The 2 Hour Marathon & What Limits Human Performance

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Twitter - @DrMJoyner

Overview of Talk & Learning Objectives

1. Current Events!
2. Where did ideas about “2 hours” come from?
3. The physiology
4. Some History
5. Technology & innovation *(& yuk – doping)*
6. Mental preparation & psychology
7. Putting it all together

References

- Joyner - Modeling: *Optimal Marathon Performance on the Basis of Physiological Factors. JAP 1991*
- Joyner & Coyle – *Endurance Exercise Performance: The Physiology of Champions. J Physiol 2008*
- Joyner, Ruiz & Lucia - *The Two-Hour Marathon: Who and When? JAP 2011*
- Hunter, Joyner & Jones: *The Two-Hour Marathon: What's the Equivalent for Women? JAP 2015*
- Joyner, Hunter, Lucia, Jones: *Physiology and Fast Marathons. JAP 2020*

1. Current Events

Eliud Kipchoge
May 2017: *Oh So Close (Sort of)!*

WR=2:02:57

1. Loop Course

2. Pacers/Drafting

3. Shoes

2018 EK Sets “Real” Record: 2:01:39

13 October 2019
EK Goes 1:59:40 at *INEOS159*
(Breaking2 – 2.0)

14 October 2019
Brigid Kosgei Breaks WR

2. Where Did *(My)* Ideas About "2 hours" Come From?

University of Arizona

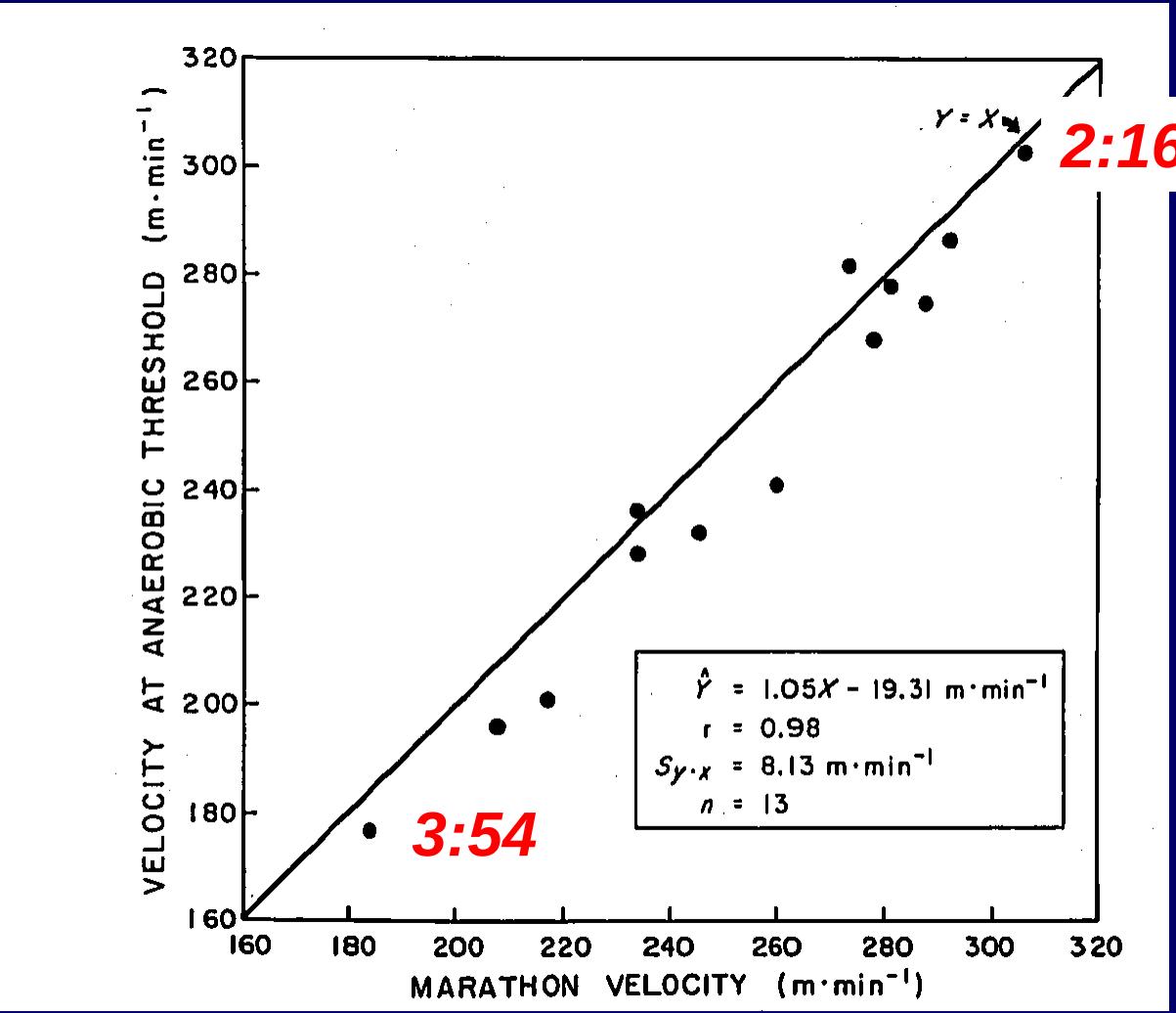
MEDICINE AND SCIENCE IN SPORTS
Vol. 11, No. 4, pp. 338-344, 1979

Plasma lactate accumulation and distance running performance

PETER A. FARRELL, JACK H. WILMORE, EDWARD F. COYLE, JOHN E. BILLING, and DAVID L. COSTILL

Exercise and Sport Science Laboratory
The University of Arizona
Tucson, AZ 85721

LT vs Marathon Speed



Farrell et al replotted by Davis MSSE 1985

1991 The 2-Hour Marathon vs. *The Conventional Wisdom*

JOYNER, MICHAEL J. *Modeling: optimal marathon performance on the basis of physiological factors.* J. Appl. Physiol. 70(2): 683–687, 1991.—This paper examines current concepts concerning "limiting" factors in human endurance performance by modeling marathon running times on the basis of various combinations of previously reported values of maximal O_2 uptake ($\dot{V}O_{2\,max}$), lactate threshold, and running economy in elite distance runners. The current concept is that $\dot{V}O_{2\,max}$ sets the upper limit for aerobic metabolism while the blood lactate

The fastest time predicted for this model is 1:57:58

tate threshold to determine the actual running speed at lactate threshold, which is generally a speed similar to (or slightly slower than) that sustained by individual runners in the marathon. A variety of combinations of these variables from elite runners results in estimated running times that are significantly faster than the current world record (2:06:50). The fastest time for the marathon predicted by this model is 1:57:58 in a hypothetical subject with a $\dot{V}O_{2\,max}$ of 84 $ml \cdot kg^{-1} \cdot min^{-1}$, a lactate threshold of 85% of $\dot{V}O_{2\,max}$, and exceptional running economy. This analysis suggests that substantial improvements in marathon performance are "physiologically" possible or that current concepts regarding limiting factors in endurance running need additional refinement and empirical testing.

maximal oxygen uptake; lactate threshold; running economy; human performance

J Appl Physiol 118: 1321–1323, 2015;
doi:10.1152/japplphysiol.00852.2014.

VIEWPOINT

The two-hour marathon: What's the equivalent for women?

2:15:25

Sandra K. Hunter,[1] Michael J. Joyner,[2] and Andrew M. Jones[3]

[1]*Exercise Science Program, Department of Physical Therapy, Marquette University, Milwaukee, Wisconsin;* [2]*Department of Anaesthesiology, Mayo Clinic, Rochester, Minnesota; and* [3]*Sport and Health Sciences, University of Exeter, Exeter, United Kindgom*

Conclusions

We provide evidence that the 2-h equivalent marathon time for women was achieved by Paula Radcliffe in her 2003 WR. Furthermore, comparison of records of elite men and women marathoners indicates a lack of depth among lower-placed women runners and a sex difference in the ethnic origin of the best runners. Radcliffe's WR may stand for many more years until a woman, possibly an East African, who possesses superior running economy and high critical velocity is afforded the opportunity to compete.

1991: The Known Unknowns

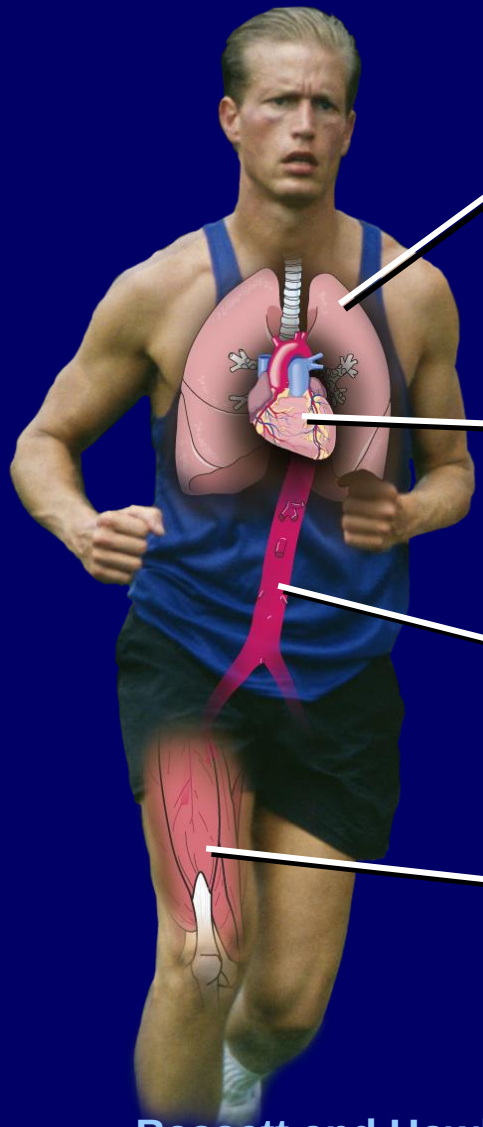
- A lot known about $\dot{V}O_2$max & lactate threshold
- Not much known about running economy
- Fatigue is a complicated thing
- Limited data on true elites
- Not much known about “genetics”

3. The Physiology

Physiology of Marathon Performance

- Most of the energy required comes from "aerobic" sources
- What are the determinants of "performance" velocity?
  - Maximal Oxygen Uptake
  - Lactate Threshold
  - Running Economy (efficiency)

