



Endurance in Homo Sapiens: An Evolutionary and Modern View

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Abstract

The endurance of Homo Sapiens has been a subject of discussion and curiosity, both from the perspectives of the past and the present. Multifaceted information is needed to further investigate the origins and future implications of this idiosyncratic ability, from anatomy to psychology. This literature review presents five major factors impacting the endurance of H. Sapiens: locomotion(bipedalism), muscle mechanics, energy expenditure, thermoregulation, and psychological perseverance. In addition, several comparisons between primates and H. Sapiens are presented to provide an evolutionary perspective: exploration of body composition, sense of self, and skeletal & muscular anatomy are presented to illustrate the difference. Generally, H. Sapiens' endurance abilities seemed to derive from interconnection between advantageous anatomy and psychology – the greater depots of energy-storing fat tissues enables sustained efforts of repetitive locomotion, and heat produced from the expenditure of energy is regulated by temperature regulation enhanced by hairlessness; the unique psychological consciousness and diverse personalities tolerate extreme physical stress. These findings could suggest that not only H. Sapiens' anatomical and psychological characteristics are fit for endurance, but are helpful to predict the future of endurance abilities in the world of recreational and competitive running.

Introduction

Long-distance running separates Homo Sapiens' – or modern humans' – from all other mammals in the world. It has become a universal sport, tool, and a competition in this modern world, whether it is used to catch a far-gone bus or to build cardiovascular fitness; it has been an asset for well-being and survival. The unique anatomy of humans enables us to run long distances – The concept of running has become quite altered since the late 19th century. Endurance running is utterly ancient – its use emerged likely by the hunter-gatherers' persistence hunting¹, now becoming a tool for competition, recreation, and health. From the first cross-country running, Crick Run in the 1838 (Fig. 1)², to the Self-Transcendence 3,100 miles race beginning in 1997³, human triumphs in their running history are yet to advance – or have they reached a limit?



Figure 1. *Runners getting ready to race in the Crick Run.*

The reason behind the Homo Sapiens' exceptional endurance, which separates them from other mammals, might change our understanding of evolution and natural selection. This review aims to explore and clarify how different aspects of physiological evolution contributed to H. Sapiens' ability to endure sustained activity, and answers the fundamental question: why was it that only humans acquired this ability? Locomotion, muscle mechanics, metabolism, and pain tolerance all correlate to create this idiosyncrasy. In running, with bipedalism and light-weight upper body, overall less stress is inputted to the limbs; as the forefoot strikes the ground, the soleus muscles contract and spring up the whole body, allowing the back foot to strike the ground and repeat the motion – and the body propels forward to travel. All the while, the arms opposite to the forefoot swings, allowing weight distribution and balance. H. Sapiens have followed a unique path to evolution; the difference between the modern and pre-modern lifestyle reinforces the idea that the human body evolved to move, through comparison with other mammals.

The Locomotion

Endurance running does not exist without the powerful locomotion of Homo Sapiens. The two long legs and the swing of two arms drive them forward – known as bipedalism – and the unique muscle construction allows for powerful propulsion. H. Sapiens' legs demonstrate a top-heavy and bottom-light muscle distribution: while the quadriceps femoris muscle holds greater size and soleus muscles tend to reduce in size. The 3D proximation of human leg muscle distribution reveals that H. Sapiens uniquely have varying muscle Center of Mass (CoM) distribution, such as that of the soleus muscle – the calves – its mass significantly larger compared to the location (Fig. 2)⁴. Endurance running demands consistent expenditure of force specifically from the soleus muscle, quadriceps femoris muscle, and gluteus maximus muscle; the large mass and CoM among those areas allows for persistent effort. And the unique variations of CoM allows for an advanced strength in endurance running, as the persistent locomotion of striking the ground and propelling forward requires increased muscle density for greater support. Although the large CoM in the quadriceps femoris and glutes maximum area reduces leg swing, its mass increases running stability.⁴

