On track for a 2-hour marathon

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The question of whether a 2-hour marathon is possible is widely discussed, despite its not representing any threshold in physical ability. In this article, power laws are used to compare world records for the marathon, as well as other distances, in road races as well as track events. Runners experience the same decay in energy over time on both surfaces, but track events have a higher performance index. This leads to a conclusion that if the marathon was a track event, we should expect elite athletes to run it on average about 3 minutes faster than on road, and perhaps even under 2 hours.

Whenever an athletics world record is broken, a question arises: what is the human limit for this particular discipline? Often 'round' numbers are mentioned as barriers, even though they rarely represent any real physical barrier. In the early 1950s, the 4-minute mile was a hot topic, and recently the question of a 2-hour marathon has been widely discussed in running circles (http://running.syr.edu/column/19991129.html; http://www.myhealthsense.com/F040413_endurance.html).

This barrier cannot possibly represent any threshold of physical performance, as both the hour (approximately one twenty-fourth of a day) and the marathon (an approximate distance between two Greek cities, adjusted to allow the British Royal Family to watch the race) are arbitrary values. The current record for the 42.195 km marathon stands at 2 hours 4 minutes and 55 seconds (established by Paul Tergat in 2003), and the debate goes on. This study examines world records for shorter distances in an attempt to contribute to this question.

In developing the concept of fractals and scale invariance, Mandelbrot[1] showed that power laws abound in nature. Phenomena exhibiting such scale invariance follow power laws. The use of such power laws in estimating running speeds, however, predates Mandelbrot by a long way. Kenelly[2] used such equations to estimate winning race times for both humans and horses almost a century ago. Here, following Garcia-Manso *et al.*,[3] velocity is defined as a function of distance raced:

$$v = cd^{-\alpha} \qquad (1)$$

where c is a constant termed the performance index, relating to the maximum speed, and α is a scaling exponent relating to the 'decay' of the runner's metabolism with increasing distance. The smaller the value of this exponent, the better the performance in longer races. Studies of world records for distances between 200 metres and the marathon found two scaling regimes, with Equation (1) holding inside each with different constants and exponents.[4,5] The threshold value separating the regimes was at just over 1000 metres. This was confirmed in a recent analysis of times for distances between 1.5 km and the marathon, for which a single power law was observed.[3]

Accepting the existence of these regimes, the world records for the following distances were assembled in Table 1: 2 km, 3 km, 5 km, 10 km, 15 km, half-marathon, and full marathon (http://www.iaaf.org). Races up to 10 km are held on athletics tracks, and from 10 km onwards on roads. Ten-kilometre races are held on both surfaces, and two official world records exist: 26 minutes 17.53 seconds on track, and 27 minutes 2 seconds on road. This is quite a significant difference (2.5 %), and strongly suggests that track running is more conducive to faster times. Figure 1 shows the plot of mean velocities achieved in world record runs as a function of the distance. Track records are marked with triangles, road races with squares. Best-fit curves are drawn for track and road races. The plots are logarithmic (natural logarithms, that is, base e) to linearize the power law.

The lines appear parallel, and this is confirmed by measuring the slopes (corresponding to α). We find $\alpha_{track} = 0.0629 \pm 0.0022$, and $\alpha_{road} = 0.0630 \pm 0.0036$. Thus the decay rate is the same for both kinds of races, and only the performance index increases for track events. The suggestion made here is that if 15 km, half-marathon and marathon races were run on a track, the records would follow the track regression line. This line passes the marathon mark at a speed corresponding to a time of 2:01:38, more than 3 minutes faster than Tergat's record. Using the maximum and minimum errors of α_{track} and the regression intercept value, the uncertainty on this predicted marathon time is calculated to be close to 150 seconds. This places a 2-hour track marathon within the error limit of the scaling factor.

One obvious problem with this analysis is that the power law governing record velocities as a function of race distance does not apply indefinitely. Worldwide races longer than a marathon are rare, and not many elite athletes participate in them. Thus, world records for these ultra distances are often weak and should not be included in a detailed analysis. However, the scenario is totally different in South Africa — there are over 50 ultramarathon races a year in the country, and they are very popular with social as well as elite runners. The two most famous of these races are the Two Oceans (56 km in Cape Town) and the Comrades (approximately 89 km in Kwazulu-Natal). Each of these attracts nearly 10 000 runners annually. Top South African athletes have always taken part in these races, and in the last decade a number of international professionals have also competed. Despite increasing international participation and alleged developments in sports nutrition, hydration and equipment, the course records were set by South Africans in the 1980s. Thompson Magawana covered the Two Oceans course in 3 hours, 3 minutes and 44 seconds in 1988, while Bruce Fordyce's Comrades record of 5 hours, 24 minutes and 7 seconds has stood since 1986. These record times, however, make a sorry reading when compared with the times one would predict if the road running power law (Fig. 1) is extended to these distances: 2 h 48 m 17 s and 4 h 35 m 22 s, respectively.

An obvious explanation for these dis-

Table 1. World record times for distances analysed here.

