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PERSPECTIVE

# How much further for the sub-2-hour marathon?

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**Abstract:** The sub-2-hour marathon is a new barrier in endurance running performance, and it has been widely debated in the scientific community. In this review we present a mathematical model to estimate the possible year when a male could break through the sub-2-hour barrier, and also an estimation of when a female could break Paula Radcliffe's marathon running record. Further, we present several aspects (ie, physiology, nationality, age, biomechanics, pacing, and drafting) that are associated with marathon running performance in elite runners and, finally, the possible characteristics of the male to break the sub-2-hour barrier. In summary, with the results of the developed equations, it is possible that a male athlete can break through the sub-2-hour barrier in the next decade (with Nike® Breaking2 performance 1920–2018 [NBP]: $y=0.0417x^2-14.18x+3{,}128$; year of 2026; without NBP 1920–2018: $y=0.045x^2-15.12x+3{,}194$; year of 2027). This marathoner will possibly have a maximal oxygen uptake >85 mL·kg$^{-1}$·min$^{-1}$ and should perform the race at a pacing higher than 85% of maximal oxygen uptake. In addition, this runner should pay more attention to strength training, endurance strength, speed training, and focus on running training at an intensity above the anaerobic threshold. Most likely, this runner originates from East Africa (especially from Ethiopia) and will have an age of ~27 years. For the females, there is poor evidence regarding the physiological profile of the female marathoner who will break Radcliffe's record, but the available literature suggests that it will not happen any time soon.

**Keywords:** endurance, running, performance, pacing, drafting

## Introduction

The marathon run is the most classic Olympic running event. Since it was introduced as a central part of the modern Olympic Games in 1896, it takes place in countless cities worldwide, mostly because of its popular appeal,[1] with the participation rates increasing continuously during the last years.[2,3] Furthermore, the record times have been progressively improved since the standardization of the peculiar 42.195 km marathon distance.[4,5]

Sports sciences have significantly evolved since the 1920s, especially regarding exercise physiology, training methods, and thus affecting physical performance.[6] In relation to this, a breakpoint regarding endurance performance were the three Olympic gold medals achieved by Emil Zátopek, who won the 5,000 m and the 10,000 m and set a new time record for the marathon at the 1952 Olympic Games in Helsinki. Zátopek was one of the first athletes to use high-intensity interval trainings in his routines, a method that has been exhaustively studied in the last decades.[7] Although Zátopek was an Olympic and World Record holder, nowadays his marathon race time would not be enough fast even to qualify to the Olympic Games.

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Even though the marathon records have progressively improved over the years for both females and males, a time barrier has been put to the marathon distance for males, the sub-2-hour performance (Figure 1A). Whereas some athletes and scientists consider a sub-2-hour marathon as a physiological impossibility,[8,9] some other authors believe that it may happen any time soon.[4,10,11]

In addition, females have also improved their marathon performance since it was included in the Olympic Games in 1984 and increased their participation rates relatively more than males during the last decades.[2] In 2003, the British athlete Paula Radcliffe ran the marathon in 2 hours 15 minutes and 25 seconds, setting a new and impressive World Record (Figure 1B). Since then, no females have been able to break it, some authors even consider this female race time of 2 hours and 15 minutes as the equivalent for the male sub-2-hour marathon.[12]

In this update of the report written by Joyner et al,[4] we aimed to summarize the key factors identified in the literature that have been argued as important in improving a marathon performance. We further performed a mathematical analysis to predict when the sub-2-hour marathon would happen for males, and also propose an speculative quantification of the possible aspects that could delay (or be delaying) this breakthrough in human running performance and the sex difference in marathon running performance.

## Analysis

All procedures used in the study were approved by the Institutional Review Board of Kanton St. Gallen, Switzerland, with a waiver of the requirement for informed consent of the participants given the fact that the study involved the analysis of publicly available data.