Maximal Oxygen Uptake

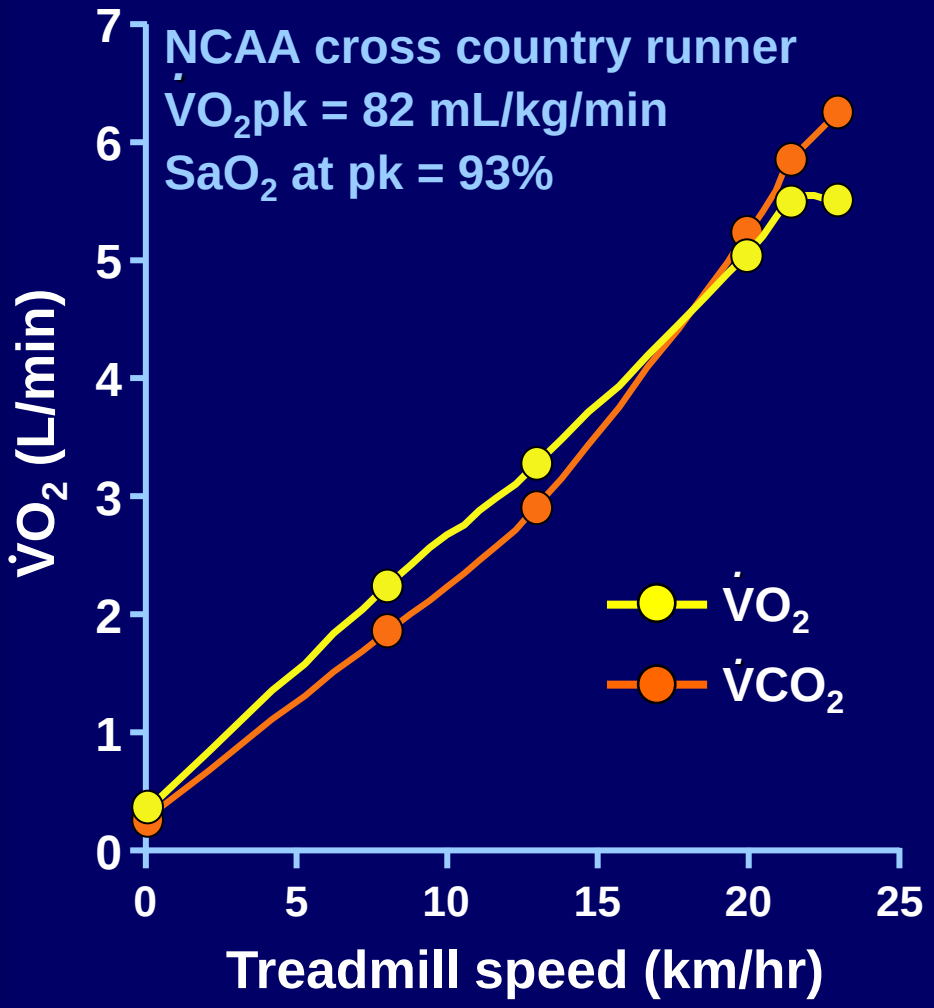


Pulmonary diffusing capacity

Cardiac output

O_2 carrying capacity

Skeletal muscles



Bassett and Howley MSSE 2000

Courtesy of B Johnson, PhD

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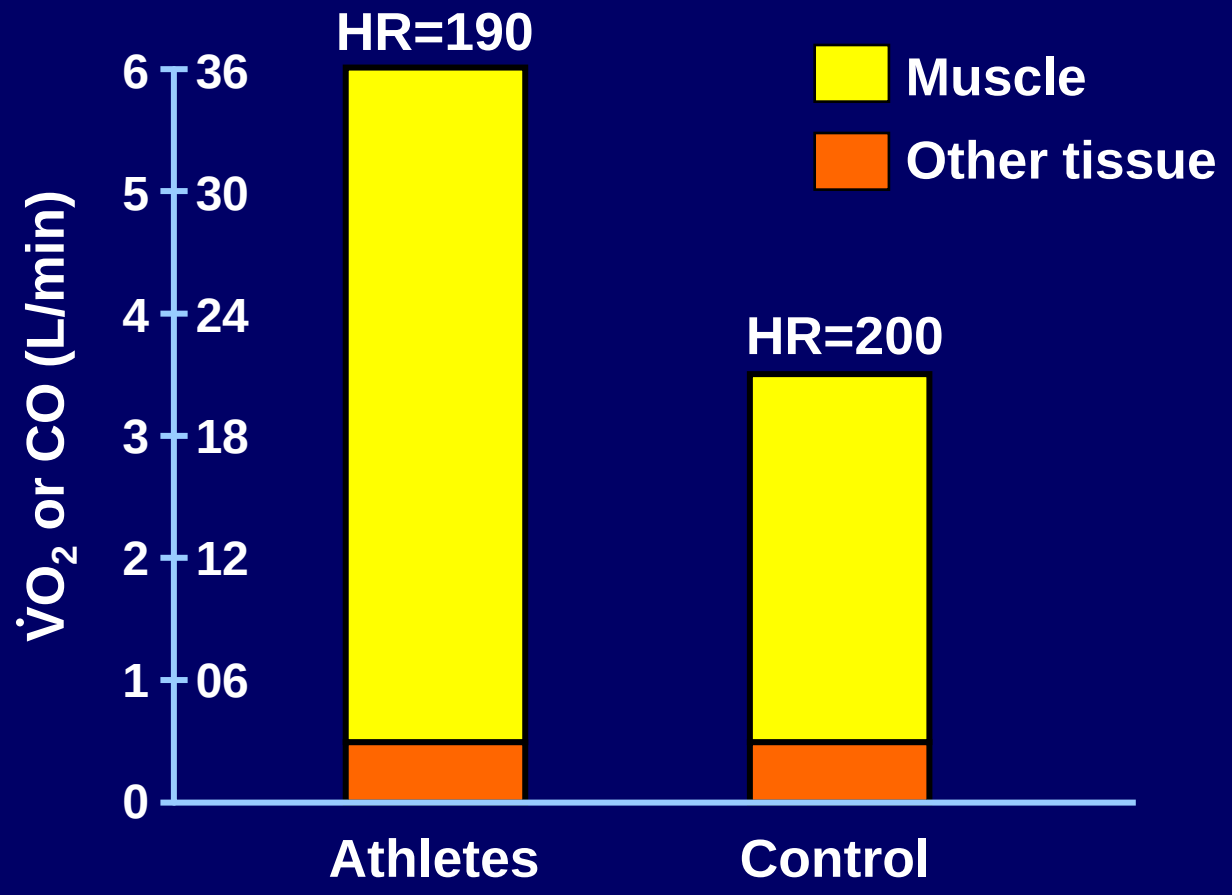
CP1278619-16

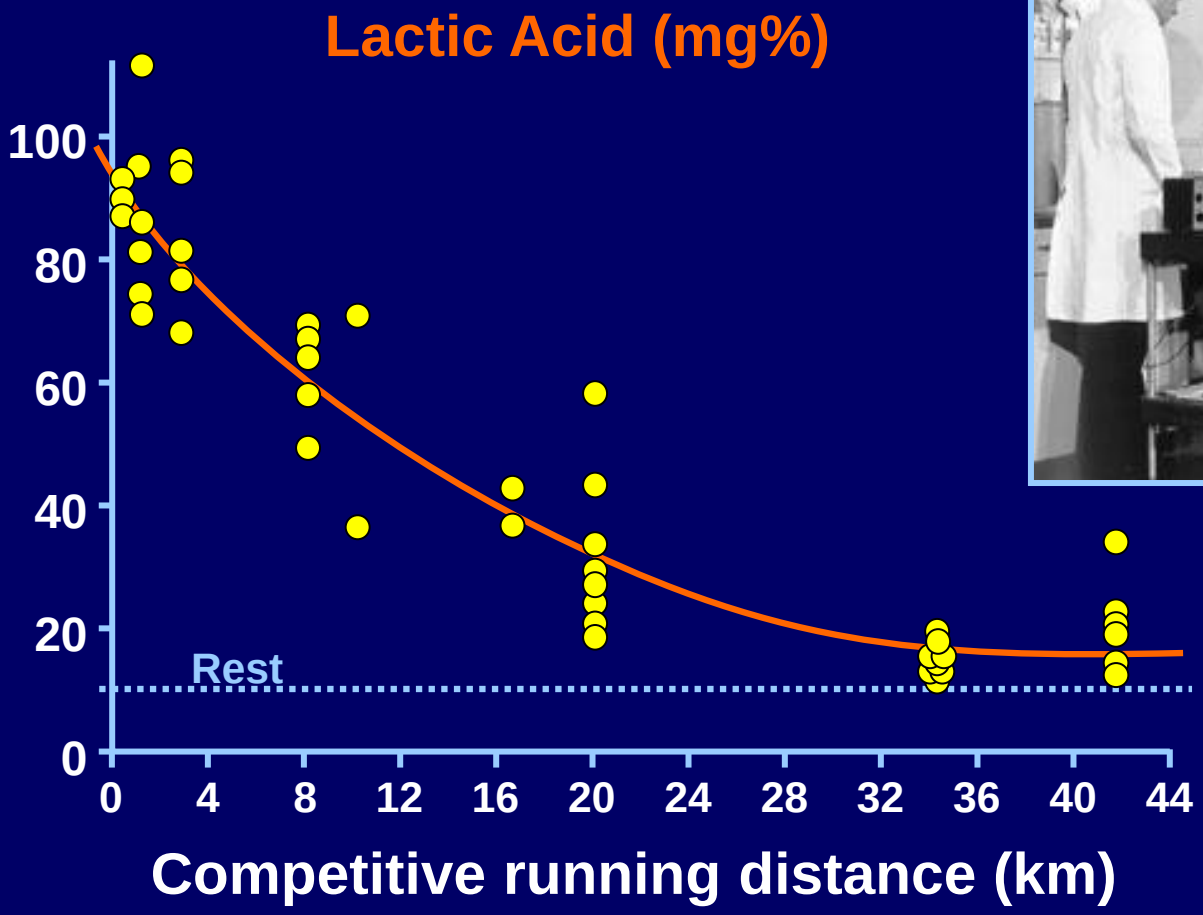
Cardiac Output and MBF:
Very High in Athletes



Maximal Oxygen Uptake

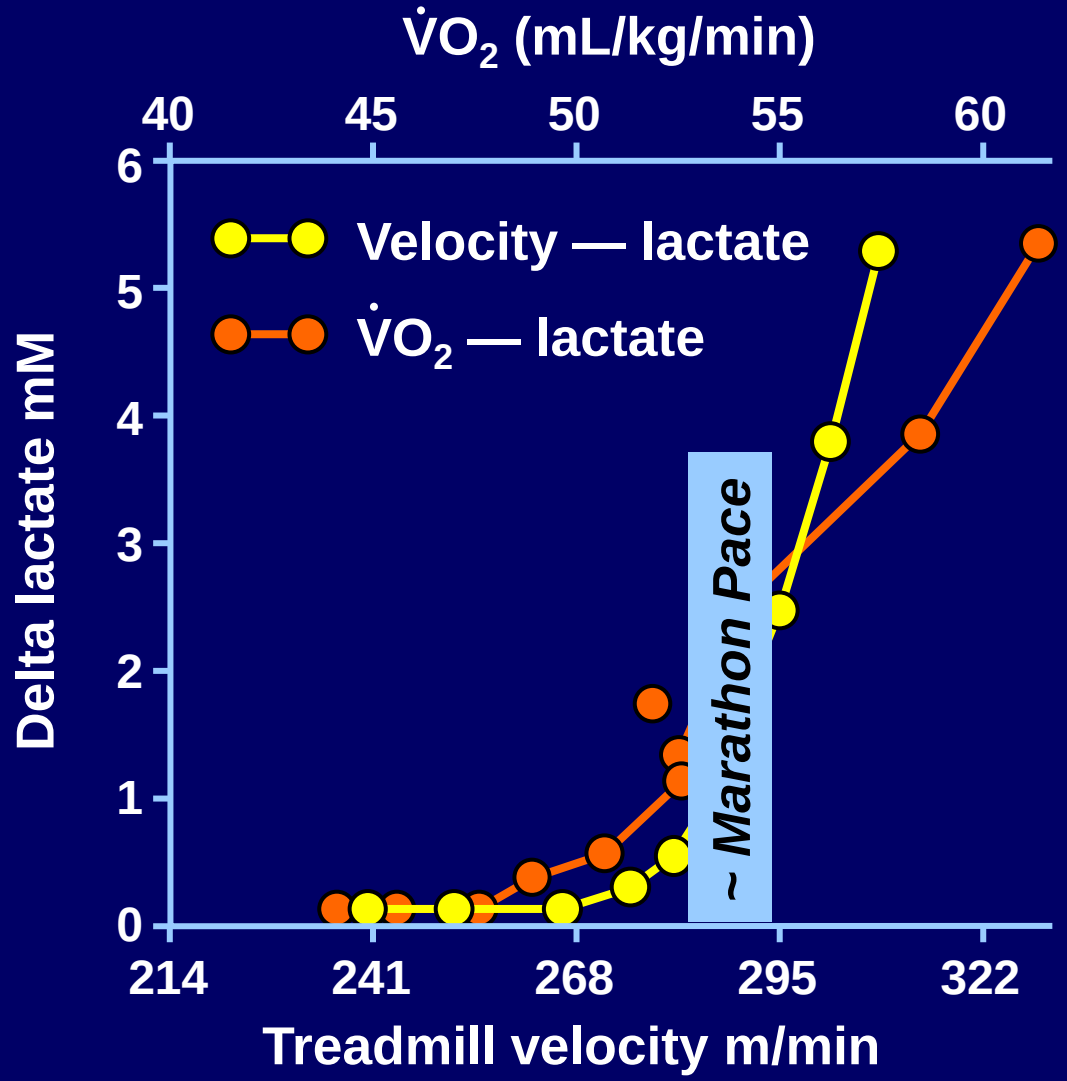
- Very high values reported in 1930s
- Only limited training needed
- High cardiac output/muscle blood flow
  - Stroke volume
  - Red cell mass
- Twin studies
  - Standard training program = 5-50% increase
  - >0.7 correlation between identical twins

