13% lower in carbohydrate than the traditional Kenyan diet but 3% higher in protein and 10% higher in fat. The carbohydrate component of the Ethiopian diet includes the staples of vegetables, fruit, rice, bread and pasta, and unrefined sugar.

In terms of supplementation, elite Kenyan runners have reported using no dietary supplements,[28] whereas elite Ethiopian runners have indicated using some, but minimal dietary supplements.[29] Although both the Kenyans' and Ethiopians' diets appear to be favorable for training and performing in middle- and long-distance running events, they do not appear to be uniquely different from the training diets of most of their European, American, or Asian competitors and therefore probably do not confer any distinctive competitive advantage.

Living and Training at Altitude

A shared characteristic of the Kenyan and Ethiopian distance runners is the fact that most of them were born and raised at an elevation of approximately 2000 to 2500 m in eastern Africa. About 75% of Kenya's best runners come from just 1 of the country's 40 tribes, the Kalenjin, who comprise approximately 10% of the total Kenyan population.[30] Furthermore, many of Kenya's best runners come from a subtribe of the Kalenjin known as the Nandi, who comprise only about 3% of the total Kenyan population.[30] The Kalenjin have lived for centuries on the western rim of the Great Rift Valley, which is the distinct geological formation running through Kenya in a north–south direction that separates the western third of Kenya from the rest of the country. The Kalenjin homeland is an area of rolling green hills located in the Great Rift region at an elevation ranging from 1830 to 2450 m. A similar altitude-based geographical residence is seen among the Ethiopian runners, who come primarily from the Arsi tribal region and secondarily from the Shewa tribal region. Both the Arsis and Shewas have lived for centuries in the highlands of the Great Rift Valley, which extends northward from Kenya into southern and central Ethiopia. The capital city of Addis Ababa serves as a major training site for Ethiopia's elite runners and is located at approximately 2355 m. In addition, Ethiopian runners take advantage of the nearby Entoto Hills to train at elevations of approximately 3000 m.

Elite Kenyan runners living and training in the area of the Great Rift Valley employ a traditional approach to altitude training—they "live high" and "train high" using natural, terrestrial altitude. It appears that they have the innate ability to train at relatively high intensity (defined as anaerobic threshold velocity to VO_{2max} velocity) despite the physiological strain and limitations imposed on humans during exercise in hypoxia. Indeed, some researchers have suggested that one of the primary factors for the Kenyans' success in distance running is their ability to train on a consistent basis at running velocities at race pace, or faster, even at altitude.[23,31] In a study of elite male Kenyan distance runners,[31] athletes were divided into 2 groups based on their 10,000-m personal-best time: international elite = 28:15 (min:s), and elite = 28:54. Total weekly running distance was 10% higher in the elite group, as was weekly distance run at lactate threshold velocity (*v*LT), a total distance that was 2.4 times higher in the elite runners. However, weekly distance run at VO_{2max} velocity (vVO_{2max}) was 7.8 km in the international elite runners versus 0 km in the elite runners.[31] Thus, it appears that the ability to train effectively at altitude by running at high-intensity velocities that most lowlanders would find difficult or impossible to replicate may be one characteristic that distinguishes the Olympic-level Kenyan runners from their European, American, and Asian competitors. This author's (R.W.) personal observation would support the contention that an important factor in the success of the Kenyan runners is their ability to do high-intensity training (*v*LT and vVO_{2max} velocities) on a consistent basis without overtraining, something that European and American athletes doing training blocks at altitude seem unable to do consistently without breaking down (R.W. personal observation). Although there is a lack of similar research on the Ethiopian distance runners, it is believed that the Olympic-level Ethiopians have a comparable capacity to do high-intensity training at altitude (Y.P. personal observation). Whether this unique ability of the Kenyan and Ethiopian runners to do high-intensity training at altitude is due to some type of genetic predisposition resulting from living at approximately 2000 to 2500 m for millennia, versus some other factor, is not clear. In fact, the Kenyans are offended when one suggests that their success is due to altitude residence alone. As successful Kenyan coach Mike Kosgei notes emphatically, "If running success is based on altitude residence, then why doesn't Colombia and Nepal produce great runners like Kenya. Our success is based on hard work and attitude, not altitude."[32(p80)] Regardless, it seems logical to assume that chronic altitude residence and moderate-volume, high-intensity altitude training may contribute in part to the exceptional performance of the Kenyan and Ethiopian distance runners and should not be disregarded.