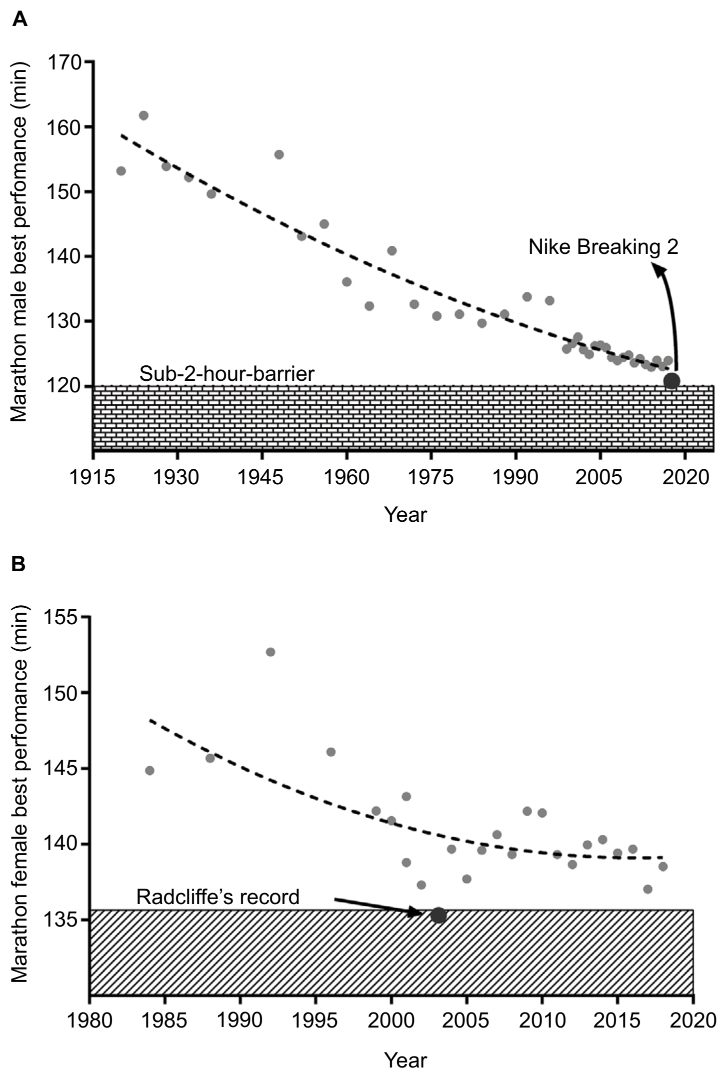


**Figure 1** Data points of the best marathon performance of males **(A)** and females **(B)** including the breakthrough human performance for each category.

We searched literature (PubMed, Web of Science, and Scopus; reverse search) for keywords related to all aspects that could be related to marathon performance in elite runners: marathon, sub-two, endurance performance, elite run, etc. We obtained data from two publicly available databases (www.olympic.org and www.iaaf.org). The best official marathon race times were recorded from males and females, being: 1999–2018 (up to April 2018) World Championships, Olympics and Annual Record for males and females both; and the best official Olympic Marathon race times since 1920 for males and 1984 for females, which was the year when the marathon running distance was standardized and involved females, respectively. In 2017, an event to reach the sub-2-hour time record was performed (Nike® Breaking2, Nike Inc., Beaverton, OR, USA), in which an athlete reached the closest performance ever since (2 hours and 25 seconds), but not yet enough to break through the barrier (https://news.nike.com/news/breaking2-results).

Since the marathon record times have been progressively decreasing over the years (Figure 1), we performed different regressions analyses to determine the possible year of the sub-2-hour performance. We calculated two nonlinear regressions using second-order polynomial adjustment, one with and one without the Nike Breaking2 record (Table 1). We used a polynomial regression because the data seem to be curvilinear (Figure 1). Moreover, polynomial adjustments are also applied if the curvilinear response function is unknown, since a polynomial function is a good approximation to the true function[13] and because linear regressions are also limited for performance progressions, since the performance never attenuates or decreases. A further analysis from 1920 to 2012 was also performed to test the accuracy of the model, with the data from 2013 to 2018 to be applied in the formula. All data analyses were performed using the Microsoft Excel (MS Excel 2011 for Mac, Google, Mountain View, CA, USA) and GraphPad Prism (v. 6.0, GraphPad Software, La Jolla, CA, USA).