Marathon Running is Mostly Aerobic



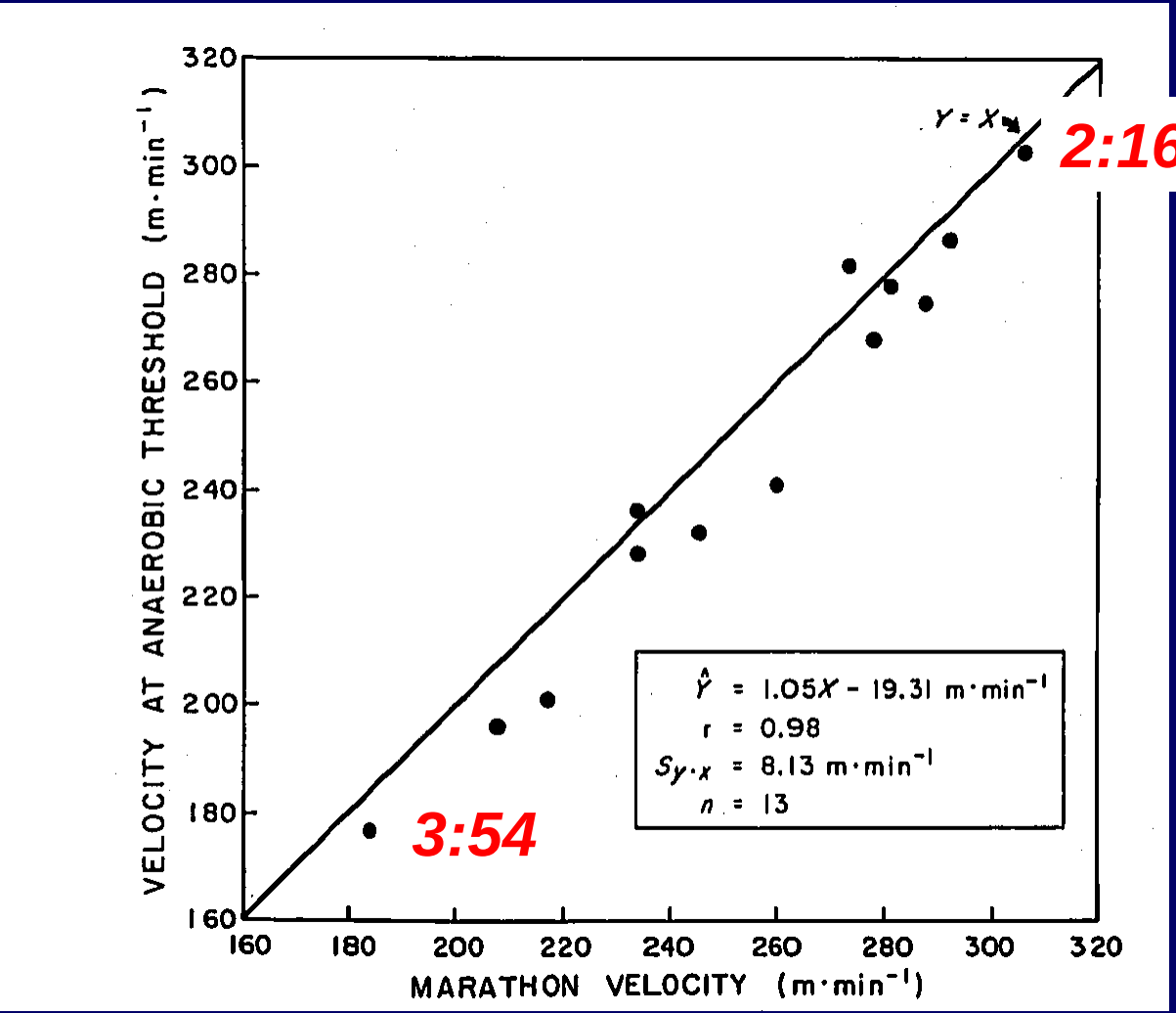
Costill 1970

Lactate Threshold: Individual Example

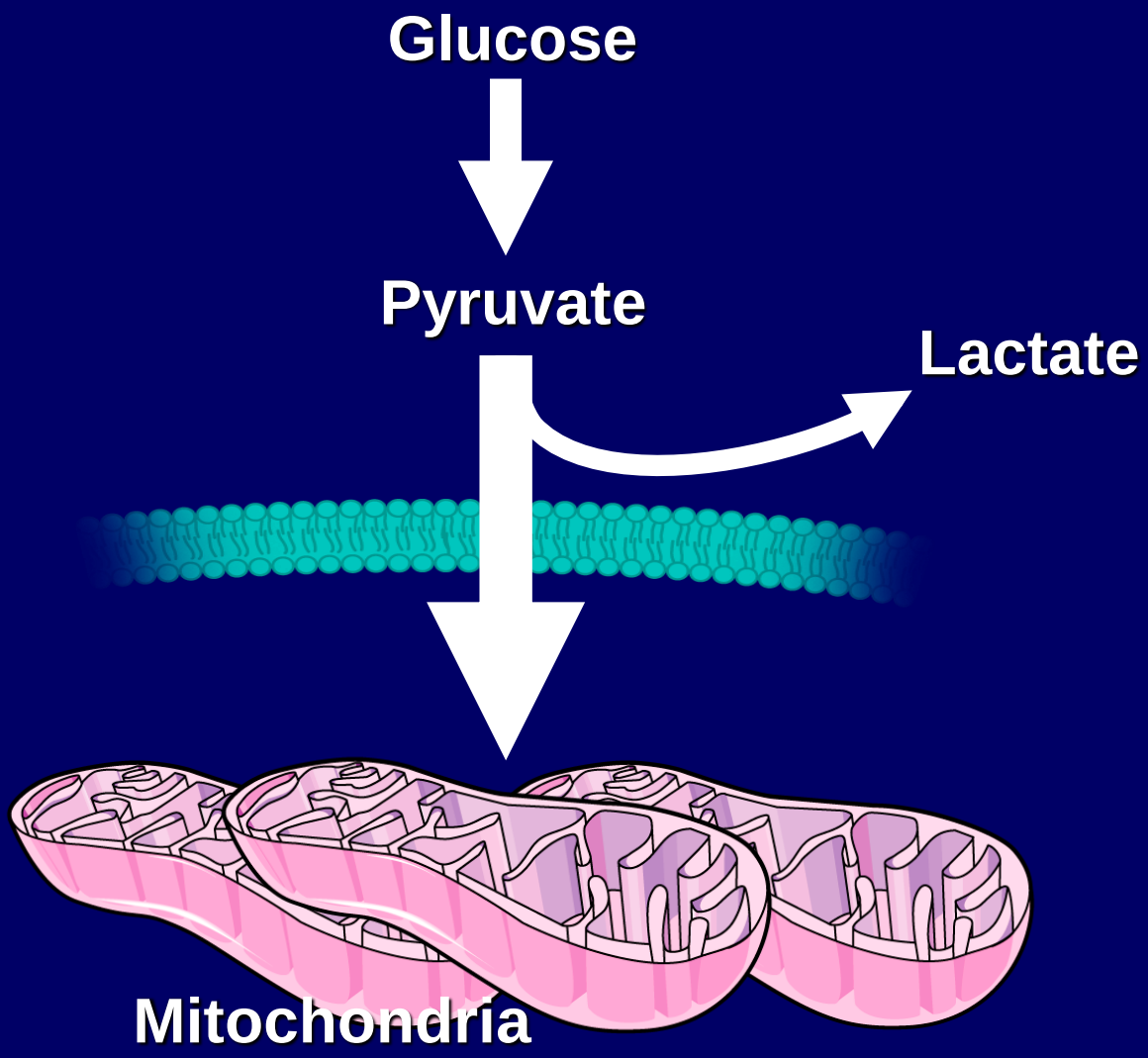


Farrell et al 1979

LT vs Marathon Speed



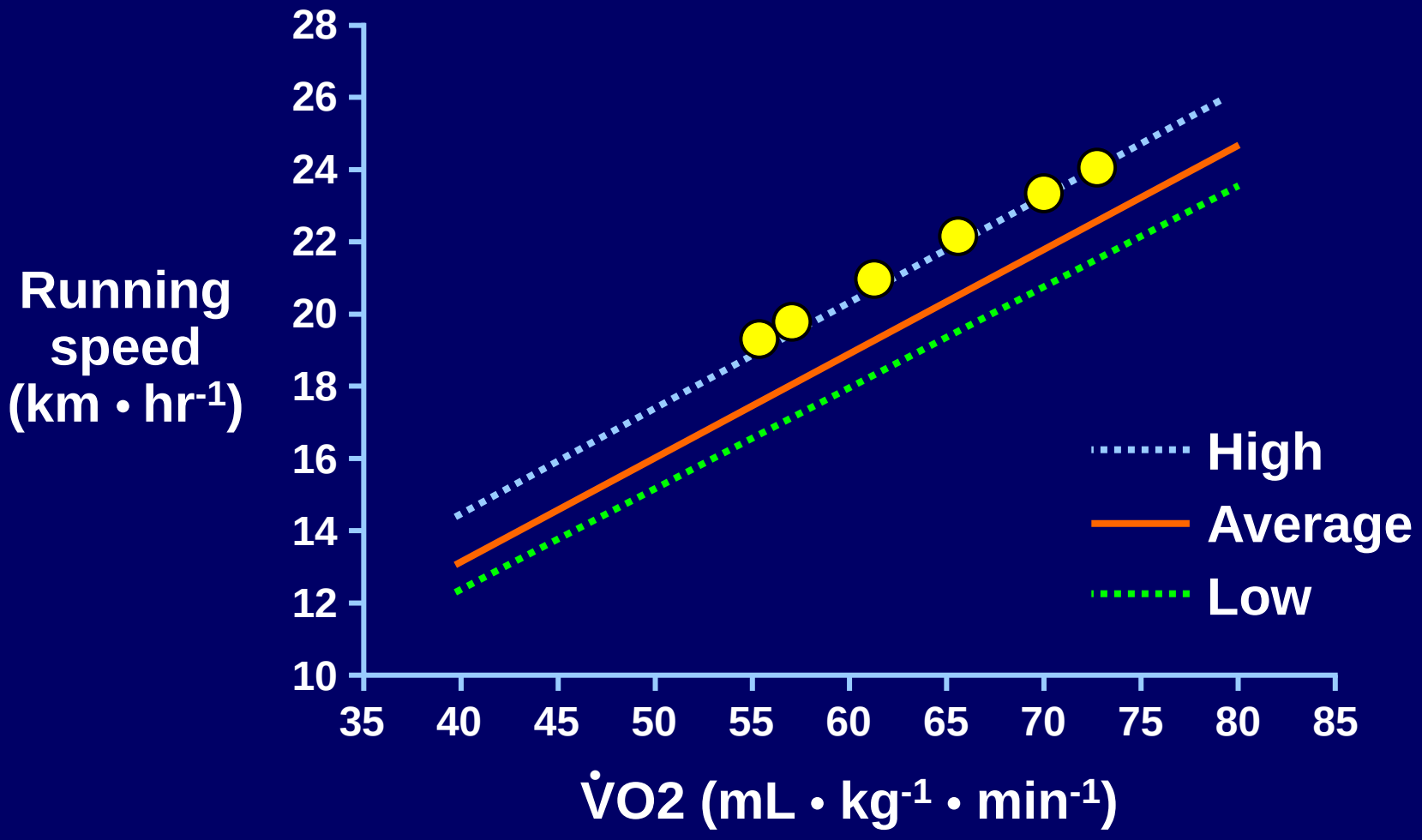
Farrell et al replotted by Davis MSSE 1985


Glucose
Pyruvate
Lactate
Mitochondria

Running Economy

- How much speed can be generated at a given $\dot{V}O_2$
- Highly variable up to 30%
- Biomechanical factors/Stiffness
- Fiber Type?
- Unclear if trainable!

Running Economy
Speed / $\dot{V}O_2$



Joyner 1991 (Plotted from Conley & Krahenbuhl)

