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Review of factors determining performance in long distance running

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Abstract
The effect of special attributes of Long distance runners that assist them to enhance their performance in various competitions need to be analysed individually as well as collectively. High altitude living and training helps athletes to develop better lung capacity which benefits them mostly for events at lower altitudes. Light body weight, healthy diets and longer legs are considered to be some of the additional advantages for the long distance runners. The objective of the review is to develop theoretical framework and formulate hypotheses for each of the special attributes that contribute to the performance in the long distance running, which can then be tested with the help of collected data from various events by the concerned individuals and organisations. This would assist in selecting the prospective athletes and formulating training strategies for their performance in the competitions. Such a holistic approach to investigate the influence of the attributes individually and jointly on the performance of athletes during long distance events has been missing in the literature. As an example, a dry run for the influence of slightly longer femur is demonstrated by considering the step lengths of both male and female athletes and computing the advantages during middle distance, long distance and marathon events. The effect on the performance of athletes in long distance races by each of the remaining attributes can be tested, through corresponding hypothesis, by collecting data from the actual events. The structures of tendons, ligaments and shoulders of athletes may have an influence on their performance, but in the study hypotheses, these are not considered.

Keywords: High altitude, body weight, healthy diets and femur length

1. Introduction
Running has substantially shaped human evolution and made us human at least in an anatomical sense. If natural selection had not favoured running, we would still look a lot like apes. Long distance running was crucial in creating our current upright body form, which our ancestors may have taken up around 2 million years ago on the African savannah. Bramble and Lieberman (2004) [1], examined 26 traits of the human body-many of these traits have also been seen in fossils of Homo erectus and some in Homo habilis that enhanced the ability to run. Traits that added running include leg and foot tendons and ligaments that act like spring, foot and toe structure that allows efficient use of the feet to push off, shoulders that rotate independently of the head and neck to allow better balance and skeletal and muscle features that make human body stronger, more stable and able in order to run more efficiently without overheating.

For long distance running, it is important to have both reasonable speed and exceptional endurance. Running of an athlete can improve with a strong respiratory system, by a simple logic that, better breathing equals more oxygen for muscles which equals more endurance. Through strength training, the hamstrings and calves improve air ability to power over hills, further athletes can tone the muscles used for breathing. One of the advantages of high-altitude training is that the muscles get a natural boost when more oxygen is available to athletes during lower altitude competitions. In sports medicine, below 4000 feet is considered as low altitude, whereas 7000 to 8000 feet above sea level or higher is referred to as high altitude. The increased rate of perceived exertion is caused by altitude induced hypoxia which is a decrease in the amount of oxygen being delivered to the muscles to burn fuel and create energy. Getting acclimated to high altitude, elite athletes require more red blood cells which allow their blood to carry more oxygen and when competing at lower altitude, they get a natural boost to the muscles due to additional oxygen. This blood expanding effect is likely to enhance the performance of elite athletes by 1 or 2 percent, which provides the final cut for a competitive team and winning a medal (Levine, 2016) [2].

Vertical oscillation (VO) is the amount that the torso moves vertically with each step while running, measured in centimeters. Lower VO has been associated with increased running economy by means of larger stride angle, which is the maximal angle between two femurs during a stride (Moore, 2016) [12]. Many coaches believe that with lower VO less energy is wasted going up and down. Another advantage of lower VO is that it typically means that there is less stress on the lower body at impact.

The leg length may be one of the important morphological factors for achieving higher running performance in endurance runners. Mooses *et al*. (2015) [3] determined a positive correlation between absolute upper leg length and running performance in Kenyan endurance runners. They also reported that absolute and relative total lengths (normalized with body height) of upper and lower legs positively correlated with running performance. Ueno *et al*. (2019) [13], by doing magnetic resonance imaging (MRI) measurements found that the relative length of tibia was significantly correlated with personal best 5000 m race. They concluded that the leg bone (femur and tibia) length, especially of the tibia, may be a potential morphological factor for achieving superior running performance in well trained endurance runners. Sano *et al*. (2015) [4] showed that considering the biomechanical theory, the degree of stride length may depend on the length of the thigh rather than the lower leg. Therefore, their findings indicate that compared to the lower leg, a longer thigh may play a role in increasing stride length in Kenyan runners. This could possibly be investigated for the athletes from other countries and in particular, for East African countries and Morocco.