**Table 1** Regression analyses to determine the possible year of breakthrough in the sub-2-hour marathon time

| | Year | $R^2$ | Equation |
|---|---|---|---|
| 1920–2018 | | | |
| With NBP | 2026 | 0.941 | $y = 0.0417x^2 - 14.18x + 3128$ |
| Without NBP | 2027 | 0.942 | $y = 0.045x^2 - 15.12x + 3194$ |
| 1920–2013 | | | |
| With NBP | AL =99.1% | 0.934 | $y = 0.039x^2 - 13.63x + 3088$ |

**Note:** $R^2$: determination coefficient.
**Abbreviations:** NBP, Nike® Breaking2 performance; AL, agreement level.

## Perspective

Data analyses indicate that if performance improvement would be linear over the years, the sub-2-hour marathon performance is quite very near (2018), considering or not the Nike Breaking2 event. However, the limits of human performance have been more difficult to break through every year.[14] In the marathon running, every minute in the final race time is achieved by a combination of factors including a great athlete with unique biomechanical[10] and physiological[15] qualities, running in a good day, with favorable environmental and race course conditions.

Previous data analyses to predict marathon indicate contradictory results.[4,5] Joyner et al[4] analyzed male's World Records and suggested that the sub-2-hour marathon will break around 2020–2022, based on a 10–20 seconds of performance improvement every year. In this update, that includes important recent records by Kimetto and Kipchoge, the results indicate that it may happen in 2026–2027 (nonlinear analysis). On the other hand, using a velocity-based analysis, Weiss et al[5] report that the sub-2-hour marathon will not be broken in the century; the authors further discuss that the female's marathon record are not supposed to be beaten any time soon. Another study reported that the sub-2-hour marathon is unlikely to happen with an analysis based on the World Records gap between males and females.[16]

The biomechanical and environmental effects that could affect human performance in marathon running have been widely discussed in a review by Hoogkamer et al.[10] In summary, cooperative drafting, tailwind, downhill, and footwear modifications seem to be fundamental to reduce the metabolic cost of running, possibly leading to a great physical performance. However, although downhill courses and cooperative strategies with fresh runners to overcome the air resistance are not allowed by the International Association of Athletics Federations (IAAF), the Nike Breaking2 performed by Eliud Kipchoge (Kenyan, 33 years old) had the best conditions possible in a non-downhill course, but the best marathon performance of all time still was not enough to beat the sub-2-hour barrier.

Despite the fact that the marathon performance of Kipchoge is unofficial, it may give some enlightenment regarding what else could be done to break through the sub-2-hour barrier. The physiological aspects that could lead an athlete to achieve such a performance have been widely discussed from different points of view.[15,17–21]

## Physiological aspects

The physiological aspects that have been considered as the determinants of performance in endurance athletes are maximum oxygen consumption ($VO_2$max), running velocity at the anaerobic threshold, and running economy.[15,17,22,23]

Champions in endurance running sports (ie, half-marathon, marathon, ultra-marathon) have a $VO_2$max of 70–85 mL·kg$^{-1}$·min$^{-1}$.[15] In view of the above, although $VO_2$max is not the most determinant physiological factor for running performance, in order to overcome the barrier of running a marathon below 2 hours, the athlete must have a $VO_2$max higher than the endurance champions have today. In addition, running a marathon corresponds to an intensity (average pace) equal to 75%–85% of the $VO_2$max.[15] Thus, perhaps, to overcome the barrier of running a marathon below 2 hours, athletes may need to maintain an average running pace higher than literature has often been pointing out that such distance has been realized.[15]

On the other hand, the running economy, which is traditionally expressed as mL·kg$^{-1}$·km$^{-1}$, seems to be a better predictor of performance than $VO_2$max.[18] An individual with a lower $VO_2$max but with better running economy may have an enhanced endurance performance than an individual with a higher $VO_2$max.[18] When comparing the running economy of Spanish runners with Eritrean runners, Lucia et al[18] showed that there was no significant difference in $VO_2$max, but Eritrean runners had a better running economy. The Eritrean runner, who became World Cross Country champion over 12 km in 2007 (Zersenay Tadese; born 1982; also participated in the Nike Breaking2), used only 150 mL·kg$^{-1}$·km$^{-1}$ when he ran at speeds of 17, 19, and 21 km·h$^{-1}$. This is the lowest $VO_2$ reported at these speeds,[24] suggesting that running economy can be an important predictor of running performance.

