

Review Article

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Why the dominance of East Africans in distance running? A narrative review

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Abstract

Introduction: Runners from East Africa including Kenya, Ethiopia and Uganda have dominated middle- and long-distance running events, for almost six decades. This narrative review examines and updates current understanding of the factors explaining the dominance of East Africans in distance running from a holistic perspective.

Content: The dominance of East African distance runners has puzzled researchers, with various factors proposed to explain their unparalleled success. Four key elements emerge: 1) biomechanical and physiological attributes, 2) training characteristics, 3) psychological motivations, and 4) African diet. Runners from East Africa often exhibit ectomorphic somatotypes, characterized by lean body compositions which lead them to an extraordinary biomechanical and metabolic efficiency. Their sociocultural lifestyle, training regimens beginning at a young age with aerobic activities, seem crucial, as well as moderate volume, high-intensity workouts at altitudes ranging from 2,000 to 3,000 m. Psychological factors, including a strong motivation to succeed driven by aspirations for socioeconomic improvement and a

rich tradition of running excellence, also contribute significantly. A multifactorial explanation considering these factors, without a clear genetic influence, is nowadays the strongest argument to explain the East African phenomenon.

Summary and outlook: To unravel the mystery behind the supremacy of East African runners, it is imperative to consider these multifaceted factors. The predominantly rural lifestyle of the East African population underscores the importance of aligning modern lifestyles with the evolutionary past of *Homo sapiens*, where physical activity was integral to daily life. Further research is required to explain this phenomenon, with a focus on genetics.

Keywords: biomechanical factors; training; genetics; diet; endurance; performance

Introduction

African male and female runners collectively hold over 90 % of the all-time world records in long-distance events (Table S1). During the past six decades, the dominance of East Africans in long-distance events has been profound, while the success of European runners in such events has been reduced dramatically [1]. Fifty years ago, athletes from European countries dominated all distances from 800 m to the marathon [2]. At that time, European athletes comprised the majority of world records and most gold medal winners at both Olympic Games and World Championships were also Europeans [1].

During the 2008, 2012 and 2016 Summer Olympics, athletes from East Africa, particularly from Kenya and Ethiopia, won two-thirds of all gold medals in middle- and long-distance events [3]. The rest of the world combined, has not been able to achieve such level of success in these events. Since the 1990s, Kenyans and Ethiopians have consistently led the World Athletics Cross-Country Championships, along with major international road races and marathons [4]. Of note, the reduced proportion of Europeans in the list of world records since the 90s (Table S1) and the list of top 10 all-time (best by athlete) for both males (Table S2) and

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females (Table S3) is not due to a decrease in running performance, but rather, due to a greater participation of East African runners and their increase in performance [1]. Several factors have been suggested to explain the success of East African runners in long-distance races, including: 1) genetic background, 2) living and training at altitude, 3) training characteristics, 4) physiological factors, 5) anthropometry and somatotype, 6) African diet, 7) childhood physical activity and running and 8) a high motivation to succeed [4].

The purpose of this narrative review is to examine and update the current state of knowledge related to the different factors explaining the supremacy of East African runners in distance events from a holistic perspective, including physiological, nutritional, genetic and other

approaches. The summary of this article is presented in Figure 1.

Genetic background

The Nandi ethnic group is considered the Kenyan running tribe for which running is known as a God-given gift [5]. Individuals from this tribe continue to be among the most successful runners worldwide, and most Kenyan records come from members of this tribe, suggesting a genetic influence [5]. The unmatched dominance of East African athletes in middle- and long-distance running has perpetuated the idea that they are genetically adapted to outperform all other