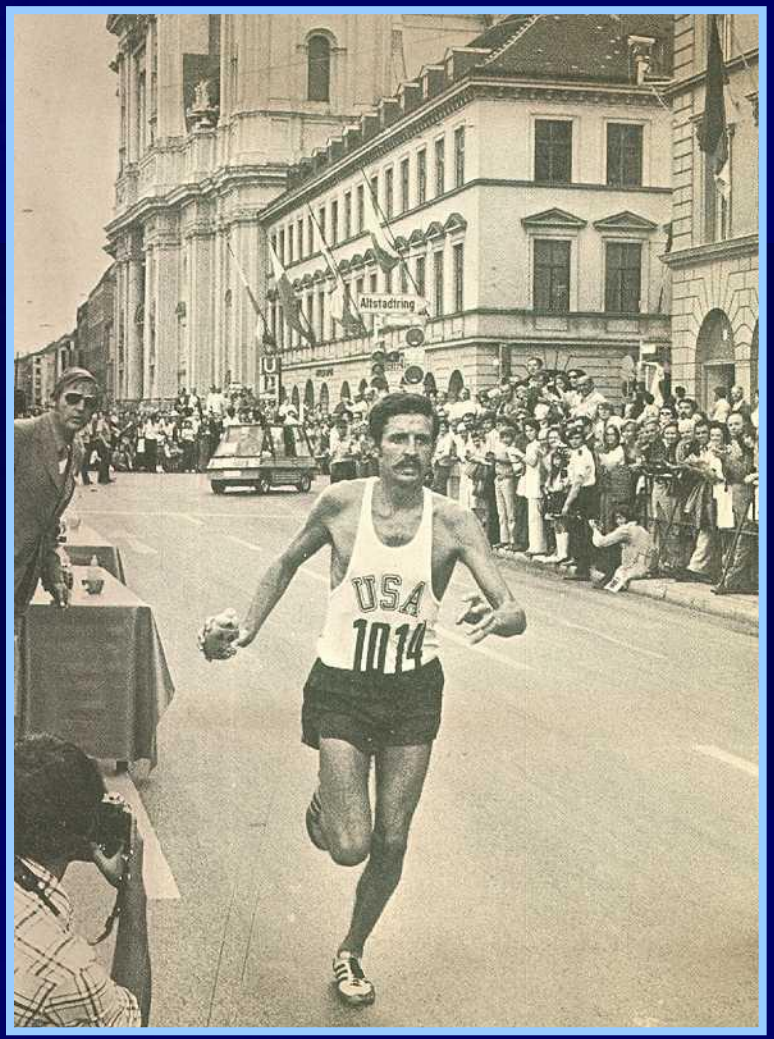
Running Economy

Frank Shorter

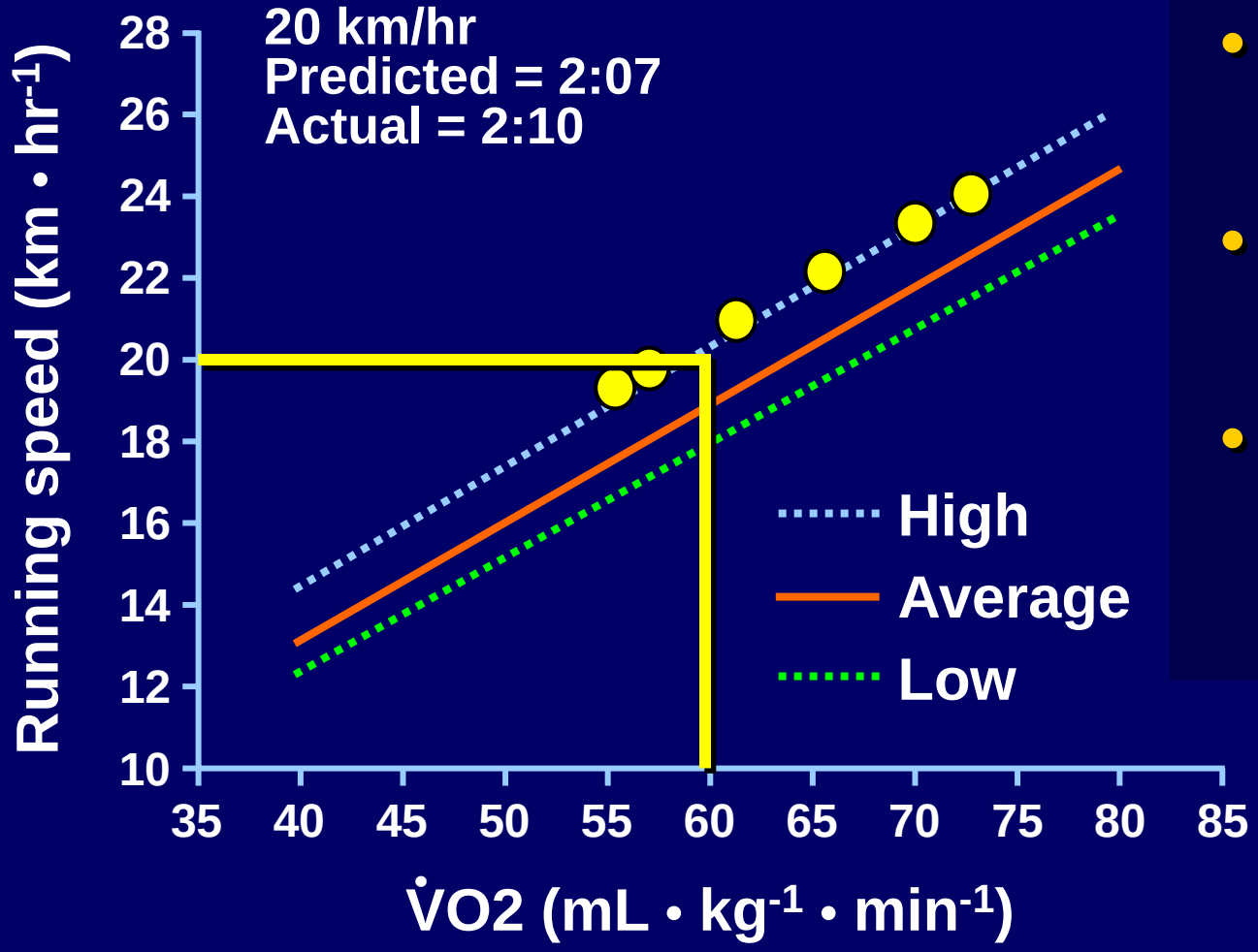
Modest $\dot{V}O_2max$

Superb RE

Olympic Champion

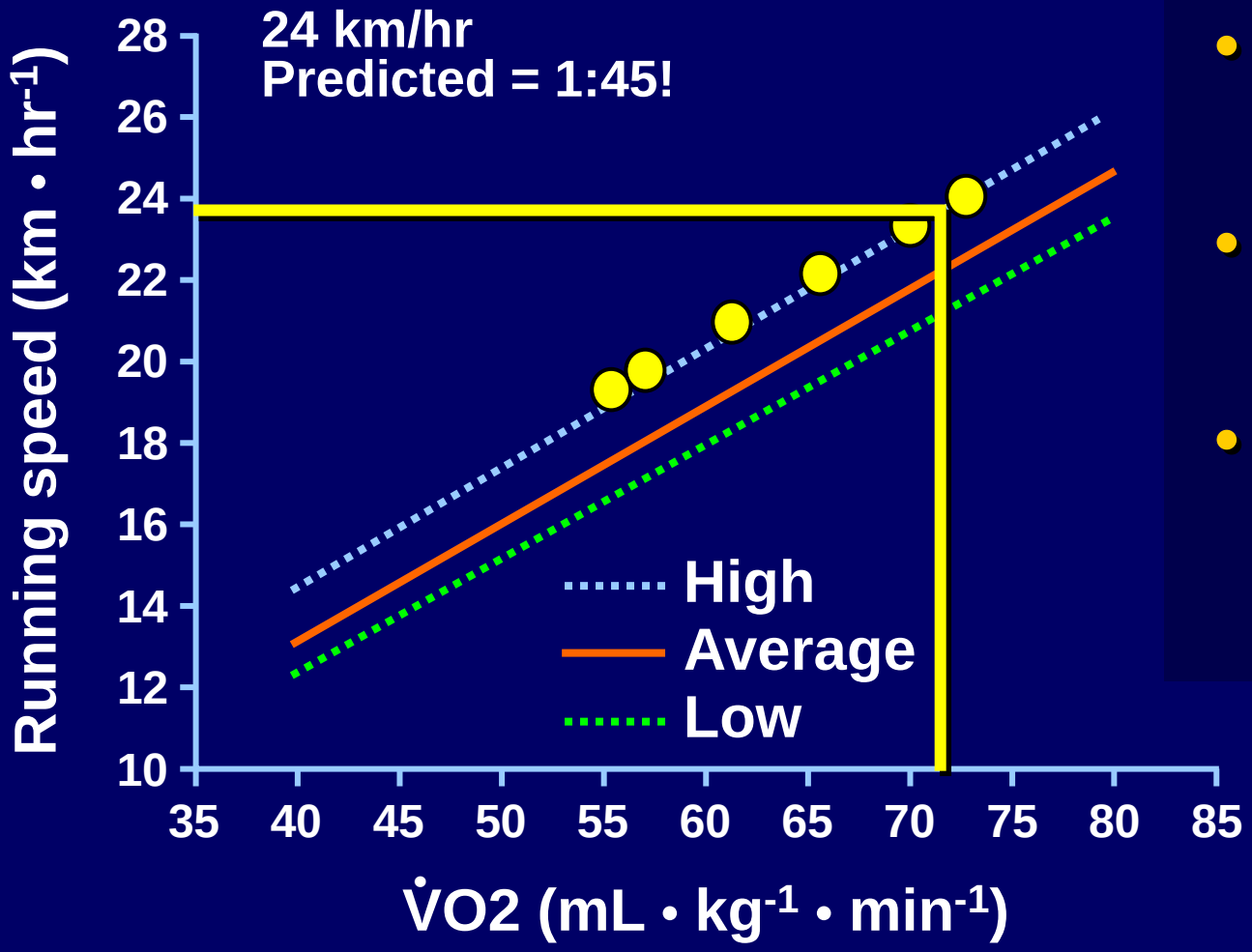


What Happens: Frank Shorter?



- $\dot{V}O_2$ max = 70 ml/kg/min
- LT = 85% of $\dot{V}O_2$ max
- Performance $\dot{V}O_2$ ~60 ml/kg/min

What Happens: Best Ever?



- $\dot{V}O_2$ max = 85 ml/kg/min
- LT = 85% of $\dot{V}O_2$ max
- Performance $\dot{V}O_2$ ~72 ml/kg/min

It’s Genetic?

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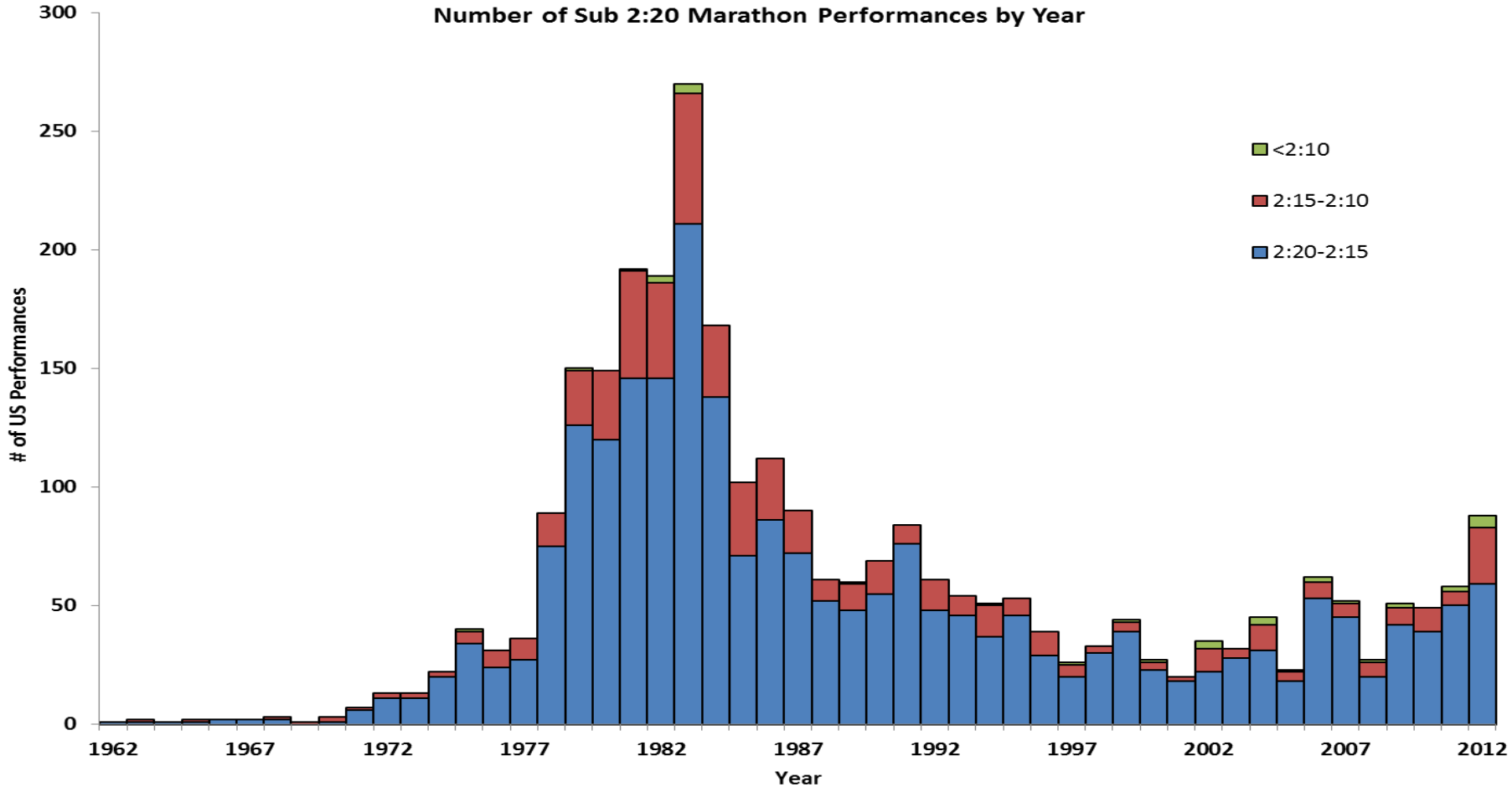
2. When will NIH fund a study to search for endurance genes in Kansas farm boys?

US Marathon Times:
Culture Beats (loses to) Genetics!



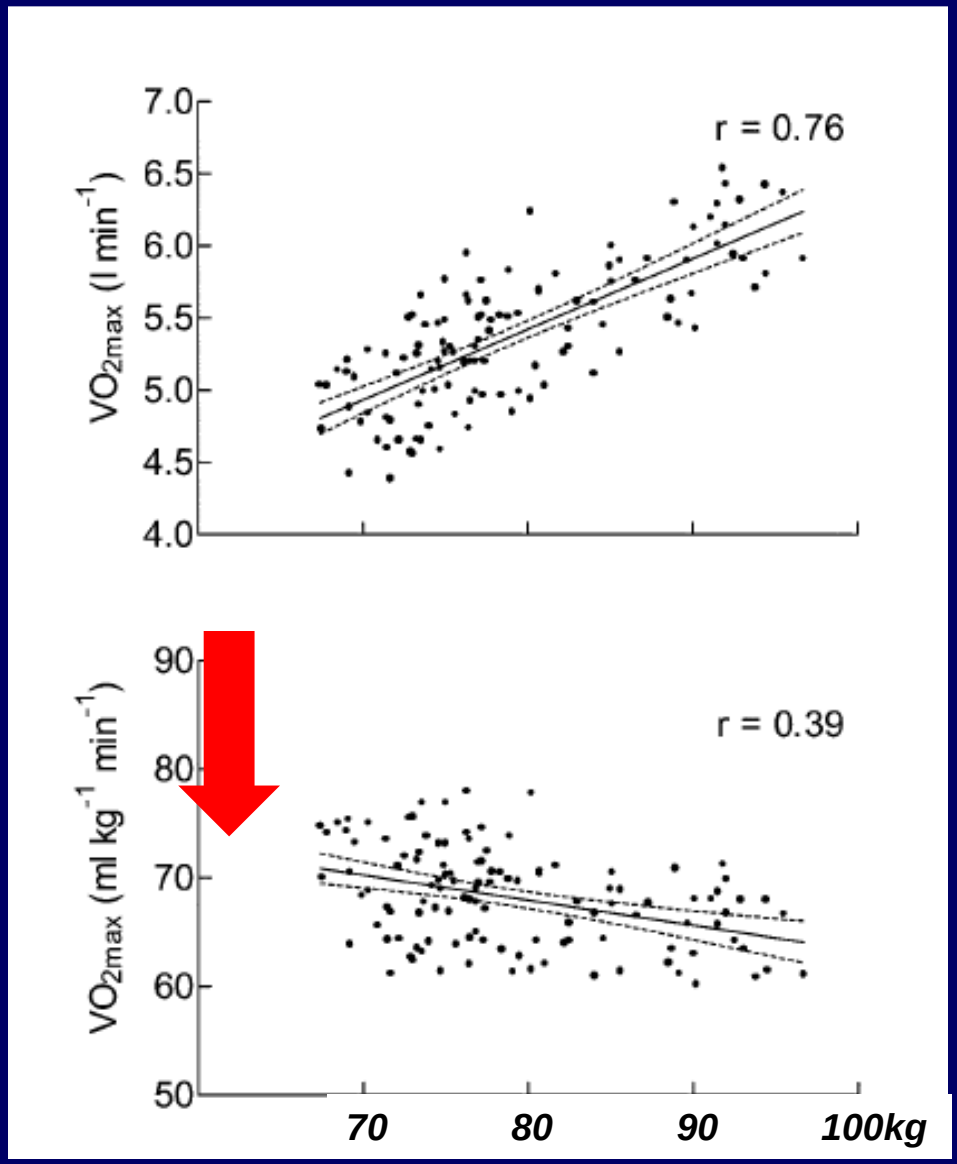
No Evidence of a Common DNA Variant Profile Specific to World Class Endurance Athletes

Rankinen et al PLOS1 2016

No variants related to blood volume, stroke volume or hemoglobin identified…

their support and active participation, thousands of world-class endurance athletes could be enrolled in genomics studies aimed at understanding the fundamentals of inherited biological traits that are necessary to perform at the world class level. Such an effort, particularly if it relied on whole genome sequencing, would allow for the exploration of not only common polymorphisms but also rare variants and copy number variants and could be complemented by the investigation of epigenomic signatures in accessible tissues. In summary, we found that the T allele in *GALNTL6* was less frequent in endurance athletes of all studies compared to ethnicity-matched controls. However, we could not find evidence for a detailed genomic signature that differentiates endurance athletes from controls.