Motivation to Achieve Economic Success

Although advanced in many areas of its society, Kenya still reports an unemployment rate of approximately 40%, and about half of the Kenyan population lives below the World Health Organization (WHO) poverty line. Similarly, 39% of Ethiopian citizens live below the WHO poverty line and their unemployment rate is approximately 35%. Success in distance running provides an athlete the means to advance to the top of Kenyan and Ethiopian society, which serves as a significant motivational factor. Onywera et al[1] reported that among Kenya's elite distance runners, 33% indicated that economic success was the primary reason they trained and competed (Figure 4). This was markedly higher than other potential motivational factors including "Olympic glory," which only 14% of the Kenyan elite runners listed as the main reason they ran.

Being a successful runner in Kenya and Ethiopia can translate into economic and social advancement for the athlete for the rest of his or her life and can have a similar positive effect on the runner's immediate and extended family. Fueling this motivation for economic and social success is the great "tradition of excellence" that links today's outstanding Kenyan and Ethiopian distance runners to their legendary predecessors. In Kenya, this tradition of excellence began with the gold-medal performance (1500 m) of Kip Keino in the 1968 Mexico City Olympics and continued with Olympic and/or World Champions Henry Rono, Peter Rono, Paul Tergat, and David Rudisha. Many of these great champions were initially trained and developed into international-caliber runners at Saint Patrick's High School (Figure 5), located in the village of Iten (~2450 m) in the Great Rift region, under the guidance and coaching of Brother Colm O'Connell. Saint Patrick's continues to serve as Kenya's "running factory," where the most-promising young runners are exposed daily to the tradition of Kenyan running excellence and accompanying high expectations. A similar tradition of excellence is seen in Ethiopia. It began with the gold-medal marathon performance of Abebe Bikila in the 1960 Rome Olympics and continued with Olympic and/or World Champions Mamo Wolde, Miruts Yifter, Haile Gebrselassie, and Kenenisa Bekele. Addis Ababa's

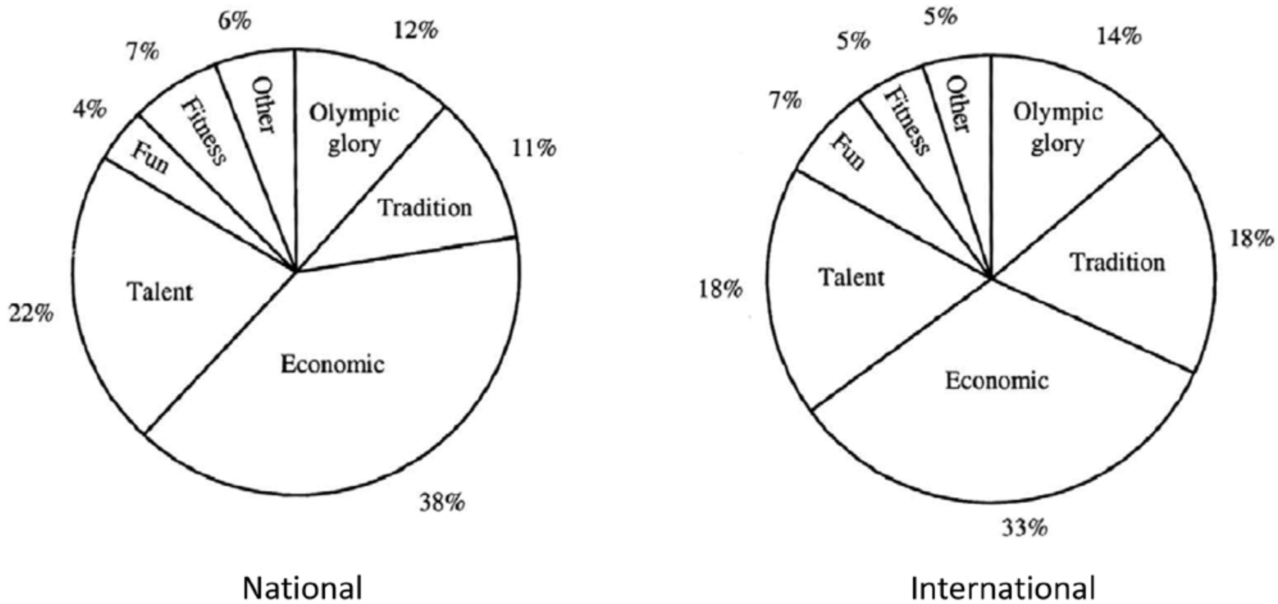

Figure 4 — Reasons given by national- and international-level Kenyan runners for why they compete in distance running. Reproduced by permission from Onywera et al. *J Sports Sci*. 2006;24:415–422.