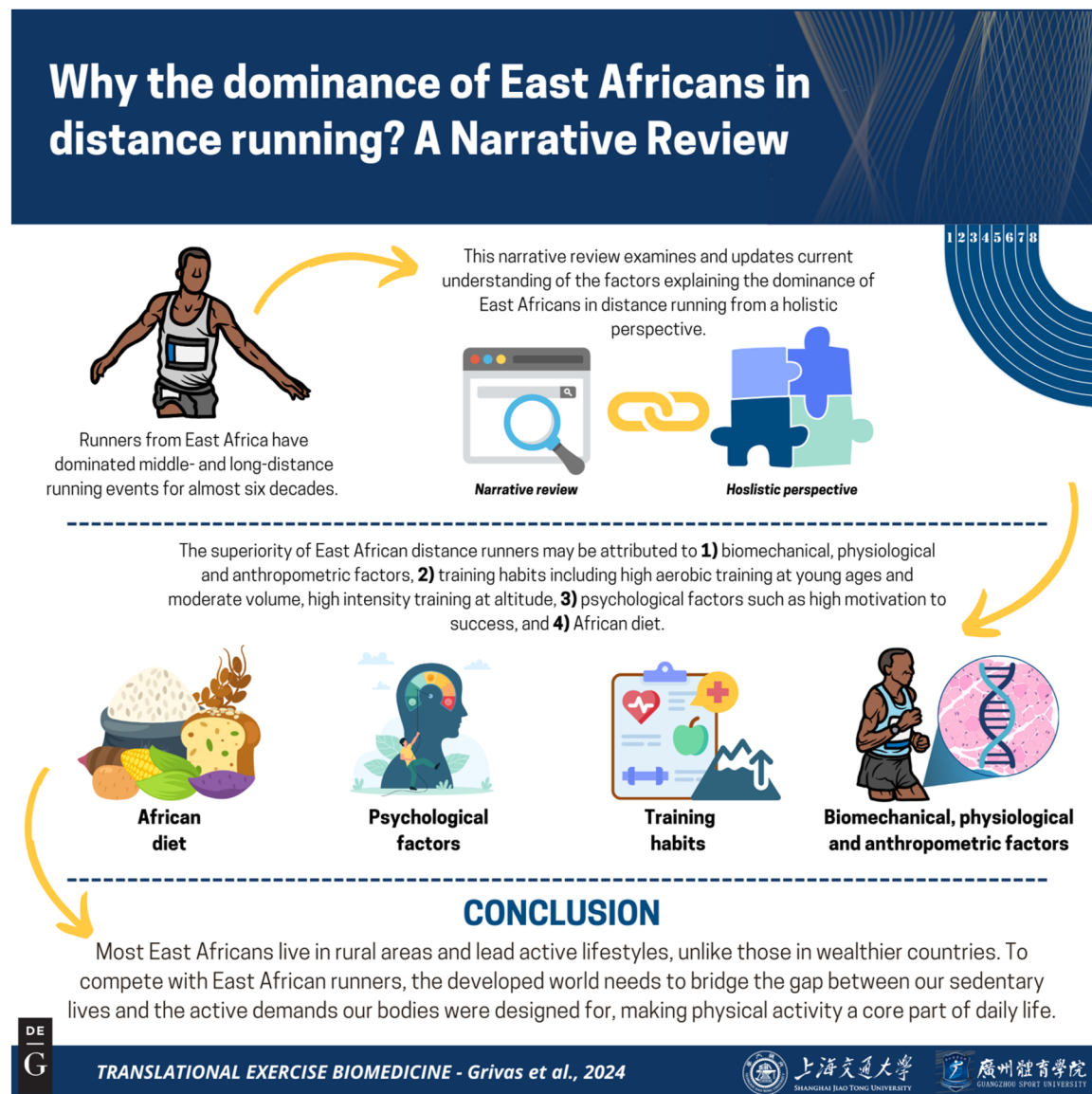


Figure 1: Graphical representation of this article. Figure created with BioRender.

ethnic groups at endurance races [6]. This is in line with the words of the great physiologist Professor Per-Olof Åstrand, who stated “*if you want to be an Olympic athlete choose your parents wisely*” [7], which illustrates the genetic influence in elite sport.

Mitochondrial DNA (mtDNA) is transferred from the mother to the child with no contribution from the father [8] and plays an important role in determining genetic predispositions. The different mtDNA types can be presented in the mtDNA tree at which root is mitochondrial eve. Each descending branch is called a haplogroup, characterized by the presence or absence of specific polymorphisms unique to that haplogroup [5]. A common belief was that the best runners belonged to a homogeneous group composed primarily by the African lineage. The earliest lineages are known as types L1, which are almost exclusively from Africa. However, the Ethiopian population shows a wide heterogeneity and is almost equally contributed by African, Asian and European types (e.g., L1, L2 and L3) suggesting L1 types are not a prerequisite for endurance performance [9]. Another hypothesis to explain the East African phenomenon is that the best athletes may predominantly come from one or a limited number of branches of the tree, maybe for example, following the ancient African types [5]. If this was confirmed, there would be unequivocal evidence that African genes are the main contributing component for the phenomenal success of East Africans, yet this has not been the case. Interestingly, many East African athletes have mtDNA types more commonly found in Europe, which make other factors more important in these cases [9].