Size Makes a Difference



168 cm
56 kg

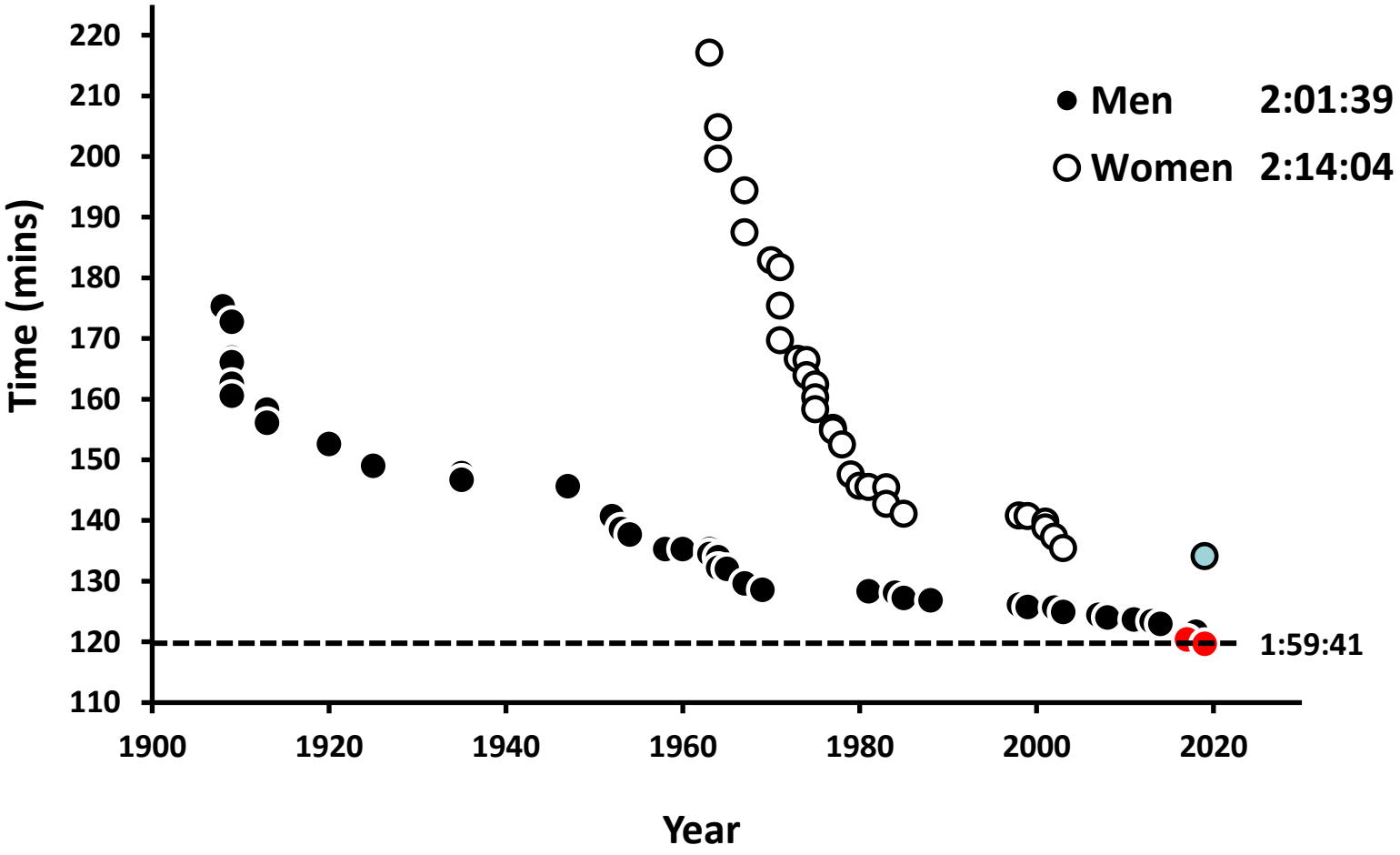
Run 4km to School

How Genetic is This?

4. Some History

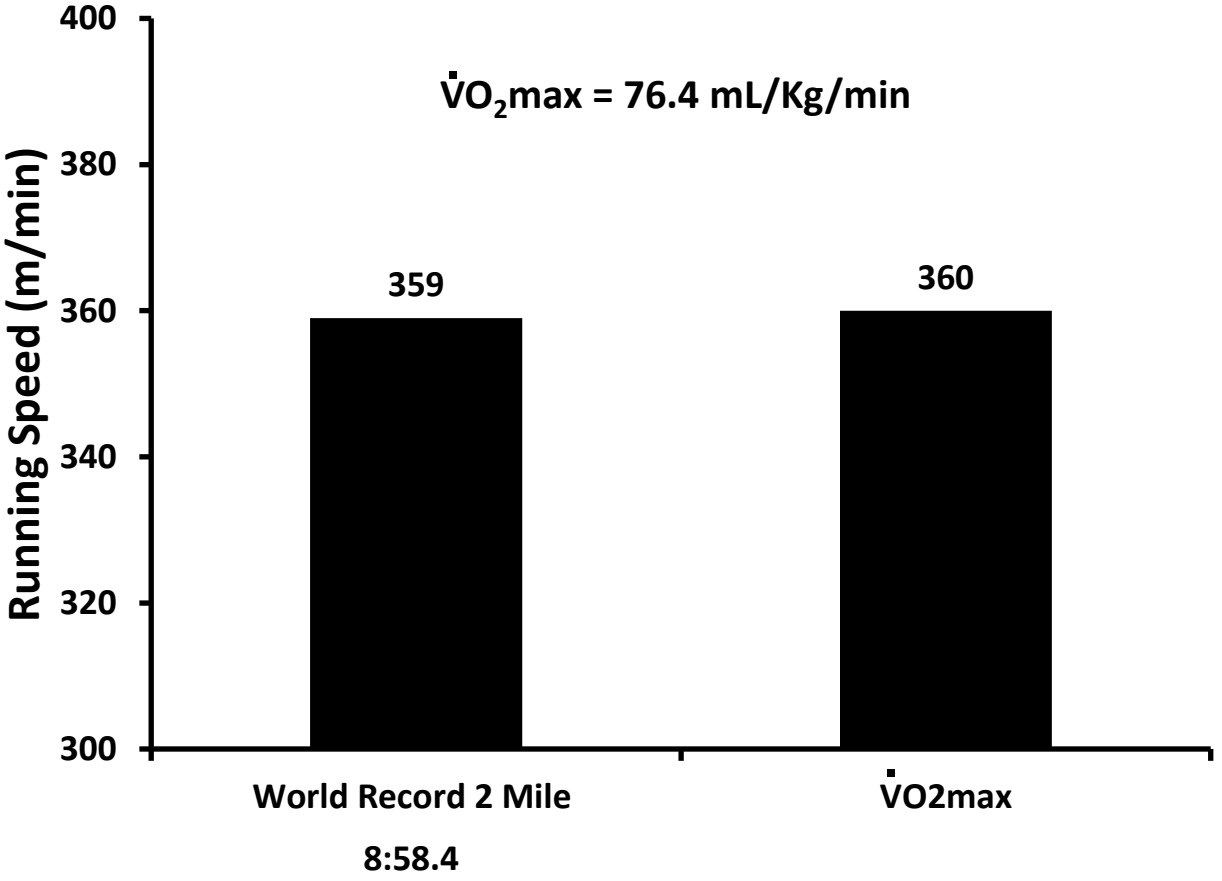
1908 London Olympics:
Windsor Castle & 26.2

Marathon WR Progression



Harvard Fatigue Lab:
Bruce Dill & Don Lash 1937

Don Lash 1930s



Robinson et al. Science. 1937; 85:409-410.

More & Harder Training

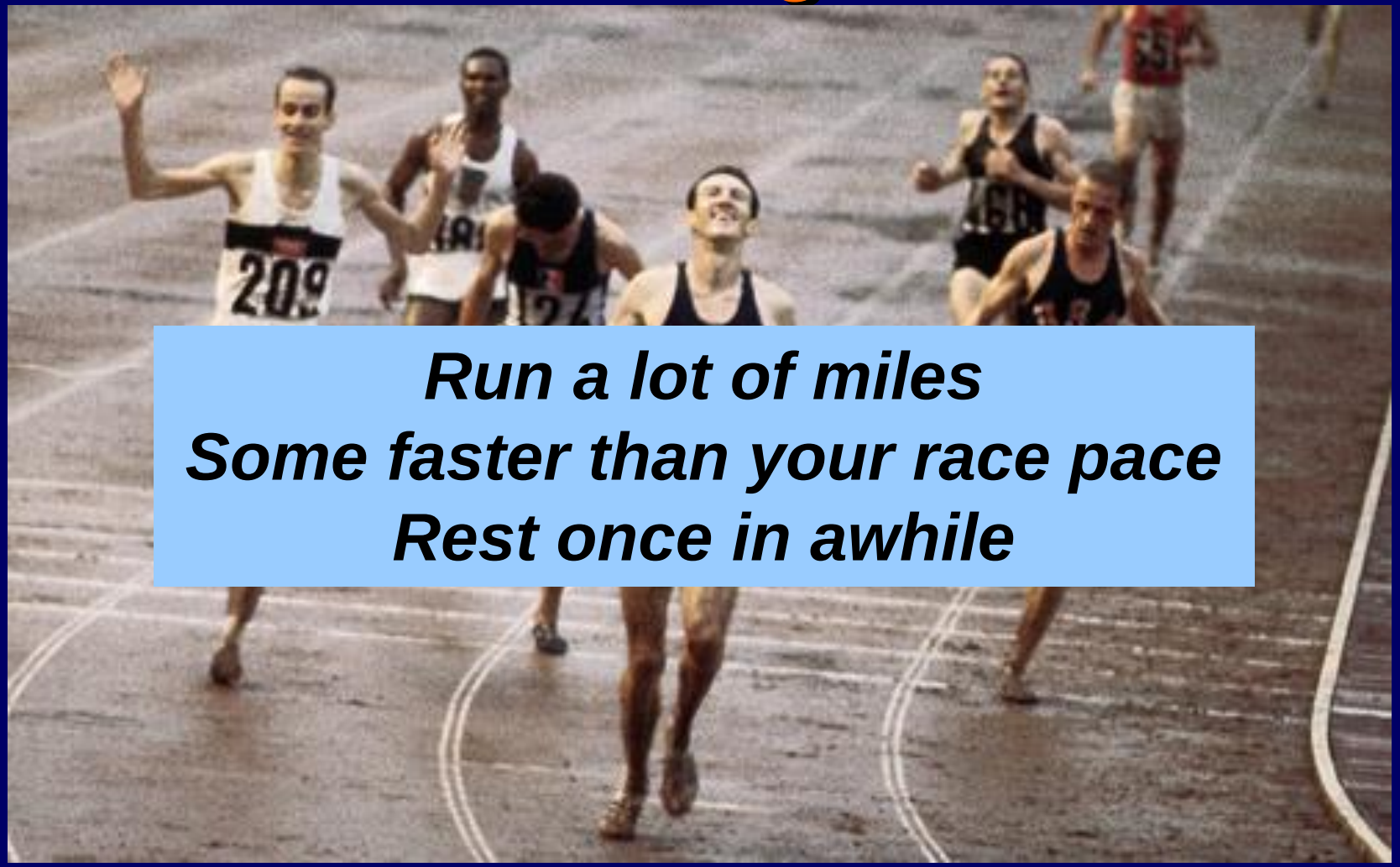
NURMI
9 gold medals
1920-28

ZATOPEK
4 gold medals
1948-52

More & Harder Training

	Frequency	Duration	Intensity
Shrubb UK ~1900	3-5 x week seasonal	<1 hour	Steady
Nurmi Finn ~1920	1-2 x day year round	>1hour	Walk, Run, Sprints
Zatopek Czk ~1950	2 x day year round	>2 hours	Interval training

