J Appl Physiol 2010 Aug 5 [Epub ahead of print]
PMID: 20689089

The Two-Hour Marathon: Who and When?

M.J. Joyner*

J.R. Ruiz†

A. Lucia§

*Department of Anesthesiology
Mayo Clinic
Rochester, MN

†Department of Biosciences and Nutrition
Unit for Preventive Nutrition
Karolinska Institutet
Stockholm, Sweden

§Universidad Europea de Madrid
Spain

Corresponding Author: Michael J. Joyner, M.D.
Department of Anesthesiology
Mayo Clinic
200 First Street SW
Rochester, MN 55905

Phone (507) 255-4288
Fax (507) 255-7300
E-mail: joyner.michael@mayo.edu

OVERVIEW

In this Viewpoint we ask if information about the physiology, genetics, and empirical history of elite endurance performance can provide insight into the question of "who" will break the two-hour marathon barrier and when this might happen. We also identify several physiological questions that we believe need attention.

The current world record in the men's marathon is 2:03:59 (Gebrselassie 2008). This record has fallen by more than 16 minutes since the early 1950s after high volume/year round training was adopted widely. Except for the 1970s, the record has fallen by ~1-5 minutes per decade since 1960 when Africans entered international competition. Improvements since 1980 likely also reflect increased prize money and competitive opportunities that allowed top athletes to earn a living running. Figure 1 shows the history of marathon times and projected improvements. Using times from 1960, the open squares suggest it will take 12-13 years to break 2 hours assuming a ~20 sec reduction per year. If times from 1980 are used the filled squares suggest it will take 25 years assuming a ~10 sec reduction per year. Consistent with the idea that marked improvement is likely, empirical models of running times suggest that the men's world records for the 10,000m and half marathon are equivalent to a marathon time of ~2:02 - 2:03 (5,21).

Physiology of the Two-Hour Marathon

The physiological determinants of distance running performance (VO_2max, lactate threshold, and running economy) have been used to develop a model of marathon performance (9,10). Elite marathon runners typically have VO_2 max values ranging from ~70 ml/kg/min to ~85 ml/kg/min. These individuals can sustain running speeds that require 85-90% VO_2 max for more than one hour, and these factors along with knowledge of the oxygen cost to run a given speed (running economy) provide a reasonable estimate of marathon pace (9,10). When outstanding values for these three key variables are used in this model, a sub- two hour marathon seems physiologically possible.

While there are many possible combinations that might lead to elite performances, it appears that extremely high values for VO_2max and outstanding running economy are rarely seen in the same person (9,10). East African runners do not have particularly exceptional values for VO_2max or lactate threshold, but generally have outstanding running economy (13,14,23). The classic study of Pollock showed that elite distance runners who focused on the marathon had lower VO_2max values and better running economy that those who focused on shorter races (19). Based on these data and other anecdotal reports, it appears that whoever breaks two hours for the marathon will have exceptional running economy (2, 4).

In this context, there is clearly a need for more information about the relationship between VO_2max and running economy and the physiological explanation for the relationship *if it exists.* There is evidence that VO_2max and gross mechanical efficiency are inversely related in cyclists and influenced by muscle fiber type (16). By contrast, running economy seems more related to mechanical factors including vertical displacement and so-called braking on foot strike (11,24). Exceptional running economy might also provide two important physiological advantages. First, fuel utilization would be lower and perhaps glycogen depletion delayed. Second, metabolic heat production would also be lower potentially reducing thermal stress. To our knowledge these potential advantages have not be studied extensively.

<u>What will the Two-Hour Marathoner Look Like?</u>

Forty-one of the 50 fastest marathons have been run by Kenyans or Ethiopians (1). Importantly, the mean height and weight of the 30 runners (29 Africans) who have broken 27 minutes for 10,000 m is `170± 6 cm, and 56±5 kg, with only one runner greater than 178 cm or 70 kg (12). Additionally, most of these athletes had exposure to high altitude and significant physical activity early in life. In this context, small body size has a favorable effect on VO_2 max; however, less is known about its influence on running economy (7).

From these observations other questions emerge: (i) Does exposure to the combination of high altitude and physical activity early in life lead to pulmonary adaptations that reduce the incidence of arterial desaturation seen during heavy exercise in elite athletes (3,5,15,16)? and (ii) would the reduction in metabolic heat production along with a favorable body weight to surface area ratio have the net affect of reducing thermoregulatory stress during periods of prolonged, intense exercise? While these questions might be difficult to study, small differences could be decisive when races are won and records set by very small margins. However, there are examples of “big” runners like Paula Radcliffe, Ron Clarke and Derek Clayton who have been highly successful. Importantly, Radcliffe and Clayton are known to have superb running economy, and Radcliffe's running economy improved dramatically over time, providing at least some evidence that this factor is "traininable" (8,19).