The study by Scott et al. [9] revealed that international-level Kenyan athletes show a higher prevalence of L0 haplogroups and a lower frequency of L3 haplogroups (European), while national-level Kenyan athletes exhibited a higher prevalence of M haplogroups, when compared to the non-athletes. Despite national and international level athletes exhibiting distinct geographical ancestry compared to the non-athletes, this did not seem to be the source of the differences between athletes and non-athletes. A meta-analysis by Konopka et al. [10], found that international level long-distance runners and cyclists (Caucasians, Africans and Asians) possess a unique genetic make-up compared to non-athletes, which likely contributes to their superior performance. Considering both the Kenyan and Ethiopian data, a key finding by Scott et al. [9] was the high levels of genetic diversity in elite East African athletes which suggests that East African athletes are not a genetically distinct population, at least as defined by mtDNA [9]. Some haplogroups were associated with elite Kenyan athletes' performance [9]. East African athletes have a very deep maternal ancestry in common, which is contrary to the view

that they arise from a single genetic origin. The findings that Ethiopian elite endurance athletes demonstrate similarity to non-athletes Ethiopians do not support the hypothesis that mitochondrial polymorphisms determine the dominance of Ethiopian distance runners [11].

Another genetic consideration is related to the Y chromosome, which remains unchanged from different generations within the same family (e.g., from father to son to grandson). Like mtDNA types, Y haplotypes are spread throughout the whole tree and notably, some Ethiopian Y haplotypes are correlated with elite athletes' performance [12]. Scott and Pitsiladis [13] reported that while there is speculation about a possible genetic advantage for African athletes over their Caucasian counterparts, there is no evidence suggesting such an advantage. From the literature, few genetic studies have examined the genetics of African athletes and these have not found evidence that these athletes possess a unique genetic make-up. Instead, these studies served to highlight the genetic diversity among East Africans, including elite East African athletes [14].

Previous studies have attempted to identify candidate genes that could potentially account for the success of African runners [15]. It has been hypothesized that specific genetic polymorphisms might contribute to their athletic success [15]. To date, only two polymorphisms have been extensively investigated: angiotensin converting enzyme (ACE), and alpha-actinin-3 (ACTN3) [2, 11]. The I/D polymorphism is the ACE polymorphism that is most studied, which is characterized by insertion (I) and deletions (D) variants and a high tolerance to altitude, while the D-allele associated with power-oriented performance. Nevertheless, there were no significant differences in ACE (A22982G genotype) allele frequencies between elite Kenyan and Ethiopian athletes and their respective non-athletic counterparts [16, 17]. Similarly, the ACTN3 gene, particularly the R577X variant, has been linked to elite performance in elite Caucasian Australian athletes, but showed no association with the performance of East African runners [18]. The lack of significant findings in these candidate genes suggests that if there was a genetic explanation for the success of East African runners, this would involve other nuclear gene variants.

Recent studies have indicated that genetic variants such as the PIEZO1 gene are associated with increased tendon stiffness, which could contribute to athletic performance [19–21]. The PIEZO1 E756del variant is found in a notable proportion of individuals of African descent, and has been associated with higher patellar tendon stiffness and improved performance in activities requiring high tendon strain-rate loading, such as vertical jumping [19, 20]. This genetic variant may influence the exceptional performance of East African athletes by enhancing tendon

mechanical properties, which could contribute to better running efficiency and endurance performance [20, 21]. As highlighted by this research, the regulation of tendon stiffness and mechanical properties by PIEZO1 could be a key factor in the great running efficiency/performance observed in these populations [20].

Moreover, metabolic adaptations to exercise are influenced by genetic factors, and these have been shown to also contribute to the performance of East African athletes. The study by Reitzner et al. [22] highlighted specific gene expressions and metabolic pathways that are associated with enhanced endurance and strength performance in trained athletes. These genetic metabolic insights underline the importance of a multifaceted approach to understanding the genetic basis of athletic excellence in East African runners. Future research should employ a genomic approach, studying multiple genes and entire genomes, to reveal the complex genetic factors contributing to the outstanding endurance capabilities of these exceptional runners.

Living and training at altitude

Most elite Ethiopian runners live and train in Addis Ababa stadium located at moderate altitudes of approximately 2,355 m, in Entoto located at approximately 2,890 m, close to Sululta at 2,680 m, and in the Arsi region the town of Assela at 2,700 m. Approximately 70 % of elite Ethiopian marathoners are from both Arsis and Sewas areas in the highlands of the Great Rift Valley, which stretches from Kenya into southern and central Ethiopia. More specifically, 38 % of elite Ethiopian marathoners are from the region of Arsi and 24 % are from another 12 regions [23].