Faster distance runners also tend to have lower body mass index and reduced body fat than their slower counterparts. Stride length has been shown to have a greater influence on velocity than stride frequency across a range of speed. The running stride can be broken down into a number of phases. The absorption phase is from the moment the foot contacts the ground to the point where the knee is at maximum flexion in mid-stance. The propulsion phase is from this point to the moment the foot leaves the ground (toe off). During the propulsion phase, the leg pushes against the ground and the body is propelled forwards and upwards. Elite runners reduce energy cost by optimizing these forward and upward movements. This is done by aligning the direction of force with the axis of the leg during the propulsion phase, which the elite runners after training and practice adjust to have relatively lower upward motion. The lower limb tendons of elite runners assist in improving running economy and performance. The Achilles tendon and quadriceps tendon are especially adapted for this purpose. Achilles tendon, being the largest and strongest in the body, is a tough band of fibrous tissues that connect the calf muscles to the heel bone and when the calf muscle flexes, the Achilles tendon pulls on the heel allowing us to stand on our toes while running, walking or jumping. Despite its strength Achilles tendon is also quite vulnerable to injuries because of limited blood supply to it as well as high tension placed on it. However, having a good source of protein, spread throughout the day during each meal may help in optimizing the body's absorption of amino acids to keep the Achilles tendon healthy. It is observed that the Achilles is similar to a spring and acts to store energy by stretching during the absorption phase and releasing the stored energy during propulsion to reduce the mechanical work required from the muscles. In order to run fast during long distance and marathon the elite runners possess a combination of inherent anatomical, physiological and biomechanical attributes that are optimized through long term training (Connick, 2018) [6].

During major championship events, 1500m, 5000m and 10000m runners need to run as close to the inside of the track as much as possible during the decisive stages of the race when speed is high. Staying within the leading positions during the last lap is recommended to optimize finishing position during 1500m and 5000m major championship races. In 1500m races, a parabolic J-shaped pacing profile is typical, where athletes begin with moderate speed on the first lap, slow their speed on the second lap, increase their speed between 700m and 1300m and eventually maintain or decelerate their speed during the final 200m. However, elite runners maintain their speed without slowing down during the last 200m of the race (Fukuba and Whipp, 1999) [7]. In 3000m steeplechase, 5000m and 10000m events world record performances from 2008 onwards were achieved through an even pacing strategy (Thiel *et al*., 2012) [9]. However, analysis of pacing patterns displayed during previous 32 world records from 5000m events and 34 world records from 10000m events revealed U-shaped profile where first and last 1000m were faster than even pace adopted during the rest of the race in both events (Tucker *et al*., 2006) [8]. The 10000m event was run by both men and women at a more even pace than the events of 5000m and 3000m steeplechase, which are mostly followed by noticeable acceleration during the last 1000m (Hettinga *et al*., 2019) [10].

2.1 Hypotheses for performance in long distance running

In order to investigate the influence of the considered special attributes of athletes on their performance in long distance running, the five hypotheses are formulated. These hypotheses can then be tested from the collected data for each attribute with the assistance of a regression line. Finally, a multiple regression line can be used to check the influence of all the attributes considered together on the performance of athletes in long distance events.

Hypothesis 1: High altitude living and training has significant effect on the performance of athletes in the long-distance running.
The corresponding regression equation (model) is given by:

$$P_1 = \alpha_{10} + \alpha_{11} X_1 + \epsilon_1,$$

where X_1 represents high altitude living and training, P_1 is the performance, α_{10} is the constant term independent of X_1, α_{11} is regression coefficient and ϵ_1 is the error term of the model.

Hypothesis 2: Light body weight has significant effect on the performance of athletes in the long-distance running.
The corresponding regression equation (model) is given by:

$$P_2 = \alpha_{20} + \alpha_{21} X_2 + \epsilon_2$$

Where

X_2 represents light body weight, α_{20} is the constant term independent of X_2 and α_{21} is the regression coefficient and $\in_2$ is the error term of the model.