Genotype: Probabilistic versus Deterministic

Genetic factors may limit or enhance the possibility of running a very fast marathon. At present much of what is known comes from association studies, with the angiotensin converting enzyme (*ACE*) I/D and α-actinin-3 (*ACTN3*) R577X gene polymorphisms having been studied extensively. The *ACE* I allele is theoretically associated with improved cardiovascular function during exercise, and could also favor muscle efficiency (26). While there is an overrepresentation of the I allele in the best Spanish marathon runners (sub 2:09 marathon performance) (15), the *ACE* I/D polymorphism is not associated with the success of the best elite endurance runners worldwide, including Kenyans (25). The association between the *ACTN3* R577X variation and elite 'power 'athlete status is strongly documented (27), yet this is not the case for endurance running (28).

Beyond potential genotype/phenotype associations (which are yet to be clearly established in elite marathoners), the task of quantifying the genetic contribution to elite marathon performance is challenging. A record holders's phenotype results from the combined influence of hundreds of genes, epigenetic factors, and non-hereditary environmental influences. Using algorithms that take into account the combined influence of several candidate gene variants associated with endurance performance [i.e., the so-called 'total genotype score' (TGS), ranging from 0 to 100], it appears that genetic factors increases the possibility of becoming a marathon champion (22). For example, a Caucasian individual with a TGS value above 75 has ~5 times greater chance of achieving elite endurance runner status compared to those with a TGS below 75. Yet, less than half of the best Spanish marathoners have TGS values above 75; and, using this approach it is estimated there are nearly 6 million Spanish individuals with the 'genetic' potential for elite marathon performance. Whether having the best possible TGS (i.e. 100) increases the odds of breaking two-hours is unknown.

Summary

Whoever breaks two hours will likely have outstanding running economy and small body size along with exposure to high altitude, and significant physical activity early in life. However, neither these factors nor any specific suite of genotypes appear to be obligatory for a time this fast. Current trends suggest that an East African will be the first to break two hours. However periods of regional dominance in distance running are not unique to the East Africans: athletes from Finland, Eastern Europe, Australia and New Zealand have all had extended periods of success at a range of distances (17). From a physiological perspective, more information is clearly needed on the relationship between VO_2max and running economy and the influence of running economy and body size on thermoregulation and fuel use.

References

1. **Association of Road Racing Statisticians.** www.arrs.net.

2. **Billat V, Lepretre PM, Heugas AM, Laurence MH, Salim D, Koralsztein JPA.** Training and bioenergetic characteristics in elite male and female Kenyan runners. *Med Sci Sports Exerc* 35: 297-304, 2003.

3. **Dempsey JA, Hanson PG, Henderson KS.** Exercise-induced arterial hypoxaemia in healthy human subjects at sea level. *J Physiol* 355: 161-175, 1984.

4. **Foster C, Lucia A.** Running economy: the forgotten factor in elite performance. *Sports Med* 37: 316-319, 2007.

5. **Gardner JB, Purdy JG**, Computerized Running Training Programs. TAFNEWS PRESS, Los Altos, CO 1970

6. **Harms CA, McClaran SR, Nickele GA, Pegelow DR, Nelson WB, Dempsey JA.** Exercise-induced arterial hypoxaemia in healthy young women. *J Physiol* 507: 619-628, 1998.

7. **Jensen K, Johansen L, Secher NH.** Influence of body mass on maximal oxygen uptake: effect of sample size. *Eur J Appl Physiol* 84: 201-5, 2001.

8. **Jones AM.** A five year physiological case study of an Olympic runner. *Br J Sports Med* 32: 39-43, 1998.

9. **Joyner MJ**. Modeling: optimal marathon performance on the basis of physiological factors. *J Appl Physiol* 70: 683-687, 1991.

10. **Joyner MJ, Coyle EF.** Endurance exercise performance: the physiology of champions. *J Physiol* 586: 35-44, 2007.

11. **Kyröläinen H, Belli A, Komi PV.** Biomechanical factors affecting running economy. *Med Sci Sports Exerc* 33: 1330-1337, 2001.

12. **LetsRun.com.** Chris Solinsky is the Tallest and Heaviest Sub-27 man in History. www.letsrun.com/2010/heightweight0504.php.