Train A Whole Lot:
1964 Olympic 5000m &
The Running Haiku



Run a lot of miles
Some faster than your race pace
Rest once in awhile

More People Participating

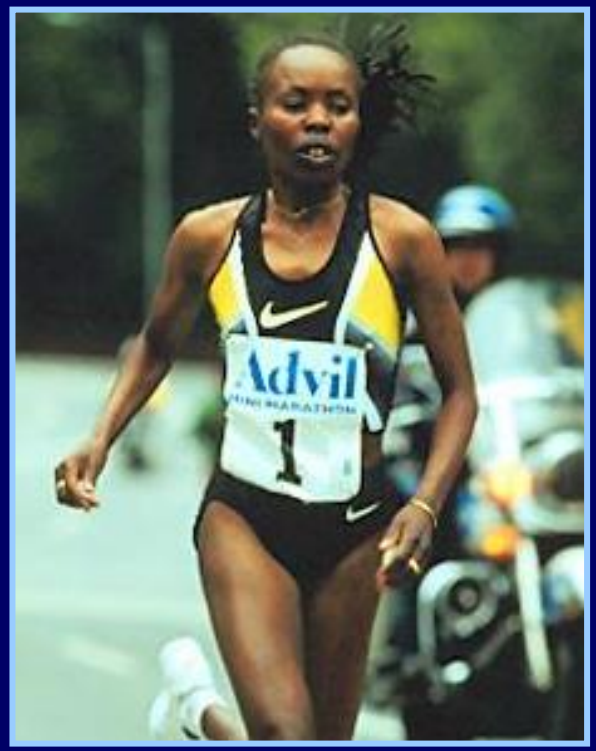
Bikila

Keino

More People Participating

Waitz

Laroupe



Radcliffe

Also….

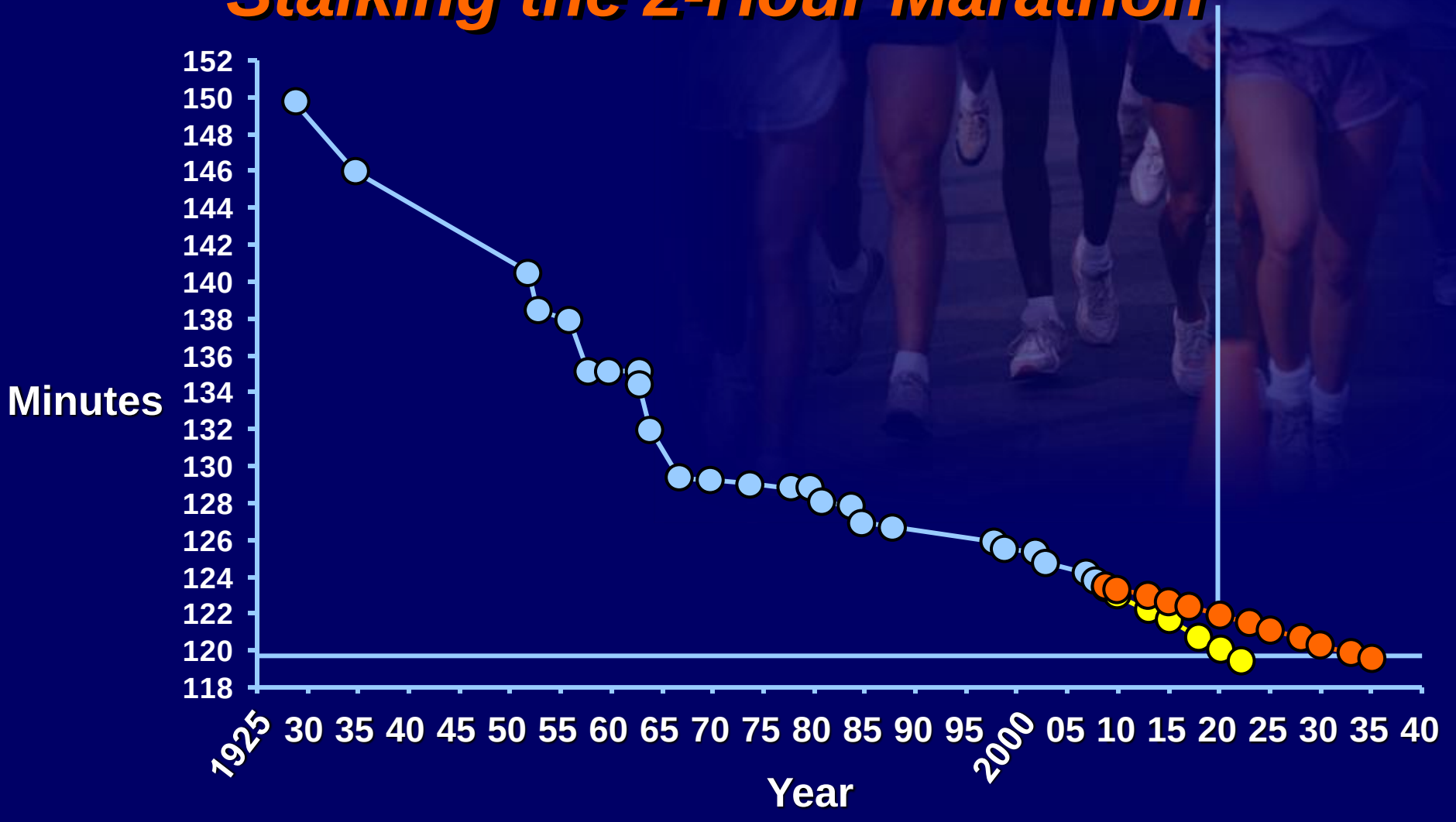
- More prize money
- Better races
- Longer careers
- Good runners move up sooner

2010s: Stalking the 2-Hour Marathon

- Outstanding 10K time?
- Good running economy
- Small size
  - thermoregulation
  - fuel
- Life long ‘training”?
- Altitude native?
- *Right field, day, race & prize money scheme?*

Joyner, Ruiz, Lucia 2011

2011 Update:
Stalking the 2-Hour Marathon



Joyner, Ruiz, Lucia JAP 2011

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5. Technology & innovation *(& yuk – doping)*

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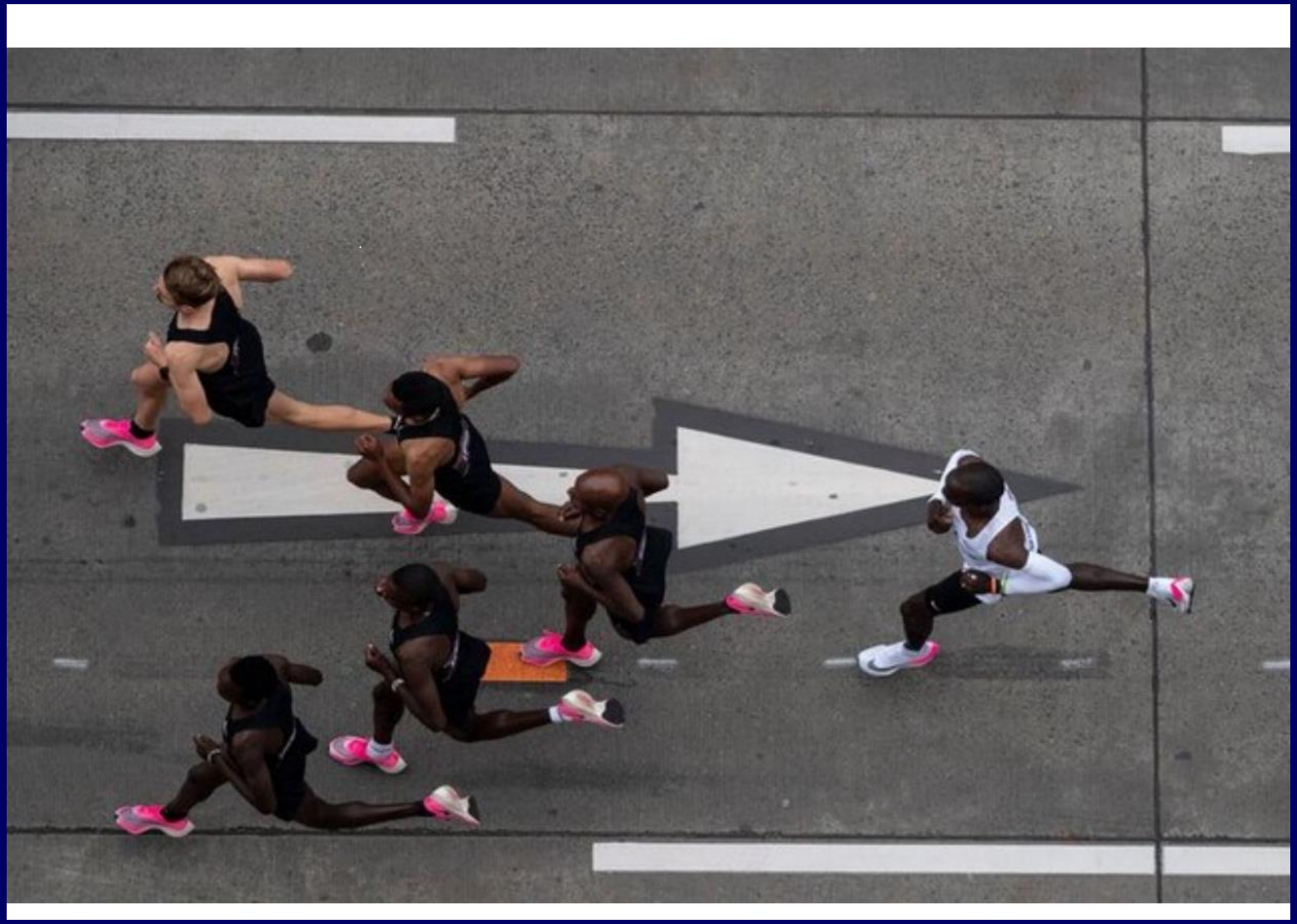
2017 Nike: *Why Wait?*
2019 INEOS: *Try Again!*

What Did Nike (& INEOS) Do?

- **Marginal gains**
  - *Course*
  - *Temp*
  - *Feeding*
- **Manipulate Economy**
  - *Drafting*
  - *Pacing*
  - *Shoes*
- **Scientists Matter**
  - Brad Wilkins
  - Brett Kirby
  - Andy Jones
  - Phil Skiba
  - Rodger Kram
  - Wouter Hoogkamer
- **INEOS**
  - Peter Vint


BREAKING2
BREAKING2



J. Physiol. (1971), **213**, *pp.* 255–276
With 9 text-figures
Printed in Great Britain

THE INFLUENCE OF WIND RESISTANCE IN RUNNING AND WALKING AND THE MECHANICAL EFFICIENCY OF WORK AGAINST HORIZONTAL OR VERTICAL FORCES

By L. G. C. E. PUGH

4. In a 65 kg athlete running at 4·45 m/sec (marathon speed) $\dot{V}_{O_2}$ increased from 3·0 l./min with minimal wind to 5·0 l./min at a wind velocity of 18·5 m/sec. The corresponding values for a 75 kg subject walking at 1·25 m/sec were 0·8 l./min with minimal wind and 3·1 l./min at a wind velocity of 18·5 m/sec.

5. Direct measurements of wind pressure on shapes of similar area to one of the subjects yielded higher values than those predicted from the relation of wind velocity and lifting work at equal O_2 intakes. Horizontal work against wind was more efficient than vertical work against gravity.

6. The energy cost of overcoming air resistance in track running may be 7·5 % of the total energy cost at middle distance speed and 13 % at sprint speed. Running 1 m behind another runner virtually eliminated air resistance and reduced $\dot{V}_{O_2}$ by 6·5 % at middle distance speed.