Kenyan runners training and living in the Great Rift Valley also use a traditional approach, living and training at moderate altitudes (LHTH) between 2,100 m and 2,700 m in the Eldoret region. Most Kenyan runners also participate in an altitude training camp (Embu County near Mount Kenya) one month before high-profile racing events (e.g., Summer Olympics) [24].

Despite the well-known benefits of altitude training, Kenyan veteran coach, Mike Kosgei, said that “if running success is solely based on altitude residence, then why do countries like Colombia and Nepal not produce such great runners like Kenya does? Our success is based on hard work and attitude, not just altitude” [25]. Considering these words, it seems that chronic exposure to moderate altitude, combined with moderate volume, and high intensity altitude training, may partly contribute to the great performances of East African distance runners [4].

The commonly used short stays at moderate altitudes (from days to 4 weeks) entail acute responses such as increased ventilation, increased heart rate, oxygen saturation decline and increased erythropoietin levels, to an eventually improved haematological adaptation and oxygen carrying capacity after around 3 weeks [26–28]. The chronic adaptation to altitude exposure (>4 weeks) and the corresponding physiological and performance changes are however less known given the difficulties of performing long-term research studies at altitude training camps. Brothers et al. [29, 30] are among the few authors to examine long-term adaptations to altitude in individuals relocating from sea-level, suggesting full physiological acclimatization to moderate altitude may require between 7 and 15 months. Athletes such as Mo Farah and Julien Wanders moved to East Africa for at least 6 months to benefit from these chronic adaptations, although this may not be feasible for most athletes due to high costs and logistic issues. East African athletes, many of whom have lived and trained at high altitude for all their lives benefit from long-term physiological adaptations to hypoxia, which are not fully understood. Current evidence from populations who reside at low and high altitude indicates that hypoxia defenses are initiated by at least five general hypoxia response systems: 1) hypoxic ventilatory response, 2) redistributed pulmonary circulation, 3) erythropoietin (EPO) response, 4) angiogenesis responses, and 5) altered expression of metabolic enzymes and transporters. These systems are key for understanding hypoxia tolerance [31]. The five hypoxia response systems, proposed as hypoxia defenses, prompt the question: “If a common hypoxic response serves as our species’ solution to the challenges of hypobaric hypoxia and endurance performance, has this solution emerged independently multiple times throughout history?”

Understanding the evolutionary pathways of our species is essential in searching for such evidence. Hochachka et al. [31] proposed a simplified “phylogenetic tree” for the human species based on the extensive work on human genetics and evolution by Cavalli-Sforza et al. [32]. This phylogenetic analysis indicates that the last common ancestors shared by Caucasians, Sherpas and Quechuas lived over 50,000 years ago, approximately half of the age of our species [31]. The last shared ancestors between Himalayan highlanders (Sherpas and Tibetans) and Andean highlanders (Quechuas and Aymaras) existed approximately 30,000 years ago. The differences between East Africans and these groups from moderate altitude environments are significant. Despite these genetic differences, Andean, Himalayan, and East African populations exhibit many similar metabolic and physiological responses to hypobaric hypoxia (e.g., terrestrial altitude) [31]. These similar responses in the three

highland populations studied could have happened independently by positive natural selection some 5,000 generations ago and may represent an ancestral condition. This condition is retained with a down-regulated low capacity in high-altitude groups, and up-regulated high-capacity in groups selected for endurance performance (i.e., East Africans) [33]. Interestingly, all hypoxic response systems reported above are also found in humans adapted to endurance performance, which includes a blunted hypoxic ventilatory response and hypoxic pulmonary vasoconstrictor response, increased blood volume, changes in metabolic enzyme and metabolite transporter expression, fuel preference adjustments, and a higher ratio of aerobic/anaerobic contributions during exercise [34]. These adaptations to hypoxia are our species' primary solution to the physiological challenges of hypobaric hypoxia and to enhance endurance performance. Notably, this solution has emerged independently multiple times throughout our species' history, providing strong evidence for selection and evolutionary adaptation [31].

Regarding the human adaptation to high altitudes, Beall [35] examined four traits related to human adaptation to high altitudes (resting ventilation, hypoxic ventilatory response, oxygen saturation and hemoglobin concentration). This study found that Tibetan and Andean populations differ in their phenotypic adaptive responses to high-altitude hypoxia. The Tibetan population showed significant genetic variance in all four traits, while the Andean population exhibited variance in only two (hypoxic ventilatory response and hemoglobin concentration). This indicated that microevolutionary processes may have operated differently in these geographically separated Tibetan and Andean populations exposed to similar environmental stresses, highlighted the need for more research on the genetic origins of these traits.