Hypothesis 3: Healthy diets have significant effect on the performance of athletes in the long-distance running.

The corresponding regression equation (model) is given by:

$$P_3 = \alpha_{30} + \alpha_{31} X_3 + \in_3$$

where X_3 represents healthy diets, α_{30} is the constant term independent of X_3 and α_{31} is the regression coefficient and ∈3 is the error term of the model.

Hypothesis 4: The leg length has significant effect on the performance of athletes in long distance running.

The corresponding regression equation (model) is given by:

$$P_{4=} \alpha_{40} + \alpha_{41} X_4 + \in_4,$$

Where X_4 represents leg length, α_{40} is the constant term independent of X_4 and α_{41} is the regression coefficient and $\in_4$ is the error term of the model.

Hypothesis 5: The high altitude living and training, light body weight, healthy diets and leg length have significant joint effect on the performance of athletes in long distance running.

The corresponding multiple regression equation (model) is given by

$$P_5 = \alpha_{05} + \alpha_{51} X_1 + \alpha_{52} X_2 + \alpha_{53} X_3 + \alpha_{54} X_4 + \in_5$$

Where X_1, X_2, X_3 and X_4 are already defined, α_{05} is the constant term, independent of the four variables, α_{51}, α_{52}, α_{53} and α_{54} are the corresponding regressions coefficients of the variables and $\in_5$ is the error term of the model.

Remark: The values of the regression coefficients in equations of the hypotheses of the corresponding attributes from the collected data would reflect the extent of their effect as well as elasticity on the performance of the athletes in the long-distance running. This could possibly assist trainers to develop appropriate strategy for enhancing the performance of each of their athletes.

2.2 East African long-distance runners

There seems to be a definite edge on the global arena of the long-distance runners, due to various natural factors, who grew up in the high-altitude environment of East Africa. Further Kenyans, Ugandans and Ethiopians have a healthy traditional diet which also plays a role in their success. East African athletes have the advantage of living and training at high altitude. In the rural settings during young age, some of these athletes were running miles to their school and back home mostly barefoot, which gives them a special edge. Kenyan and Ethiopian athletes are also motivated to pursue professional running careers because of poverty in the areas of their countries, which pushes them to avail every opportunity and succeed through hard work. Generally, the staple diet of Kenyan and Ugandan runners, who seem to be of same ethnic group, include ugali (stiff porridge made from maize flour), sukuma wiki (kale) and spinach (green leafy vegetables), cow milk, various types of beans and eggs. Average leg of Kenyan athletes was found to be 400gms lighter as compared to other athletes, which translates to energy saving of nearly 8% when running and provides an edge over other athletes in the long-distance race. Kenyan long-distance runners have developed over the years, a psychological advantage as they see themselves as unbeatable on the global stage and have an aura of invincibility both in their and their opponent's mind (Esomnofu, 2019) [11].

2.3 Influence of femur length on long distance running (Example)

Obialor *et al*. (2015) [5] measured the length of femur to estimate the height of adult runner population of Oguta local government area of Imo state, Nigeria. Results of the study were: Male: femur length 41.79±0.16 cm; height 167±0.78 cm, with correlation 0.9927. Female: femur length 40.82±0.26 cm; height 161.90±0.95 cm, with correlation 0.9126. Overall: femur length 41.18±0.03 cm; height 164.47±0.67 cm, with correlation 0.9866. Revealing the proportionality of femur length to height, they found that the height of an individual is nearly four times the femur length.

In order to explore the possible effect of longer thigh (femur) on the step (half of the stride) length reported in Kenyan runners by Sano *et al*. (2015) [4], the effective distance covered on the ground is computed. Let L denote the femur length, θ be the angle between femur and its horizontal projection X measuring the effective distance covered on the ground by an athlete (Appendix-figure). Thus, we have $X = L \, Cos \, \theta$. The angle $\theta = 45$ has been taken as an example. In the real situation the optimum value of θ would vary for the elite runners depending upon some of their attributes like height, weight and stride angle. Though the actual values of femur length would be different for individual athletes, the femur length from the literature Obialor *et al*. (2015) [5] have been used to compute the effective distance covered on the ground for male and female athletes.