Strength training, strength endurance, and also speed training have been suggested as an important intervention for the improvement of the running economy. Johnston et al[19] examined the effect of 10-week strength training on a range of physiological variables. The training did not result in any significant increase in $VO_2$max, but the running economy at a given submaximal load improved by 4%. Berryman et al[25] in a meta-analysis assessed the effects of strength training in middle- and long-distance runners and concluded that endurance athletes could benefit from it by improving their energy cost of running, locomotion, maximal power, and maximal strength. Thus, strength training and sprint training seem to be important interventions to allow runners, at some point, to be able to run a marathon in <2 hours.

In addition, it appears that training at the anaerobic threshold intensity is also effective in improving running economy, and in turn, favoring performance in endurance trials.[20] Tjelta et al[21] demonstrated that both $VO_2$max and running economy explain 89% of the anaerobic threshold velocity. Moreover, Maffulli et al[26] reported strong ($r$ =0.80–0.90) and significant ($p$<0.05) correlations between running velocity at the anaerobic threshold and performance over running distances from 5,000 m to the marathon. In order to increase running velocity at the anaerobic threshold and, in turn, running performance, studies demonstrated that running training above the anaerobic threshold velocity may be more effective.[27,28]

Taken together, the three main physiological factors affecting a marathon performance in elite runners could be summarized as running economy, anaerobic threshold, and $VO_2$max, in this order of importance (Figure 2). It is elementary that each one of these aspects affects the other, but evidence seems clear pointing that the sub-2-hour marathon runner will have an outstanding running economy with a great running velocity at anaerobic threshold.

## Pacing, aging, and nationality

Another major aspect for endurance performance is the pacing strategy, the ability to affectively expend energy to prevent premature fatigue prior to the completion of the event.[29–31] In that regard, there are evidences suggesting that, in a marathon, older athletes run at a steadier pace (smaller changes) than younger athletes.[30] It has been suggested that an "even" or "constant" pace is the best strategy for endurance performance.[31,32] Moreover, the pacing strategy used by elite marathoners have been suggested as not being optimal,[33] which means that coaches and athletes may still have room for improvement in their tactical methods.

Noble and Chapman[34] recently reported that African marathoners reach a peak of performance earlier than

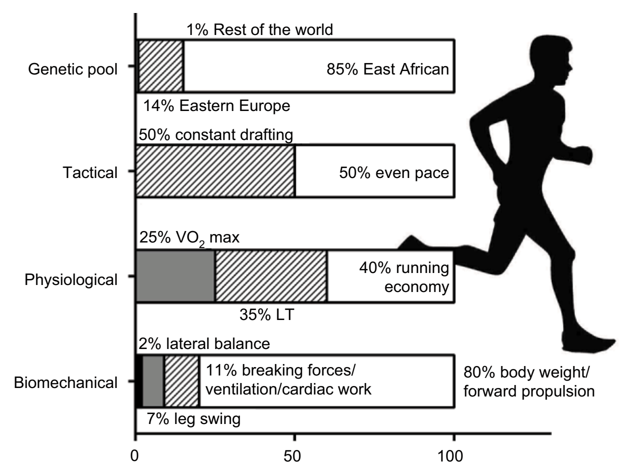


**Figure 2** Speculative estimates of key points in each fundamental factor affecting marathon performance in elite runners.

**Notes:** Each fundamental factor was based on hierarchical importance as biomechanics,[10,44] physiology,[15,22] tactics,[29,30,42] and genetic pool.[4,14,30]

**Abbreviation:** LT, lactate threshold.

non-Africans counterparts (27.1±0.1 versus 30.1±0.1 years, respectively). Further, African marathoners have also the fastest marathon time compared with non-Africans (2:05:47±0:00:06 versus 2:08:41±0:00:06 h:min:s). These authors also showed that African marathoners specialize earlier and have an elevated rate of performance improvement and, finally, that there is a positive correlation between age of specialization and rate of improvement.[34] More specifically, there are also reports that East Africans (ie, Kenyan, Ethiopian) are faster than others.[14,35,36] Especially, Ethiopian males were faster than all other males in the marathon run when the performances of the world's best runners in marathon from the IAAF during 1999–2015 were considered.[14] Furthermore, Tam et al[37] compared physiological variables in elite Kenyan marathoners with European controls. Although the authors reported no difference in $VO_2max$ (64.9±5.8 versus 63.9±3.7 $mL·kg^{-1}·min^{-1}$) and energy economy in submaximal running speed (18 km $h^{-1}$: 178±16 $mL·kg^{-1}$ $km^{-1}$ for both), Kenyan runners were faster in half- and full marathon.[37]