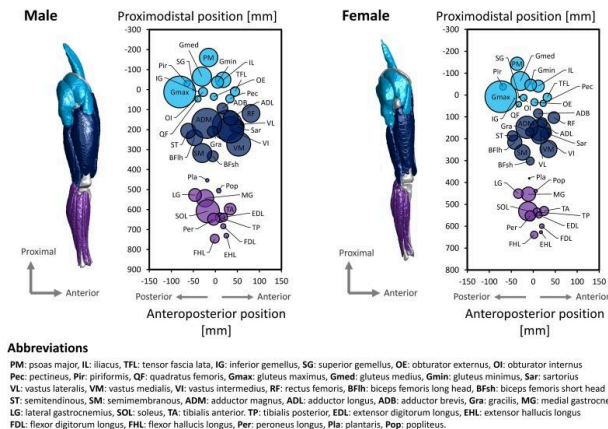


Figure 2. Bubble plots of CoM positions and muscle mass(expressed with the size of the bubble) in the human leg.

Posture and Force production

The longitudinal study conducted to train four male Japanese Monkeys(Macaca Fuscata), a close relative of Homo Sapiens, to acquire bipedalism displayed a trend that bipedalism calls for a more upright, stable posture; a more compact placement of the pelvis while walking; and the adoption of greater coordination of walking even with high speeds⁵. Habitual bipedalism, idiosyncratic to H. Sapiens, enables greater control and stability during endurance running. Moreover, the elastic component of the body – namely muscles and tendons – creates enhanced support in running. The running mechanics remained unchanged in the study of surface stiffness variations and their influence on running economy. At the same time, a slight decrease in metabolic efficiency was observed (-12%) with decreased surface stiffness.⁶ In other words, the running mechanics' tolerance to varied surfaces shows that H. Sapiens have developed greater endurance in part due to their limbs' compositional advantage over time. The stable posture, pelvis placement, and mechanical advantage allow for H. Sapiens to run economically and thus enhance endurance.

Contraction of the Muscle

Sustained muscle contraction is a necessary mechanism in endurance running. Human muscles are composed of heterogeneous fibers: largely, two types of fibers – type I and type II. The general abundance of type I muscle fibers in Homo Sapiens distinguishes their endurance ability from other mammals. Type I muscle fibers are characterized by their high concentration of mitochondria, dependence on aerobic respiration for producing ATP, low force production, and slow contraction speed.⁷ ATP requires it to be hydrolyzed – or broken down by water – to release energy and thus contract the muscle. While type I muscle fiber contracts slowly, the oxygen provided by anaerobic respiration allows for an enduring, slow-to-fatigue muscle use⁷, which may be why an abundance of type I fibers are seen in endurance athletes. Still, H. Sapiens' composition of muscle fibers differs greatly from that of other mammals. For instance, while H. Sapiens' muscles exhibited more heterogeneous mixtures of type I, type IIA(which

produces power for short duration but also are moderately resistant to fatigue), and type IIX(which produce significant power for short duration), mice and fish exhibited a homogeneous mixtures of type I and type II(Fig. 3).⁸