Beall et al. [36], also presented a third unique pattern of human adaptation to high-altitude hypoxia in Ethiopia, which differs from both the Andean model (characterized by erythrocytosis with arterial hypoxemia) and the Tibetan model (marked by normal venous hemoglobin concentration with arterial hypoxemia). A field survey of 236 Ethiopian residents living at an altitude of 3,530 m revealed an average hemoglobin concentration of 15.9 g/dL for males and 15.0 g/dL for females, with an average oxygen saturation of 95.3 %. This indicates that Ethiopian highlanders maintain hemoglobin concentrations and oxygen saturation levels similar to those at sea-level, despite the reduced oxygen partial pressure at high altitudes.

The extent to which chronic adaptation to altitude plays a key role in East African dominance in endurance events is unknown and more research is needed. However, the logistics to test the long-term (months/years) physiological

and performance adaptations of terrestrial athletes to moderate altitude in a representative sample of athletes is extremely difficult. Future research should use next generation sequencing and advanced bioinformatics to significantly advance the field. If altitude alone explained the success of these athletes, all high-altitude countries would consistently produce numerous world-class athletes, suggesting that a combination of factors is at play [37].

Training characteristics

An essential element elucidating dominance of Kenyan runners in long-distance running is their ability to train at very high intensities even at altitude [38, 39]. This idea of giving more importance to intensity than volume when training at high altitude is not new. A study by Coetzer et al. [40] reported that although there were no differences in training volume at low intensities between Caucasian and East African athletes, East Africans trained a greater volume at high intensities ($>80\%$ $\text{VO}_{2\text{max}}$).

A study by Billat et al. [41] examined elite male Kenyan distance runners and divided the athletes into two groups: high-speed training runners (training at velocities at or above $\text{vVO}_{2\text{max}}$) and low-speed training runners (training at velocities below the $\text{vVO}_{2\text{max}}$). The 10,000 m personal best time of the high-speed training group was 28:15 min:s and of the low-speed training group was 28:54 min:s. The total weekly running distance was 10 % greater in the low-speed training group, and the distance run at lactate threshold velocity (vLT) was 2.4 times higher in this group, compared to others. The weekly running distance at $\text{vVO}_{2\text{max}}$ was 7.8 km in the high-speed group, whereas the low-speed group did not perform any volume at $\text{vVO}_{2\text{max}}$. A review study by Casado et al. [39] showed that elite distance runners typically accumulate >100 km/Wk in their training, with a significant portion of this mileage conducted at vLT . These runners use continuous tempo runs and long and medium aerobic interval training with short recovery periods to train at vLT .

Another important factor contributing to East African running, is the ability of East African runners to maintain high levels of cerebral oxygenation during maximal self-paced exercise even at altitude [42]. Wilber and Pitsiladis [4] reported that a crucial factor in the success of Kenyan and Ethiopian runners is their capacity to train at intensity training at vLT and $\text{vVO}_{2\text{max}}$ velocities without overtraining, unlike athletes from other regions who often get injured or cannot attain such intensities at altitude. For example, Kenyan runners typically engage in high intensity interval

training (“bone breaking” sessions) always at altitude [43]. These sessions are built on a solid foundation developed over many years of running and pre-season aerobic training as well.

A classic training program for Kenyan long-distance runners is 200 m repetitions, usually between 7 and 12 repeats at 120 % of $v\text{VO}_{2\text{max}}$ (duration: 21–24 s) with 3–5 min recovery or 200 m repetitions at 25–28 s with 30 s–2 min recovery or $10\text{--}20 \times 400\text{--}600$ m at 100 % $v\text{VO}_{2\text{max}}$ [32]. Other training programs used by Kenyans are “tempo running” (between 45 and 70 min) and longer interval training designs (e.g., 6×1 mile completed at an intermediate speed between the distance over 3,000 m and 10,000 m with a rest of 200–400 m recovery run in between) [41]. Whether the exceptional capability of Kenyan and Ethiopian elite runners to perform high-intensity training at moderate altitudes may be attributed to a genetic predisposition developed over millennia of living at approximately 2,000–2,500 m, this hypothesis remains unclear as previously mentioned. A speculation along these lines is the idea that Kenyan runners are able to maintain their cerebral oxygenation during high-intensity exercise, possible due to specific early-life factors common among them, such as prenatal exposure to high altitude and high levels of childhood physical activity [42].