Distance (km)	Time	v (m/s)	Record holder	Year record set
2	4 m 44.79 s	7.02	Hicham El Guerrouj	1999
3	7 m 20.67 s	6.81	Daniel Komen	1996
5	12 m 37.35 s	6.60	Kenenisa Bekele	2004
10 (track)	26 m 17.53 s	6.34	Kenenisa Bekele	2005
10 (road)	27 m 02 s	6.17	Haile Gebrselassie	2002
15	41 m 29 s	6.03	Felix Limo	2001
21.0975	59 m 16 s	5.93	Samuel Wanjiru	2005
42.195	2 h 04 m 55 s	5.63	Paul Tergat	2003

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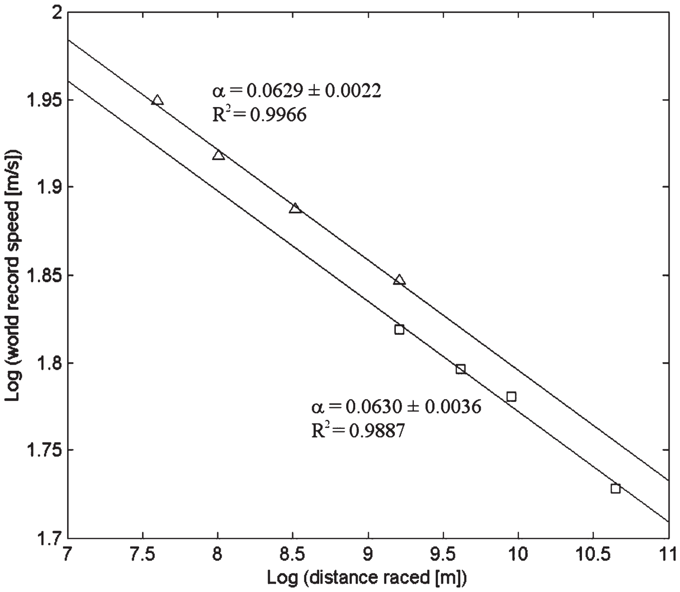

Fig. 1. World record velocities as a function of the distance raced. Axes are logarithmic (base e) to linearize the power law [Equation (1)]. Track disciplines (2 km, 3 km, 5 km and 10 km) marked with triangles, road races (10 km, 15 km, half-marathon and marathon) with squares. Regression lines for each surface have beendrawnand extended over the combined distance range.

crepancies would be to dismiss these records as 'weak', established by runners who dominate the small group of ultra-marathoners, but cannot be called elite athletes. A case study of Willie Mtolo, a rare example of a runner who excelled at distances between 10 km and the Comrades, will show nothing could be further from the truth. His personal records are given in Table 2. Clearly, Mtolo is an elite runner. He has won the New York Marathon, the Two Oceans, and finished second in Comrades twice. Figure 2 shows the logarithmic plot of his record velocities (marked with stars) as a function of distance raced. On the same graph are velocities of the slightly faster world records (squares). Clearly, two power laws are present in the figure. The relationship governing record speeds from 2 km onwards ends near the marathon distance, and a different, ultra-marathon, scaling regime is entered. Can we determine on which side of the threshold the marathon lies? The only way to do that is to convince elite athletes to compete in races between 35 and 50 km, and their cooperation for that seems unlikely at best.

Another point worth commenting on is the world record for the half-marathon, which is considerably faster than the corresponding value on the road running regression. It has been shown[3] that this anomaly exists not only for the world record, but also for lower ranked times compared to similar rankings of other races. These authors attribute that to a wider field participating in half-marathons, and saying that specialists in the marathon and 10 km races can successfully compete in this discipline. This argument has an interesting implication for South African running. The nation's obsession with ultra-marathon running is well known, and Athletics South Africa recently started a programme to develop half-marathon running. If we end up with specialists over these two distances, both groups will be able to run marathons competitively, perhaps resulting in a marathon time faster than expected from a regression curve. Thus we can hope that in a few years' time the world marathon record will belong to a South African.

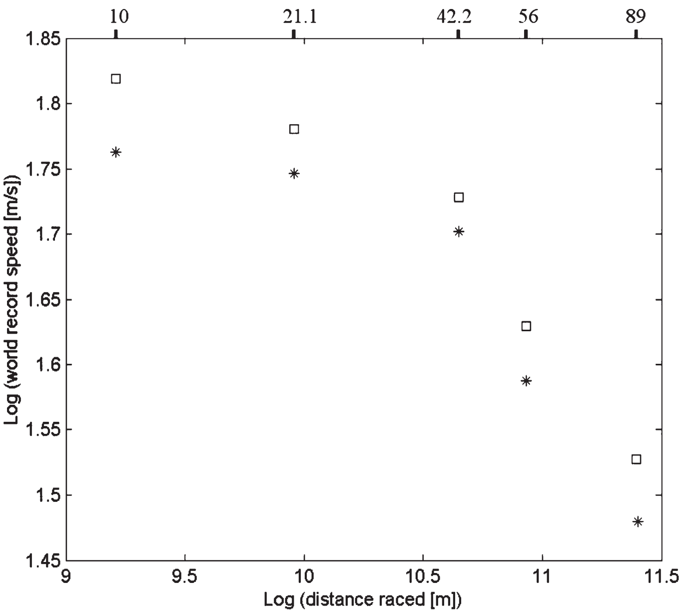

Fig. 2. Personal best velocities of Willie Mtolo for races of 10 km, half-marathon, marathon, Two Oceans (56 km) and Comrades (~90 km), marked in stars as a function of distance. World record velocities marked in squares. Axes are logarithmic. For clarity, distance in km is marked at top of the figure.

Table 2. Best performances of Willie Mtolo.

Distance (km)	Time	v (m/s)
10	28 m 36 s	5.83
21.1	1 h 1 m 20 s	5.73
42.2	2 h 8 m 15 s	5.48
56	3 h 10 m 51 s	4.89
89.6	5 h 39 m 59 s	4.39

Can a marathon be held as a track event? One cannot imagine the athletes being excited about the prospect of running 105 times around the 400 metre track. But if they did, would they run 3 minutes faster than on road? Tergat said after his record run that a 2-hour marathon is not possible, but then admitted that 'Maybe time will chide me'. Mathematicians and physiologists can do as much research as they want about the '2-hour barrier', but only the athletes can ever answer the question.

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