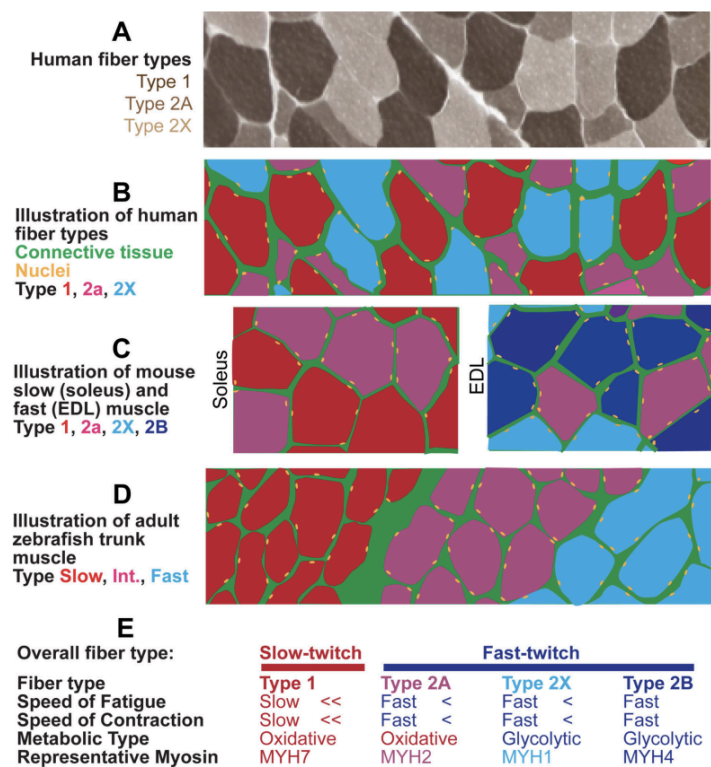


Figure 3. Composition of skeletal muscle fiber types in Human, Mouse, and Adult Zebrafish.

Therefore, H. Sapiens’ heterogenous skeletal muscle type composition in contrast to other mammals implies that H. Sapiens are able to perform a variety of physical activities, including endurance running, and are able to manipulate the diverse muscle fiber types to use for their own advantage. Additionally, chimpanzees’ muscles are composed of more than 50% of type II muscle fibers, with power output greater than – 1.35 times that – H. Sapiens.⁹ While H. Sapiens’ unique lifestyle and a modern, personalized training may create wide variations of muscle fiber compositions between individuals, it can be said that their muscle fiber composition variations and the fundamentally greater composition of type I muscle fibers makes it advantageous to develop endurance ability.

Moreover, the upper-and-lower-limb muscle composition for H. Sapiens is distinct from that of other primates: H. Sapiens have 20% of its muscle in the upper limb, while other primates have >35%(Pongo, 46%; Gorilla, 37%; Pan, 36%), and H. Sapiens have 60% of its muscle in the lower limb, while other primates have <50%(Pongo, 35%; Gorilla, 43%; Pan, 46%)(Fig. 4).¹⁰ This implies that the habitual use of lower limbs of H. Sapiens due to bipedalism accounts for this difference, and the greater muscle composition on the legs also allows for optimized

propulsion for endurance running, since the light weight upper limb reduces downward-stress when in constant forward motion.

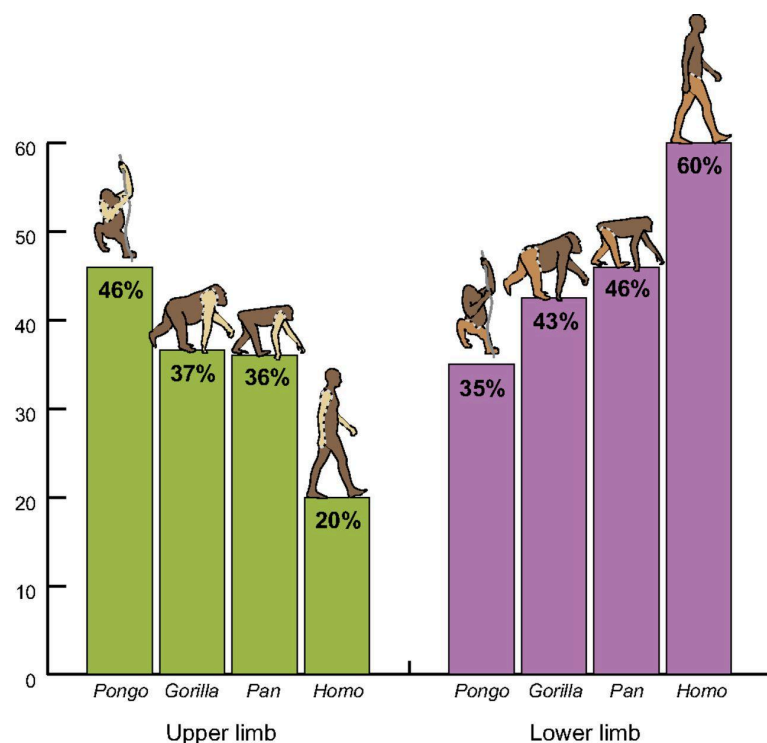


Figure 4. Percentage of muscle distribution between *H.Sapiens*, *Pongo*, *Gorilla*, and *Pan*.