13. **Larsen HB.** Kenyan dominance in distance running. *Comp Biochem Physiol A Molec Integr Physiol* 136: 161-170, 2003.

14. **Lucia A, Esteve-Lanao J, Oliván J, Gómez-Gallego F, San Juan AF, Santiago C, Pérez M, Chamorro-Viña C, Foster C.** Physiological

characteristics of the best Eritrean runners-exceptional running economy. *Appl Physiol Nutr Metab* 31: 530-540, 2006.

15. **Lucía A, Gómez-Gallego F, Chicharro JL, Hoyos J, Celaya K, Córdova A, Villa G, Alonso JM, Barriopedro M, Pérez M, Earnest CP.** Is there an association between ACE and CKMM polymorphisms and cycling performance status during 3-week races? *Int J Sports Med* 26: 442-447, 2005.

16. **Lucia A, Hoyos J, Pérez M, Santalla A, Chicharro JL.** Inverse relationship between VO_2max and economy/efficiency in world-class cyclists. Med Sci Sports Exerc 34: 2079–2084, 2002.

17. **Megede EZ, Hymans R.** *Progression of World Best Performances and IAAF Approved World Records.* Monaco: International Athletic Foundation, 1991, 705 pp.

18. **Nielsen HB.** Arterial desaturation during exercise in man: implication for O2 uptake and work capacity. *Scand J Med Sci Sports* 13: 339-358, 2003.

19. **Pollock ML.** Submaximal and maximal working capacity of elite distance runners. Part I: Cardiorespiratory aspects. *Ann NY Acad Sci* 301: 310-322, 1977.

20. **Ravikumar P, Bellotto DJ, Johnson RL Jr, Hsia CC.** Permanent alveolar remodeling in canine lung induced by high-altitude residence during maturation. *J Appl Physiol* 107: 1911-1917, 2009.

21. **Riegel PS.** Athletic records and human endurance. *Am Scientist* 69: 285-290, 1981.

22. **Ruiz JR, Gómez-Gallego F, Santiago C, González-Freire M, Verde Z, Foster C, Lucia A.** Is there an optimum endurance polygenic profile? *J Physiol* 587: 1527-1534, 2009.

23. **Saltin B, Larsen H, Terrados N, Bangsbo J, Bak T, Kim CK, Svedenhag J, Rolf CJ.** Aerobic exercise capacity at sea level and at altitude in Kenyan boys, junior and senior runners compared with Scandinavian runners. *Scand J Med Sci Sports* 5: 209-221, 1995.

24. **Saunders PU, Pyne DB, Telford RD, Hawley JA.** Factors affecting running economy in trained distance runners. *Sports Med* 34: 465-485, 2004.

25. **Scott RA, Moran C, Wilson RH, Onywera V, Boit MK, Goodwin WH, Gohlke P, Payne J, Montgomery H, Pitsiladis YP.** No association between angiotensin

converting enzyme (ACE) gene variation and endurance athlete status in Kenyans. *Comp Biochem Physiol A Mol Integr Physiol* 141: 169-175, 2005.

26. **Williams AG, Rayson MP, Jubb M, World M, Woods DR, Hayward M, Martin J, Humphries SE, Montgomery HE.** The ACE gene and muscle performance. *Nature* 403:614, 2000.

27. **Yang N, MacArthur DG, Gulbin JP, Hahn AG, Beggs AH, Easteal SH, North K.** ACTN3 genotype is associated with human elite athletic performance. *Am J Hum Genet* 73: 627-631, 2003.

28. **Yang N, MacArthur DG, Wolde B, Onywera VO, Boit MK, Lau SY, Wilson RH, Scott RA, Pitsiladis YP, North K.** The ACTN3 R577X polymorphism in East and West African athletes. *Med Sci Sports Exerc* 39: 1985-1988 2007.

Figure Legend

Figure 1. Progression of world record times in the marathon since the late 1920s. The rapid fall in record time in the 50s and 60s likely reflects: i) the widespread adoption of high volume/year round training after WWII; and ii) the participation of East-African runners in international competition starting in the 1960s. There was limited progress during the 1970s, but the record has fallen more than 5 minutes over the last ~30 years. On average, there has been ~20 s reduction per year since 1960. The open squares show that if this rate of improvement continues, a time under 2 hours could occur in 12-13 years (by 2021-2022). The closed squares show that if only data from 1980 are used, a time under 2 hours would occur in ~25 years based on an estimated improvement of ~10s per year. The recent increase in the number of high profile races on fast courses that offer substantial prize money may also contribute to faster world records in the near future.