From Sci American 1978 a better surface might be worth 2-3%

Fast Running Tracks

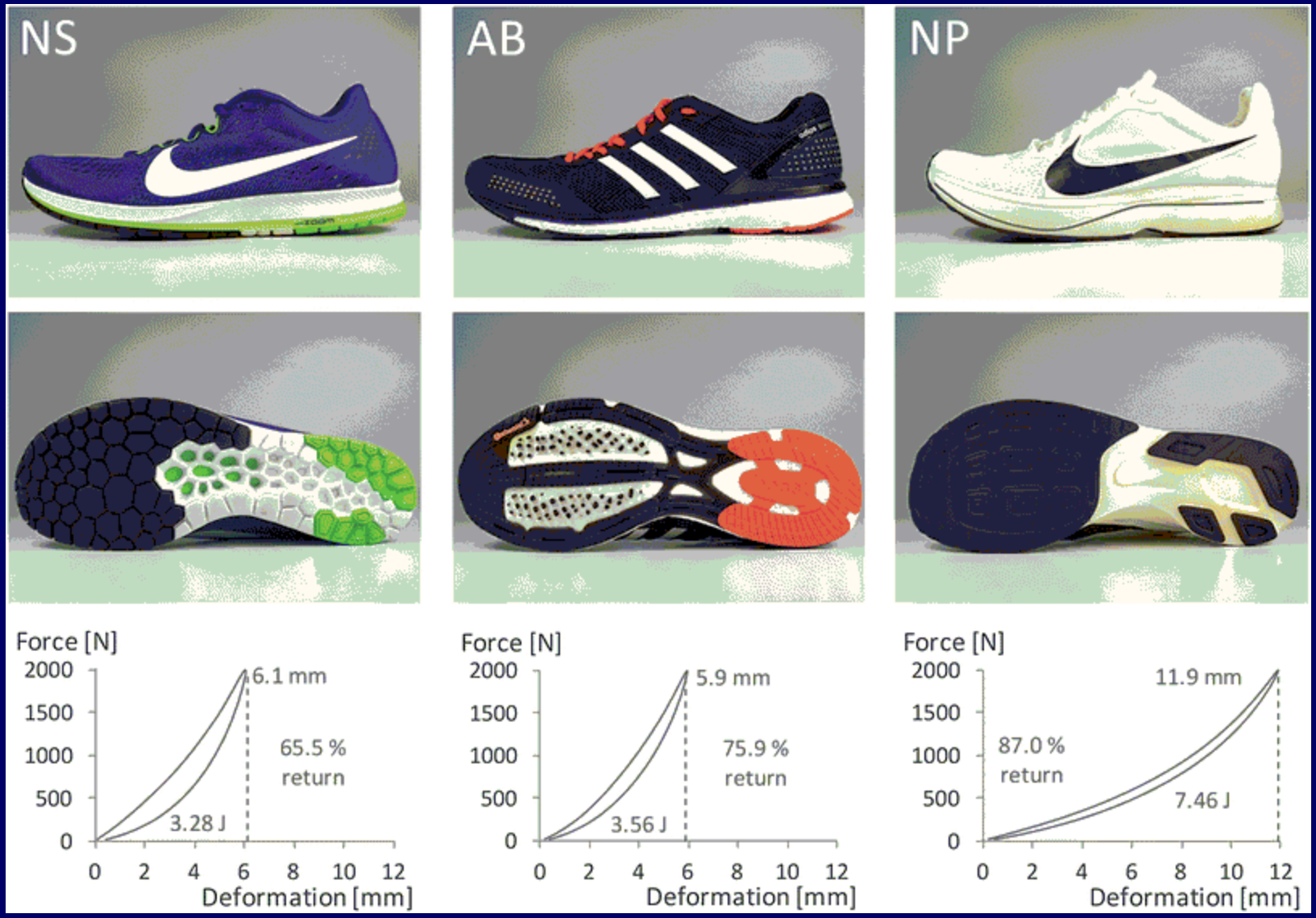
On a springy new indoor track at Harvard University runners can run faster than they can on standard tracks. The design of the track was arrived at through a close analysis of the mechanics of human running

by Thomas A. McMahon and Peter R. Greene

No outdoor track of the optimum mechanical design has yet been built. If such a track is built, we predict that the world record for the mile could be improved by as much as seven seconds. The opportunity stands as a challenge.

The goal was to tune the stiffness and recoil properties of the track

The Track In The Shoes Trick?



Shoes – The 1980s Prequel

9;15 a.m.

LOWER O_2 COST WHILE RUNNING IN AIR CUSHION TYPE SHOE

E. C. Frederick, E. T. Howley and S. K. Powers. Departments of Physical Education and Zoology, University of Tennessee, Knoxville, TN 37916

Eleven highly trained male distance runners were subjected to a series of oxygen uptake ($\dot{V}O_2$) measurements to compare the oxygen cost of running in two types of shoe. Shoe type A was constructed with a conventional EVA foam midsole. Shoe type B was constructed with a special midsole consisting of a thick plastic air cushion encapsulated in polymeric foam. After an initial warmup period, each subject ran a set of three tests on each of two days. The sequence of wearing shoes was staggered to control ordering effects and to assure that each subject ran a total of three tests in each shoe type. A test consisted of a twelve minute treadmill run at a speed equivalent to the average speed the individual would be expected to run in a marathon (range of speeds used; 215-273m/min.). There were rest periods of five minutes between tests. Continuous samples of expired air were collected from 8 to 10 and from 10 to 12 minutes of each test to measure $\dot{V}O_2$. The average $\dot{V}O_2$ values for each test were converted into net oxygen cost ($ml O^2/kg/km$) and data from all subjects were tabulated according to shoe type. Group mean O_2 costs were 205.7 ± 3.95 ml O_2/kg/km for shoe A and 200.0 ± 3.73 ml O^2/kg/km for shoe B. Data from all 66 tests (33 tests per shoe type) were compared statistically using a two-way ANOVA with replication. The O_2 costs of running in the two shoe types were statistically different ($p<<0.001$). The air cushioned shoe B cost an average 5.7 ml O_2/kg/km less to run in even though shoe B weighed slightly more than shoe A ($\overline{X}$ shoe A = 646.9g/pr; $\overline{X}$ shoe B = 677.8g/pr). An energy cost saving of this magnitude is physiologically significant and may significantly affect performance in long distance events.

Supported in part by a grant from Blue Ribbon Sports, Inc.

OUR NEW AIR SHOE MAY BE GOOD FOR ABOUT THREE MINUTES.

Maybe a couple more. It depends on which marathoner you talk to.

Regardless, there are a number of world class athletes who are not only winning in our new Mariah, but turning in some impressive P.R.'s to boot. From the 5K on up.

We're not promising anything. But you ought to know that independent lab reports show the Nike Air-Sole™ in this racing flat saves runners energy. Over 2 percent with every step, compared to conventional shoes of similar weight.

That's like running with a 9 mile an hour wind at your back. Or on a slight downgrade.

Many claim the Mariah also gives them a quicker recovery time between races.

Could be. When runners take to our air, tests show they lessen damage to red blood cells, and quite possibly muscles and connective tissue as well.

We've made some important changes with this new air shoe. The weight is down—under 7 ounces. The ride is firmer. The air is tuned for high-speeds.

Mariah. Think of it as a second wind.

NIKE

Beaverton, Oregon

MAYO CLINIC

R Kram via Twitter

Shoes – The 1990s Prequel

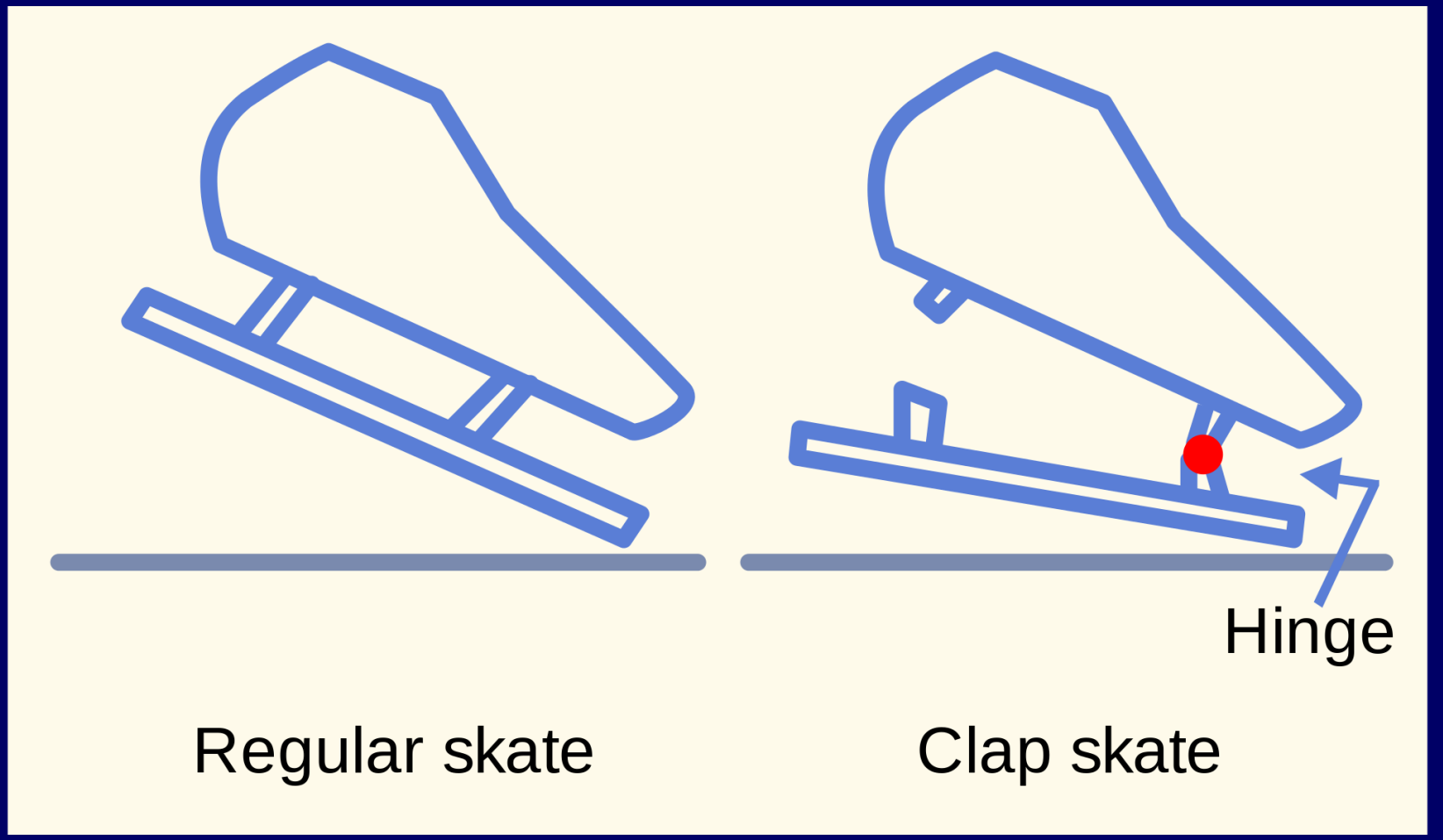
R Kram via Twitter

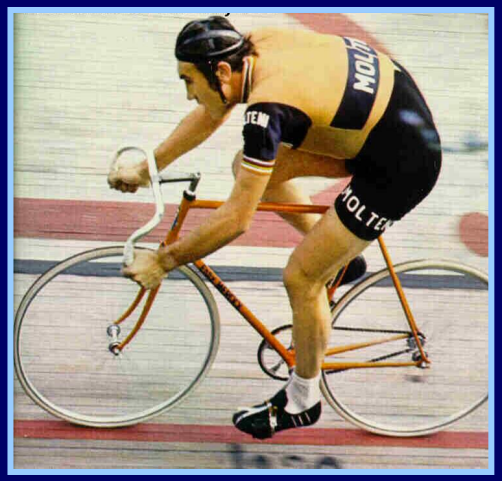
Shoe Innovation Was Hiding In Plain Sight……

2009 Talk at Nike
I Asked About “Slap” Skates

- Hinged skate
- Permits better “push off” and glide
- Is there a parallel technology that could be invented in shoes?
- “regulatory issues”

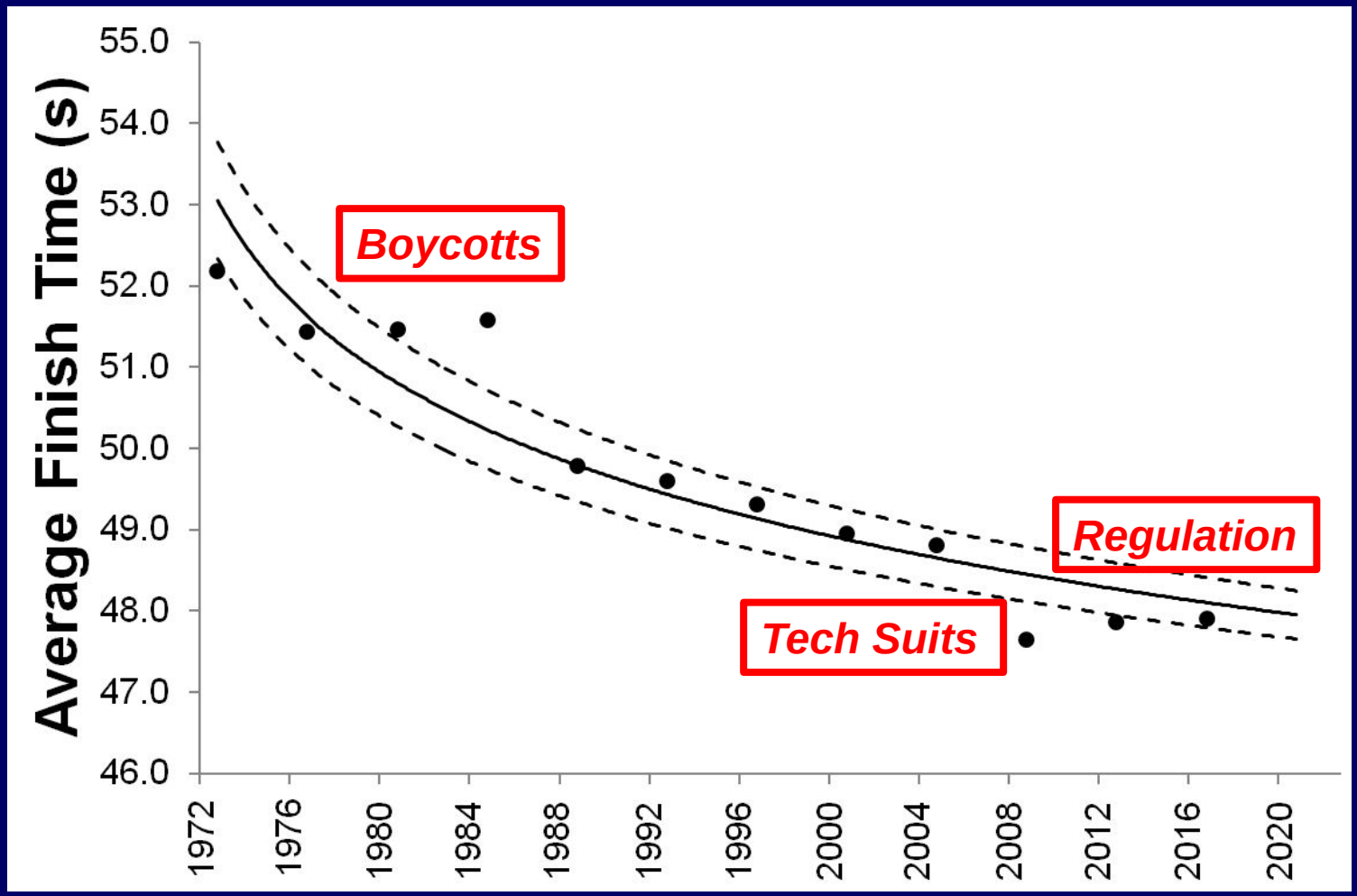
Clap (Klap, Slap) Skate





Bikes & Swimsuits: *Regulation?*

Average of Top 8 100m FS Times: *Olympics 1972-2016*



Should They Be Banned?