Metabolism and Energy Expenditure Efficiency

As *Homo Sapiens* began to travel long distances and developed a larger brain, an evolutionary step was necessary to create an advanced energy storage system and greater energy expenditure efficiency. It is known that *H. Sapiens* have paucity of Brown Adipose Tissue (BAT) relative to White Adipose Tissue (WAT). Generally, adipose tissues comprise mitochondria and lipids, often called “fat tissues”. BAT – thermogenic adipose – are specialized in generating heat, and thus have a higher population of mitochondria, giving it “brown” color; WAT stores energy, thus having a greater amount of lipids than mitochondria.

Homo Sapiens may have acquired greater depots of WAT over time by discovery of heat, clothing, and construction of lifestyle requiring less energy expenditure – such as sitting – which had resulted in a situation where evolution “had not caught up with modernization”; the thermogenic adipose tissue reduced in composition due to dearth of need for heat generation by the development of external heat-genesis tools. In contrast, the advanced ability to store energy resulted in greater energy expenditure during sustained physical activity, which may have benefited persistence hunting and extended travel.

Additionally, when compared to that of humans, the composition of adipose tissues of other mammals differ greatly: while, for instance, in a study comparing body composition between *H. Sapiens* and other primates, primate species Bonobos have <5% body fat composition (Male, 0.005%; Female, 3.6%), *H. Sapiens* have >20% body fat (Male, 20.3%; Female, 36.3%)¹⁰. This disparity reveals that *H. sapiens*' larger brain and long-distance travel due to habitual bipedalism demanded greater energy input, thus developing more body fat depots. Additionally, the muscle composition for Bonobos ranged from 30.1% to 55.0% (accounting for Males and Females), while *H. Sapiens* 16.8% to 45.5%¹⁰: the lower muscle composition may result from bipedalism, which calls for efficiency over power production, and has adapted to hold lower mass, resulting in lighter propulsion, increasing capacity for prolonged movement.

Finally, the modern *Homo*'s exceptional endurance, in part, is due to their ability to store prodigious amounts of energy, which allows them to thrive in extended activity. Metabolic rate or Total Energy Expenditure (TEE) in *H. Sapiens* displays inverse correlation with the physical activity duration: that is, as duration increases, TEE decreases. The study of maximum SusMS utilized six Race Across USA (RAUSA) athletes, who ran one marathon per day for 6 days per week to run from coast to coast of North America, to measure the difference in TEE between pre-race and post-race. TEE in RAUSA athletes decreased substantially over time throughout the race, revealing the significant metabolic compensation over extended activity.¹¹ This unveils that *Homo Sapiens*, together with the advanced energy storage, can tolerate sustained activity through reduction of TEE, and this conservation system has likely evolved from persistence hunting and long travel. Because of their ability to resist uneconomical energy expenditure, modern humans can train with higher intensity and develop greater endurance, yet this in turn suggests an increased risk for unwanted body mass gain. Additionally, the higher metabolic rate of *H. Sapiens* relevant to larger brain size¹² and complexity compared to other primates implies that to sustain and manage the greater metabolic need of the brain and increase in TEE due to distance travel, *H. sapiens* developed a greater depot of WAT and the energy conservation system to both maintain larger brain size and increased physical activity.