For the females, it seems that they reach a peak of performance a little later than males, and most of the female athletes participating in marathons are from Ethiopia and Kenya.[14] Although the current rankings are dominated by east African females, the World Record was achieved by a British runner, Paula Radcliffe. Furthermore, Joyner[38] recently discussed the possible sex differences for marathon performance, and apart the social factor, the $VO_2max$ in females is the possible limiting factor.

On the other hand, recent evidence shows that Mo Farrah, Olympic champion in the 5,000 and 10,000 m and recently retired from the tracks, started a career in marathon events. This athlete has the conditions and may be the one to run a <2 hour marathon. However, he would be an outlier by being a non-African runner and 35 years of age. Suggesting that it may be an exception to the athlete profile we have outlined previously to break this barrier.

Taken together, although eastern Europeans have a good historical performance regarding marathon records, it is reasonable to assume that the male to break the sub-2-hour marathon is likely to be an East African (especially from Ethiopia) at around 27 years old with a steady pacing strategy. From a practical point of view, this would mean running the marathon at a steady pace of 4′34″/mile or 2′50″/km. Although difficult to imagine that a few seconds could affect a marathon performance, Kipchoge finish the Nike Breaking2 with 5 km partials with a mean pace variation from 2′49″/km to 2′51″/km, with the slowest partial being the last 2′53″/km and missed the record by 25 seconds. Perhaps a steady pacing that makes it possible to stay a few seconds ahead of the deadline could help motivate the athlete within the last and most demanding kilometers.

## Drafting

Performing an activity in a sheltered position is defined as "drafting," which has been studied in many sports, such as cycling,[39] swimming,[40] and running.[41] In summary, evidences show that drafting improves performance in endurance sports and that the benefit would likely increase with increasing speed of performance.[42]

In a marathon, the first half has an optimal performance possibly because of potential saving of energy due to drafting. However, the second half is more difficult because there are few runners that could provide drafting for more than the first half of a marathon race.[10] As pointed out by Hoogkamer et al[10] and performed in the Nike Breaking2, the best option would be to have several runners in a loop course, then when the first ones starts to fatigue, fresh runners would replace then. Nevertheless, this scenario is not allowed by the IAAF.[43] For the females, little is known regarding the physiological peculiarities of elite marathoners, but there is no reason to believe that regarding pacing strategies and drafting they would respond different. Paula Radcliffe's record is a clear outline marathon performance, and the limited evidence available suggests that this record will endure a little longer.[5]

## Conclusion

In summary, although it is possible that a male athlete breaks through the sub-2-hour barrier in the next decade (2025–2028), we warn that empirical models may be intrinsically weak, but it could give us an idea that this breakout human performance is close. This marathoner will possibly have a $VO_2max$ >85 $mL·kg^{-1}·min^{-1}$ and should perform the race at a running intensity higher than 85% of $VO_2max$. In addition, this runner should focus on running training at intensities above the anaerobic threshold. Most likely, this runner originates from East Africa (especially from Ethiopia) and will have an age of ~27 years. Regarding Radcliffe's record, it could be beaten at any time; however, there is poor evidence regarding the physiological profile of the female marathoner who will achieve it.

## Author contributions

CVS, MMS, PTN, TR, and BK have made substantial contributions to conception, design, data acquisition, data analysis, and interpretation of this manuscript; CVS, MMS, PTN, TR, and BK have also worked on the draft, critically revised for important intellectual content, and approved the final version of the manuscript. All authors agreed to all aspects of the work in ensuring that questions related to the accuracy or integrity of the work are appropriately investigated and resolved.

## Disclosure

The authors report no conflicts of interest in this work.

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