Physiological factors

Physiological factors are of crucial importance in the dominance of East African runners, particularly regarding $\text{VO}_{2\text{max}}$, running economy and muscle fiber type. Saltin et al. [38] found that elite Kenyan long-distance athletes had a very high $\text{VO}_{2\text{max}}$ but this was not significantly different compared to Scandinavian distance runners when tested at sea-level (Kenyans: $79.9 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ and Scandinavians: $79.2 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$), or at 2,100 m (Kenyans: $66.3 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ and Scandinavians: $67.3 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$). These findings were later confirmed by the review of Wilber and Pitsiladis [4], which indicated that the $\text{VO}_{2\text{max}}$ of elite Kenyan distance runners ($71.5 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) was not significantly different compared with elite German distance runners ($70.7 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$). Despite elite Kenyan and Ethiopian distance runners having a similar $\text{VO}_{2\text{max}}$ to their Caucasian counterparts, East Africans are characterized by exceptional running economy (defined as the oxygen cost at a given running speed [44]) and important differences in performance [45].

Regarding running economy, Saltin et al. [38] found that elite Kenyan distance runners exhibited greater running economy than elite Scandinavian distance runners, especially

when running at race pace velocities. Similarly, Lucia et al. [45] studied the running economy of elite distance runners from Eritrea and Spain, revealing equivalent $\text{VO}_{2\text{max}}$ but greater running economy in the Eritrean athletes. The study by Weston et al. [46] also reported that African distance runners showed greater running economy compared to Caucasian distance runners. Collectively these findings suggest that East African runners exhibit a superior running economy than their Caucasian counterparts, which would partly explain the success of East Africans in long distance running [38, 44–46].

The last of physiological factors is the muscle fiber type. Distance running performance shows a significant correlation with the proportion on type I muscle fibers [1]. Some researchers have proposed that the percentage of type I muscle fibers could indicate the potential for muscular trainability [47]. Nonetheless, intensive endurance training has been shown to equally enhance mitochondrial oxidative capacity in both type I and type II muscle fibers. Both Kenyan and Scandinavian elite distance runners exhibit a high proportion of type I muscle fibers [48]. Kenyan junior runners also show a high proportion of type I muscle fibers, which is similar to that of Kenyan elite runners (~70 % type I fibers). In contrast, South African distance runners show a difference, with fewer type I fibers (~58 %) [40].

In conclusion, while the current evidence is limited and does not clearly establish whether Kenyan and elite distance runners possess a higher proportion of type I muscle fibers compared to other runners, the small number of muscle biopsies and lack of cross-sectional statistical comparisons contribute to this uncertainty. Further research is indeed necessary to clarify this matter [1].

Childhood physical activity and running

The 2020 World Health Organization guidelines recommend that children and adolescents should participate in at least 60 min of moderate to vigorous physical activity daily to promote health and cardiorespiratory fitness [49]. However, children living in high-income countries often fall short of achieving the recommended 60 min of moderate to vigorous physical activity daily, with less than 40 % of children or adolescents meeting physical activity recommendations [50].

Previous studies found that Kenyan adolescents who live in rural areas maintain high levels of physical activity, walking or running 3 h per day on average and also spending an average of 40 min/day working in the fields [44, 51].

Ojiambo et al. [52], examined the physical activity levels of Kenyan schoolchildren aged 10–17 years from the Nandi tribe and found that moderate-to-vigorous physical activity ranged from 131 to 234 min/day for boys and 109 to 193 min/day for girls. Kenyan adolescents showed to be highly active and exhibited high energy expenditure per day, which reflects the active rural African lifestyle [52]. This supports the study by Gibson et al. [53], who reported that the active and energy-demanding lifestyle of the Kenyan children is associated with their high levels of physical fitness. This combination likely leads to their later athletic success and promotes the early identification of talent in the region.

The study of Scott et al. [23] examined the distance and method of travel to school of a group of Ethiopian elite athletes during their childhood. They reported that 73 % of marathon athletes traveled 5–20 km to school daily, compared to 40 % of 5–10 km athletes and 36 % of track and field athletes. In terms of method of travel to school, once again the marathoners ran more than the other groups (marathoners: 68 %; 5–10 km athletes: 31 %; track and field athletes: 16 %). Similar results were witnessed in Kenya, Onywera et al. [51], reported that 86 % of Kenyan international-level runners used running as their primary means of transportation to school during childhood. On the contrary, only 23 % of non-athletic Kenyan subjects reported running to school as children. Additionally, Saltin et al. [38] found that children who ran as a form of transportation had a $\text{VO}_{2\text{max}}$ 30 % higher than those who did not and lived in the town. However, it remains unclear whether early running experiences among Kenyan and Ethiopian athletes contribute to their exceptional running performance in adulthood.