The Unique Thermoregulation Mechanism Mediated by Hairlessness

Homo Sapiens are perhaps the most distinguishable by their lack of hair on the surface of the skin. The paucity of hair coverage on the body of *H. Sapiens* significantly affects their endurance capacity, due to the ability to dissipate heat effectively during endurance activities, and therefore allowing the elevated body temperature to remain within homeostasis continuously. There are primarily two modes in which *H. Sapiens* can cool their temperature to homeostasis (37 degrees C): evaporative cooling by sweating and vasodilation. The effectiveness of vasodilation and evaporative cooling is enhanced by *H. Sapiens*' lack of hair: the greater the amount of hair, the more heat is trapped, thus preventing heat dissipation.

Vasodilation releases heat through dilating the blood vessels and allowing more heat to escape the skin; evaporative cooling utilizes sweating and loss of heat through water evaporation. Vasodilation does not require any release of water¹³, and as water is crucial for maintaining the body's smooth delivery of nutrients and other fluids, heat dissipation through vasodilation is the essential step towards temperature homeostasis. In turn, evaporative cooling requires the release of water. Hair, as does heat, traps water, thus preventing evaporation. Therefore, H. Sapiens' hairlessness greatly enhances the two modes of thermoregulation and thus allows extended duration of physical activity: running.

A model prediction suggests that early humans, hairless, dissipated a maximum of approximately 400 watts, and hairy humans, a maximum of roughly 150 watts, during the day.¹⁴ This difference suggests that hairlessness provided a greater advantage for heat dissipation for early humans, as well as modern humans. Moreover, exercise, particularly endurance activities such as running, increases the core temperature through ATP to contract the muscles; to regulate the continuous temperature elevation, the lack of hair reduces the heat dissipation (citation). Thus, it can be said that human endurance is greatly enhanced by advantages in dissipation.

Psychological Resistance to Pain, or Grit

What allows Homo Sapiens to "push through the limits"? In other words, how can they endure intense physiological and psychological stress? Stress and pain often occur simultaneously¹⁵; that is, acute pain causes acute stress in H. Sapiens. Pain is an integral part of endurance running, mainly due to repetitive muscle contraction resulting in micro-tears, which cause soreness. However, grit – or perseverance and passion for long-term goals – allows for this exceptional endurance ability. What seems to be a trend is that H. Sapiens holds great potential in pain resistance; a study that examined 71 (33 Females, 38 Males; athletes and non-athletes) volunteers, with 39 in control-group, revealed that elite or high-level athletes had greater pain tolerance.¹⁶ The average grit score for endurance athletes was 3.73, on the scale of 1-5 from a self-reported questionnaire, and the average time of enduring the Cold-Pressor Test (CPT) for endurance athletes was 179.67 seconds.¹⁶ The CPT time was comparably higher for endurance athletes and the grit score (soccer players, 113.90 seconds, 3.39; non-athletes, 116.8 seconds, 3.30). These results reveal that athletic H. Sapiens may have greater pain and stress tolerance due to self-awareness, which results in grit – and the physiological ability to tolerate extreme stress from pain.

It is only recently that the term "Grit" is found to have played an integral role in personal achievement¹⁶; in modern days, running has transformed into a form of achievement, and Grit likely is a crucial component of endurance running. While mechanisms of Grit remains largely unexplored, a study revealed that Grit is negatively related to the right dorsomedial prefrontal cortex, which is involved with self-regulation; using resting-state functional magnetic resonance

imaging to 217 healthy adolescents from Chengdu, China, the study illustrated the link between Grit and academic performance. This study presented the past study which found strong associations between personality traits and Grit; using the Grit-S, the study assessed individual differences in Grit – the consistency of interest and the perseverance of the effort.