Figure 5 — Left: Saint Patrick High School located in the village of Iten in the Rift Valley Province of western Kenya. Right: Brother Colm O'Connell, retired headmaster and running coach of Saint Patrick High School. Photos courtesy of author (R.L.W.).

Meskel Square is often referred to as Ethiopia's "field of dreams," where dozens of the country's most promising runners have come for years to train in pursuit of running excellence. This motivation for economic success nurtured by a strong tradition of excellence should not be discounted as an important factor behind the success of the Kenyan and Ethiopian distance runners. As Haile Gebrselassie has stated,

> We have so much inspiration. We want to be like Bikila, Wolde, Yifter. They gave us a reason to dream and hope. They are our role models. We see in them something that sparks our imagination and encourages us to change our lives for the better.[33]

Summary

It would be naive to think that there is a single prominent genetic, physiological, or psychological factor that explains the extraordinary success of the Kenyan and Ethiopian distance runners. To date, no genetic traits (eg, mtDNA, ACE, ACTN3) and few physiological (eg, VO_{2max}, skeletal-muscle-fiber characteristics, enzymatic profile, diet) or hematological advantages (eg, total hemoglobin mass, total blood volume) have been identified that can conclusively explain the unique success of the East African runners. Nevertheless, we offer the following model (Figure 6) as a potential supposition for the success of the Kenyan and Ethiopian distance

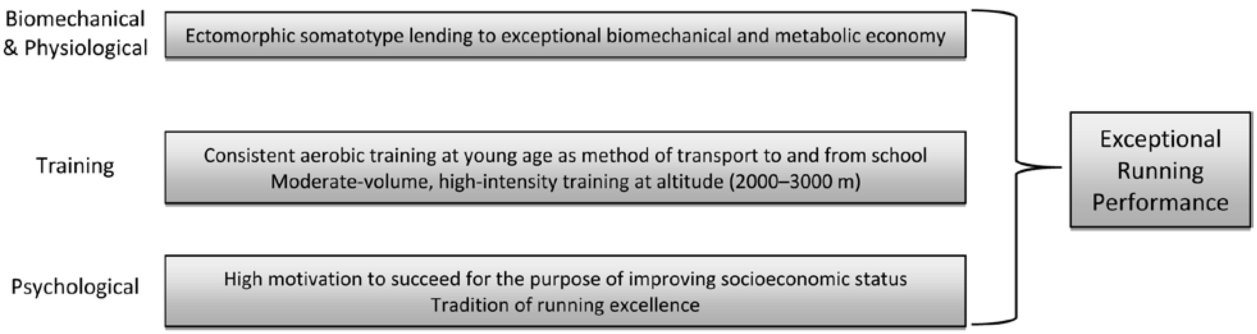

Figure 6 — Hypothetical model to explain the extraordinary success of Kenyan and Ethiopian distance runners.

runners based on what is currently known from scientific and observational perspectives. Among the Kalenjin and Arsi tribes that traditionally produce the best runners in Kenya and Ethiopia, respectively, it is common for schoolchildren to begin distance running at an early age, both as a sporting activity and as the primary method of transport to and from school. Although this early aerobic training does not appear to ultimately result in a higher VO_{2max} in adult Kenyan and Ethiopian runners than in non–East African elite distance runners, it cannot be ignored as a potential factor contributing to their success. For the Kenyan runners, it appears that their ectomorphic somatotype characterized by long, slender legs might provide advantages in biomechanical and metabolic economy/efficiency, resulting in enhanced performance in middle- and long-distance events. Although the Ethiopian runners tend toward a mesomorphic somatotype, they also demonstrate exceptional physiological economy, but specific mechanisms have not been identified at this time. Both the Kenyans and the Ethiopians have lived for millennia at moderate altitude (2000–2500 m) in the highlands of the Great Rift Valley. It is not illogical to assume that this chronic hypoxic exposure has conferred certain as-yet unidentified genetic and phenotypical benefits that allow them to consistently train at altitude at running velocities (*v*LT and vVO_{2max}) that their non-altitude-based opponents do not seem to be able to achieve without overtraining. This ability to conduct moderate-volume, high-intensity training at altitude on a consistent basis ultimately translates into exceptional running performance for the Kenyans and Ethiopians on descent to lower elevations. Overlapped with these potential somatotypical and physiological characteristics is the fact that Kenyan and Ethiopian runners are extremely motivated psychologically. They realize that success in distance running will result in socioeconomic rewards and ultimately elevate them and their families to the top ranks in their respective societies. Finally, both of these East African nations have established a venerable tradition of excellence in the sport of distance running, which continues to fuel the dreams and work ethic of Kenya's and Ethiopia's current and future Olympic champions.

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