Barefoot running during childhood has also been proposed as an important factor contributing to adulthood running performances. This factor has been shown to promote forefoot and midfoot strike patterns during later stages in life, which has been associated with improvements in running economy and performance [54]. Aibast et al. [55] conducted a study that examined the differences in foot structure, foot function, injury rates and physical activity levels between Kenyan children and adolescents who are typically barefoot and those who usually wear shoes. They reported significant differences in foot parameters, injury rates (8 % in habitually barefoot and 61 % in habitually shod) and overall foot health between habitually barefoot and habitually shod participants, with habitually barefoot participants having better foot health. These findings suggest that footwear choices can influence foot structure, function, and general foot health [55]. Children and adolescents who were habitually barefoot spent more time participating in moderate to vigorous physical

activities and less sedentary time when compared to their habitually shod counterparts [55]. In addition, two studies from the same lab [56, 57] reported that forefoot and midfoot strike patterns are likely more prevalent during barefoot running, potentially offering protection against impact-related injuries that are common among a significant number of runners. Hence, barefoot running from a young age may be a key factor contributing to the success of the East Africans by allowing them to train intensely and for many hours with reduced risk of injury.

Anthropometry and somatotype

Kenyan and Ethiopian distance runners exhibit distinct differences in their general somatotypes. Elite Kenyan runners, especially those from the Great Valley tribes, typically have an ectomorphic somatotype, marked by long, slender legs, a common trait among central and southern African tribes. Conversely, elite Ethiopian runners generally exhibit a more mesomorphic somatotype, characterized by physical traits typical of northern Africa and shared with some populations from Europe and the Middle East [4]. When comparing Kenyan and Ethiopian runners, Ethiopian runners are more light-skinned than their Kenyan counterparts, they are also shorter and typically have a greater thigh circumference [4]. Larsen et al. [44] examined the anthropometric characteristics of elite Kenyan distance runners and also the running economy of age-matched Kenyan boys and untrained Caucasian boys. They found that elite Kenyan distance runners had longer legs (5 % longer legs) and slimmer/lighter calves (12 % lighter) than elite Scandinavian distance runners. Additionally, Kenyan boys appear to demonstrate superior running economy compared to Caucasian boys.

Regarding morphological characteristics, a study by Saltin et al. [48] demonstrated that muscle morphology is similar between Kenyan and Scandinavian runners. Other morphological indices, such as fiber area and capillarity, were also similar in both Kenyan and Scandinavian runners, indicating no significant difference from what has been observed in endurance-trained muscle with no effect of altitude training.

African diet

The study by Beis et al. [58] found that the Ethiopian traditional diet consists of 64 % carbohydrate, 23 % fat, and 13 % protein. The carbohydrate component of the diet includes fruit, bread, rice, pasta, unrefined sugar, and vegetable

staples. Similarly, Onywera et al. [59], reported that the traditional Kenyan diet is composed of 77 % of carbohydrate, 13 % fat, and 10 % protein. This long-standing Kenyan diet, which is low in fat and high in carbohydrates, has been adhered to for centuries and meets with the majority of guidelines for endurance athletes. The Kenyan diet's carbohydrate sources include fruits, unrefined sugar, rice and vegetable staples, as well as the traditional Kenyan maize dish, called “ugali”, which has a very high glycemic index.

Regarding diet supplementation, elite Ethiopian runners reported minimal use of dietary supplements [58], whereas elite Kenyan runners indicated that they do not use any [59]. However, both the Kenyan and Ethiopian diets met most macronutrients recommendations of endurance athletes [58, 59]. Fudge et al. [60] showed that Kenyan runners stayed hydrated day-to-day with ad-libitum fluid intake, with their main source being water (0.7 L/D) and milk tea (1.2 L/D) [60]. Traditionally, Kenyan athletes drink “chai” tea after their training sessions, which has a high glycemic index and might effectively replenish glycogen stores. Furthermore, the diets of Kenyan and Ethiopian runners do not differ significantly in composition from those of their European, American and Asian counterparts.