Conscientiousness, neuroticism, extraversion, and agreeableness was found to be related to Grit.¹⁶ Conscientiousness and neuroticism may play a role in endurance running, especially given in modern days that it has become a form of achievement, emphasizing that running has increasingly become obligatory among elite and amateur athletes, creating a sense of anxiety, worry, or stress that terminating or reducing training efforts will diminish one's endurance ability. Due to this, there may be a positive correlation between the personality traits of conscientiousness and neuroticism in modern runners and thus creating Grit. The study also utilized whole-brain regression analysis to find that Grit is significantly negatively associated with the fractional amplitude of low-frequency fluctuations (fALFF) of the right dorsomedial prefrontal cortex (DMPFC), which is involved in self-control, motivation, and emotional regulation (Fig. 5).¹⁶ fALFF measures the spontaneous cell activities, specifically the slow changes (hence the low-frequency fluctuations) of the certain brain regions; the brain is constantly under activity even in rest, and thus there exists random, spontaneous activities of brain cells. This finding implies that the Grit trait diminishes as the spontaneous cell activities intensify – in other words, as we engage in tasks requiring less activities from the right DMPFC, Grit reduces. It may show that in running, as H. Sapiens gauge to resist the termination of, for example, long-distance race, Grit increases, given that as spontaneous activities decrease Grit buttresses.

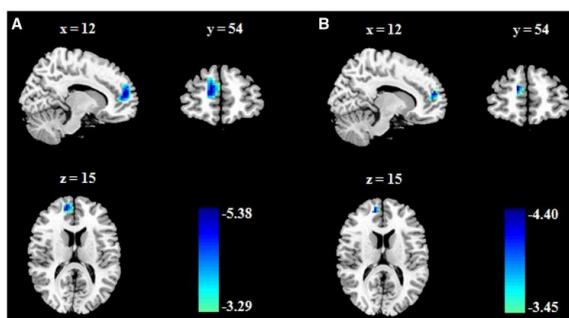


Figure 5. Brain regions associated with Grit(A).

And while Grit is often subject to investigation of academic achievement as this study did, it also plays an integral role in endurance sports; it can be said that self-regulation in H. Sapiens is controlled by Grit and that they regulate their desire to terminate the endurance activity.

Additionally, the quality of Grit in H. Sapiens may also be a result of reward seeking; a relief from acute pain, or anxiety, is rewarding¹⁸: the passion for completing a long-term goal – for example, to finish a race – results in both seeking reward and acute pain. In endurance running, H. Sapiens seek reward out of the termination of prolonged co-occurring acute pain and stress, resulting in grit, and therefore psychological endurance.

Conclusion

Several studies had certain limitations: the study of Japanese Monkeys, which conducted a survey of four male monkeys instead of multiple, diverse monkey species; and the study of pain tolerance across various athletes, which only used 3 groups of athletes (endurance athletes, soccer players, and cross country skiers) and a group of non-athletes of unknown age. Addressing these biases, an implication can be made that studying human endurance requires longitudinal effort and evolutionary knowledge.

Homo Sapiens' exceptional endurance ability is not a product of one evolution, but a correlation of multiple. Bipedalism allowed for extended travel distance and thus increased demand for fuel, which changed our energy storage and expenditure system and resulted in an advantageous temperature regulation mechanism through hairlessness. Moreover, the development and advantages of human endurance are yet to be discovered, as current studies evolve around theories and hypotheses. Yet, the various theories of endurance evolution – persistence hunting, hairlessness, adaptation to long-distance travel, discovery of fire, and more – tell us that there may not be a single reason for this characteristic; after all, organisms must survive, and endurance was the product. Ultimately, despite these adaptations, the modern lifestyle may inhibit and diminish endurance, such as a sedentary lifestyle and the advancement of various technologies limiting physical movement. In turn, a modern lifestyle may also aid in developing endurance through elevated nutrition, a personalized training environment, infrastructures, and social support; availability of those factors may influence one's ability to endure. The modern research and technology surrounding training wears, nutrition, and training plans significantly elevates one's ability to endure, and further research into those factors' relation to running could enhance H. Sapiens' endurance.

Still, there are questions: Where can a modern environment take humans' endurance to? Are there limits? In future investigation of human endurance, one could explore the implications of survival mechanisms, constraints on speed and duration of running relating to the limits of H. Sapiens' physiological endurance ability, and predictions of pre-modern lifestyles concerning endurance.

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