Male: X = 41.79 Cos45= 41.79 (0.707106781) = 29.54999239 cm.

Female: X =40.82 Cos45= 40.82(0.707106781) = 28.86409881 cm.

The effect of longer femur by ***δ*** cm on the distance covered on the ground for both male and female athletes is now computed by allowing the (assumed) value of δ=1 cm and δ=2 cm. In reality δ can take any value within a prescribed interval.

Male: X= (41.79 + δ) Cos 45=42.79 (0.707106781) = 30.25709917 cm, with δ=1 cm.
X=43.79 (0.707106781) = 30.96420595 cm, with δ=2 cm.

Female: X= (40.82 + δ) Cos45 =41.82 (0.707106781) = 29.57120559cm, with δ=1 cm.
X= 42.82 (0.707106781) = 30.27831237cm, with δ=2 cm.

Thus, the advantage in the effective distances covered per step (in cm) for male and female athletes with longer femur are given as follows.

Male: with δ=1cm, 30.25709917-29.54999239=0.707106784 cm.
with δ=2cm, 30.96420595- 29.54999239=1.414213564 cm.

Female: with δ=1cm, 29.57120559-28.86409881 = 0.70710678cm.
with δ=2cm, 30.27831237-28.86409881= 1.414213576cm.

The possible estimated advantages for both male and female elite runners having femur longer by δ cm, in 800m to marathon are now computed (dry run) in the following table.

Table 1: Relative Advantage in Events with longer Femur

Race Meters	Male (SL=79cm) No. of steps	Relative advantage		Female (SL=66cm) No. of steps	Relative advantage	
		δ=lcm	δ=2 cm		δ=1cm	δ=2cm
800	1013	7.16m	14.33m	1212	8.57m	17.14m
1500	1899	13.43m	26.86m	2273	16.07m	32.15m
3000	3798	26.86m	53.71m	4546	32.15m	64.29m
5000	6329	44.75m	89.51m	7576	53.57m	107.14m
10000	12658	89.51m	179.01m	15152	107.14m	214.28m
Marathon	53411	377.67m	755.35m	63932	452.07m	904.14m

The relative advantage is not very prominent during the middle-distance races of 800m and 1500m, as many elite runners maintain their speed during the final 200m resulting in close finishes. However, for the long-distance races and marathon, the relative advantages are clearly visible in the outcomes of these events. In the training camps of sports associations, the actual measurements of femur length of various athletes can be taken, that may differ by values other than 1cm or 2cm, and then the influence of relatively longer femur on the performance during long distance races can be investigated, assuming that all other factors are nearly similar in the athletes. Further, the influence on the performance of athletes in long distance races by each of the remaining attributes can found by testing the corresponding hypothesis by collecting data from the events. Finally, the combined effect of all the attributes on the performance of athletes in the long-distance races can be checked by testing the hypothesis 5 and the values of the regression coefficients and their elasticity of the corresponding equation.

3. Discussion

The computed values indicate a definite advantage for elite runners having longer thigh (femur), particularly during the long-distance races, under the assumption that all athletes have high altitude training, similar food habits and lighter legs as well as upper limb. The values used for femur length and step size for male and female athletics in the computation are taken from the literature. The actual measurements for femur length and number of steps taken by elite athletes during the various races can however be recorded with the help of electronic watches or any other devices in order to validate the pattern of calculations that are arrived from the proposition, shown in the table. For the individual as well as overall performance P_i, i=1, 2, 3, 4, 5 data for the parameters of the suggested regression models can be collected for the elite runners. The nature (sign and magnitude), elasticity and statistical significance of coefficient of each parameter would reveal the extent of influence of the model parameters on the performance of athletes in the long-distance running. By computing the coefficient of determination, the goodness of fit of the each model would be determined. Comparing the estimated values from the model with the actual values recorded from the event, for each athlete, the error of estimation can also be computed. This would assist in the practical applications by making the corresponding amendments in the proposed model and its parameters, to guide the sportspersons, coaches and sports federations, in order to achieve enhanced performance of athletes in long distance races.

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5. Declarations

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Appendix: Picture of the leg while running