East African athletes tend to constantly consume high amounts of carbohydrate in their diets and not only immediately prior to competition. East African athletes also tend to consume hypocaloric diets especially in the buildup to competition thus allowing for significant weight loss [61], which is beneficial to endurance performance as long as there are no symptoms of relative energy deficiency in sport (RED-S), as witnessed in recent research [62]. Önnik et al. [62] recently examined the prevalence of RED-S in Kenyan runners, observing low daily energy intakes, but no indication of increased prevalence of low bone mineral density, or hormonal abnormalities with triad-red-s-related [62]. Therefore, the East African diet and dietary practices may in part explain the success of these athletes compared to their European counterparts.

High motivation to succeed

Despite economic growth, unemployment rates remain high in Kenya and Ethiopia at 40 and 35 %, respectively, with around half of the population living below the WHO poverty line [51, 63]. Success in sports is a crucial motivation factor for distance runners from these countries. The study of Onywera et al. [51] found that 33 % of Kenyan distance runners train and compete primarily to achieve economic success. For Kenya and Ethiopia, becoming a successful runner translates into lifelong economic and social advancement, allowing

them to financially support their families. In their review, Wilber and Pitsiladis [4] reported that the motivation of social and economic success, combined with a long-standing tradition of excellence, connects today's exceptional Kenyan and Ethiopian distance runners with their predecessors. In Ethiopia, this tradition of excellence started with Abebe Bikila who won the marathon gold medal at the 1960 Olympic Games in Rome and has continued with Olympic and World Champions such as Mirtus Tifter, Mamo Wolde, Haile Gebrselassie, Kenenisa Bekele, Derartu Tulu, Meseret Defar Tirunesh Dibaba and many others. Addis Ababa which means “new flower” is frequently called Ethiopia's “field of dreams” and is situated at an altitude of 2,355 m. For years, many of the country's most promising runners have come here to train in pursuit of running excellence.

Kenya has a similar tradition of excellence in distance running. This legacy began at the 1968 Mexico Olympics, with Kip Keino winning a gold medal in the 1,500 m. From that moment, many other Olympic and world champions followed such as Henry Rono, Peter Rono, Paul Tergat, David Rudisha, Eliud Kipchoge, Vivian Cheruiyot, Faith Kipyegon, Brigid Kosgei, Kelvin Kiptum and many others. A number of these Olympic and world champions initially trained at Saint Patrick's High school in Iten, located at 2,450 m in the Great Rift Valley. Guided by brother Colm O'Connell, the school has become renowned as Kenya's “running factory,” nurturing young talent and immersing them in the country's esteemed tradition of Kenyan running excellence and high performance expectations [4].

In addition to the possible influencing factors as discussed above, East African distance runners from Kenya, Ethiopia and Uganda dominate over athletes from neighboring countries such as Somalia and Tanzania due to several other factors. These countries (Kenya, Ethiopia and Uganda) benefit from robust infrastructure, high-altitude environments, and elite coaches who scout for talent. Kenya and Ethiopia historical success had created strong cultural and support system, inspiring the younger generation [4]. On the other hand, Somalia's conflict and instability hinder sports development and Tanzania despite stable socio-economic conditions, may not invest heavily in athletics due to its lower popularity [64, 65]. Uganda has also produced notable runners like Joshua Cheptegei and Jakob Kiplimo, while Somalia and Tanzania lack this historical depth and development in distance running [66]. Kenya and Ethiopian athletes benefit from world-class coaches, whereas other East African countries lack similar quality coaching. Effective talent identification and development systems, starting in schools and local athletic events, are supported by government investments in Kenya and Ethiopia [51]. In contrast, political instability and

limited resources in some East African countries (e.g., Somalia and Tanzania) impede sports development and might not prioritize athletics as much. A significant problem that hinders the development of good long-distance runners in some East African countries (e.g., Somalia and Tanzania) is the migration of talented athletes to more developed countries (e.g., Mo Farah, Abdi Nageeye). These factors likely contribute to the differing levels of success in long-distance running between these countries.

Conclusions

This narrative review analyzes the factors behind the success of East African runners in long-distance races. It identifies genetic, environmental, training, physiological, and psychological factors, as well as the impact of the African diet. Four key factors are highlighted: biomechanical and physiological attributes, training habits including childhood physical activity and running, psychological motivation, and diet. These factors collectively explain the dominance of East African runners in long-distance races.

Most of the East African population now live in rural areas and that means that they have different lifestyles and are more physically active than most people from other wealthier countries. This East African running phenomenon will continue as long as there exists a mismatch between our bodies and the sedentary demands of the modern world. So, to compete with East African runners, the developed world needs to correct this mismatch, understand our evolutionary heritage, and find ways to align our body's physiology with the modern world we are creating, aiming to establish a successful future where physical activity, much like in our ancestral past, remains a central component of daily life [67].

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