We've Had This Discussion Before!

Breaking2 & INEOS vs. *Bannister & Breaking4*

- I get the yapping about it being contrived
- Bannister in perspective
  - *Refurbed track*
  - *2 WC pacers*
  - *Custom shoes*
  - *State of the art coaching*
  - *Physiology Expertise*

J. Physiol. (1954) 125, 118–137

THE EFFECTS ON THE RESPIRATION AND PERFORMANCE DURING EXERCISE OF ADDING OXYGEN TO THE INSPIRED AIR

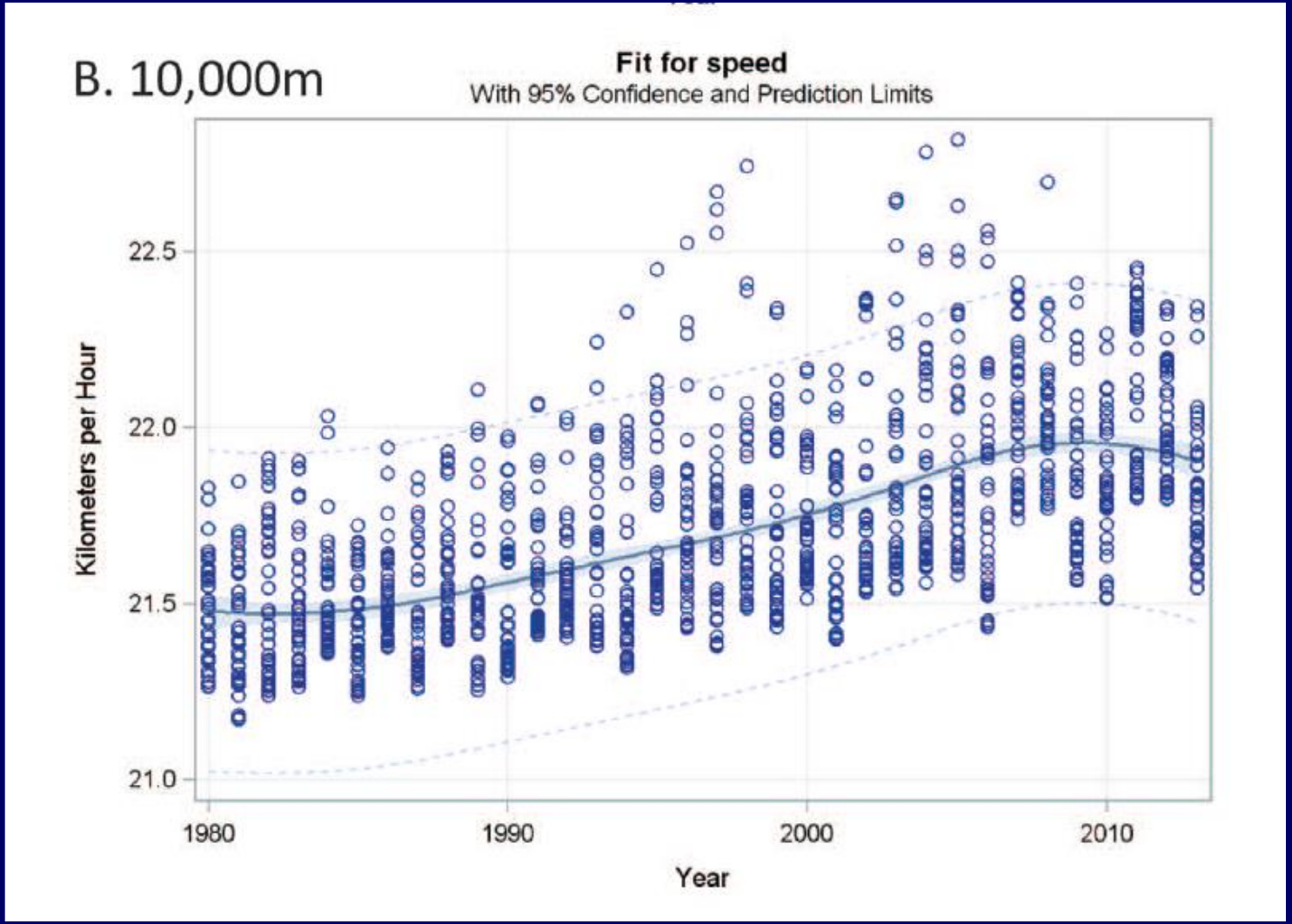
By R. G. BANNISTER and D. J. C. CUNNINGHAM

From the Laboratory of Physiology, University of Oxford

(*Received* 22 *December* 1953)

Doping?

~2005 Testing Getting Better?



Kruse et al PlOS1 2014

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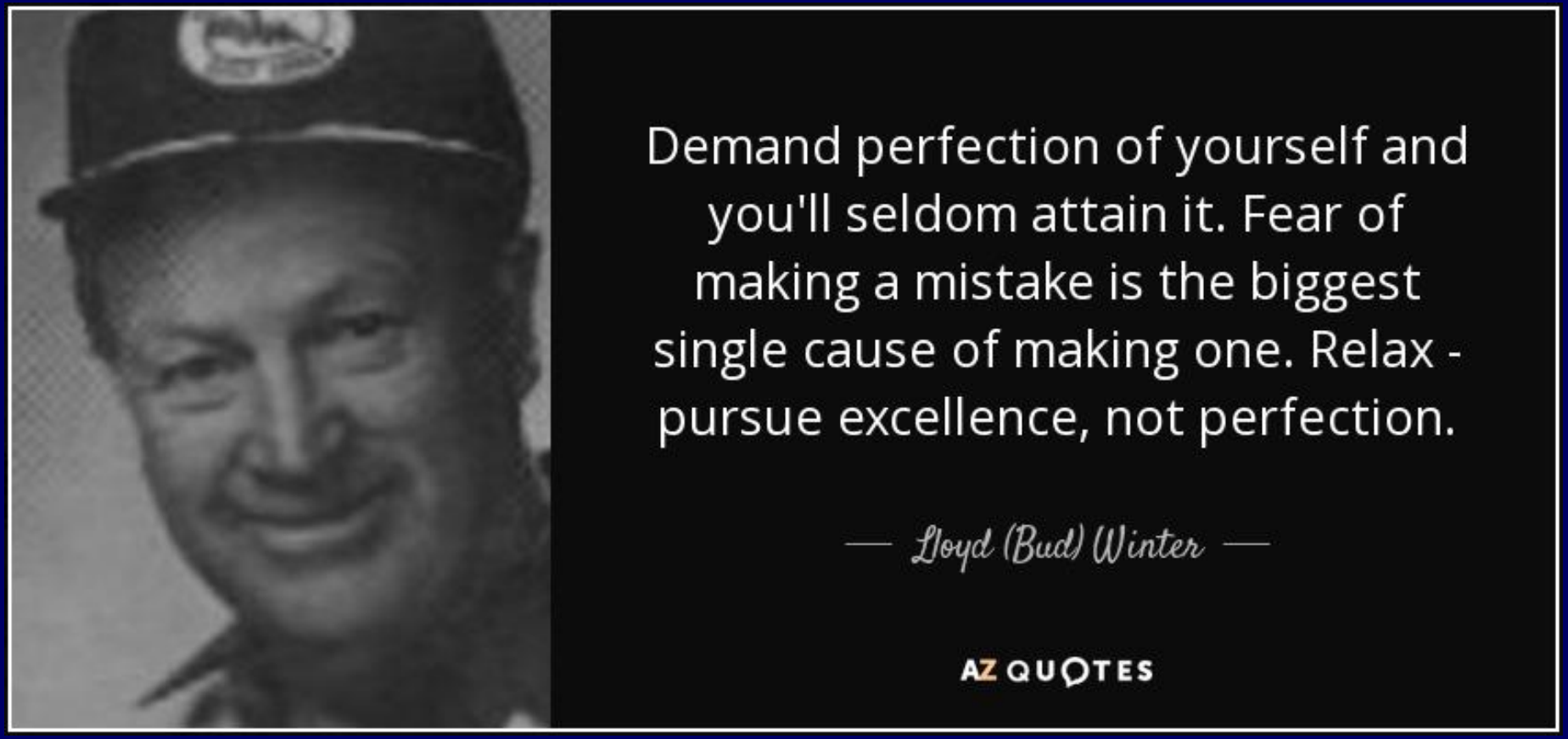
6. Psychology

"The will to win is not nearly so important as the will to prepare to win."

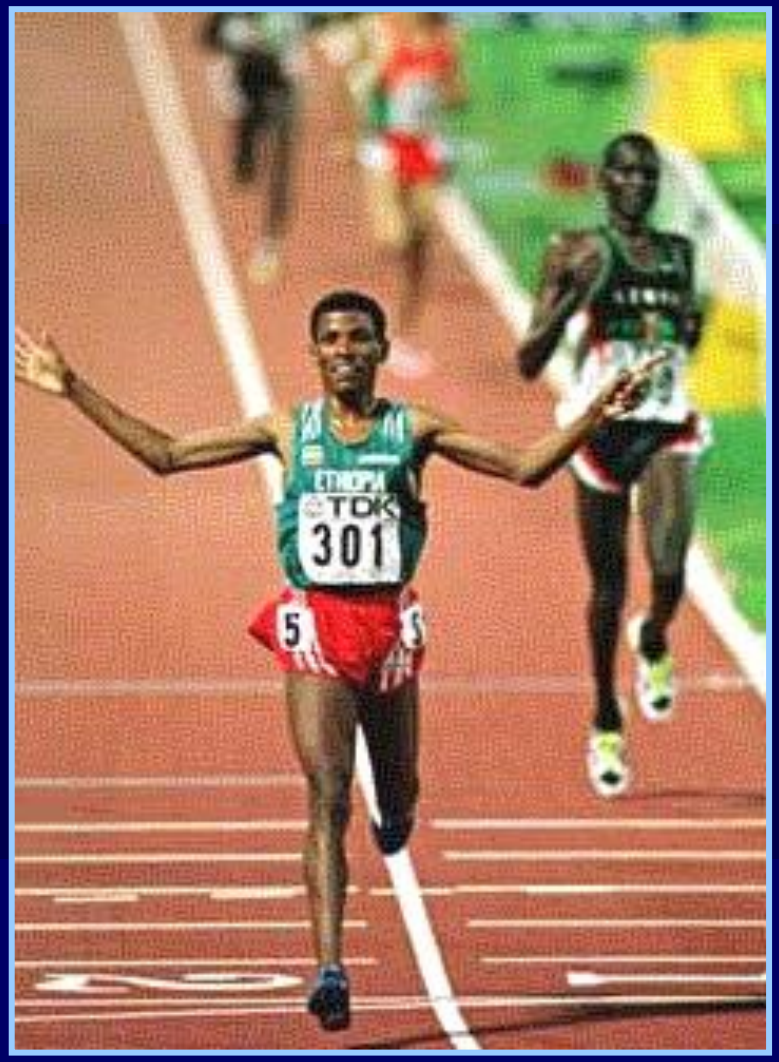
- Daily training for many years
- Willingness to accept feedback
- Resilience
- Suffering
- *Run 20x400m with 200m jog "recovery" –*
- *Come face to face with God…..*

Relax & Win


Demand perfection of yourself and you'll seldom attain it. Fear of making a mistake is the biggest single cause of making one. Relax - pursue excellence, not perfection.
— Lloyd (Bud) Winter —
AZ QUOTES

Phelps Crushes A Turn

TOUGHNESS



Gebrselhasse & Elliot

Beyond E Africa: *Al Waquie*

- ***Mountains of New Mexico, born 1954***
- ***Sandia Peak 8 x winner and Record Holder***
- ***Empire State Building 5 x winner and Record Holder***
- ***2 x winner of Pikes Peak Run , record set in 1981***

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Discussion

MAYO CLINIC

7. Putting It All Together
About 3 Minutes

Optimizing Non Tech Issues

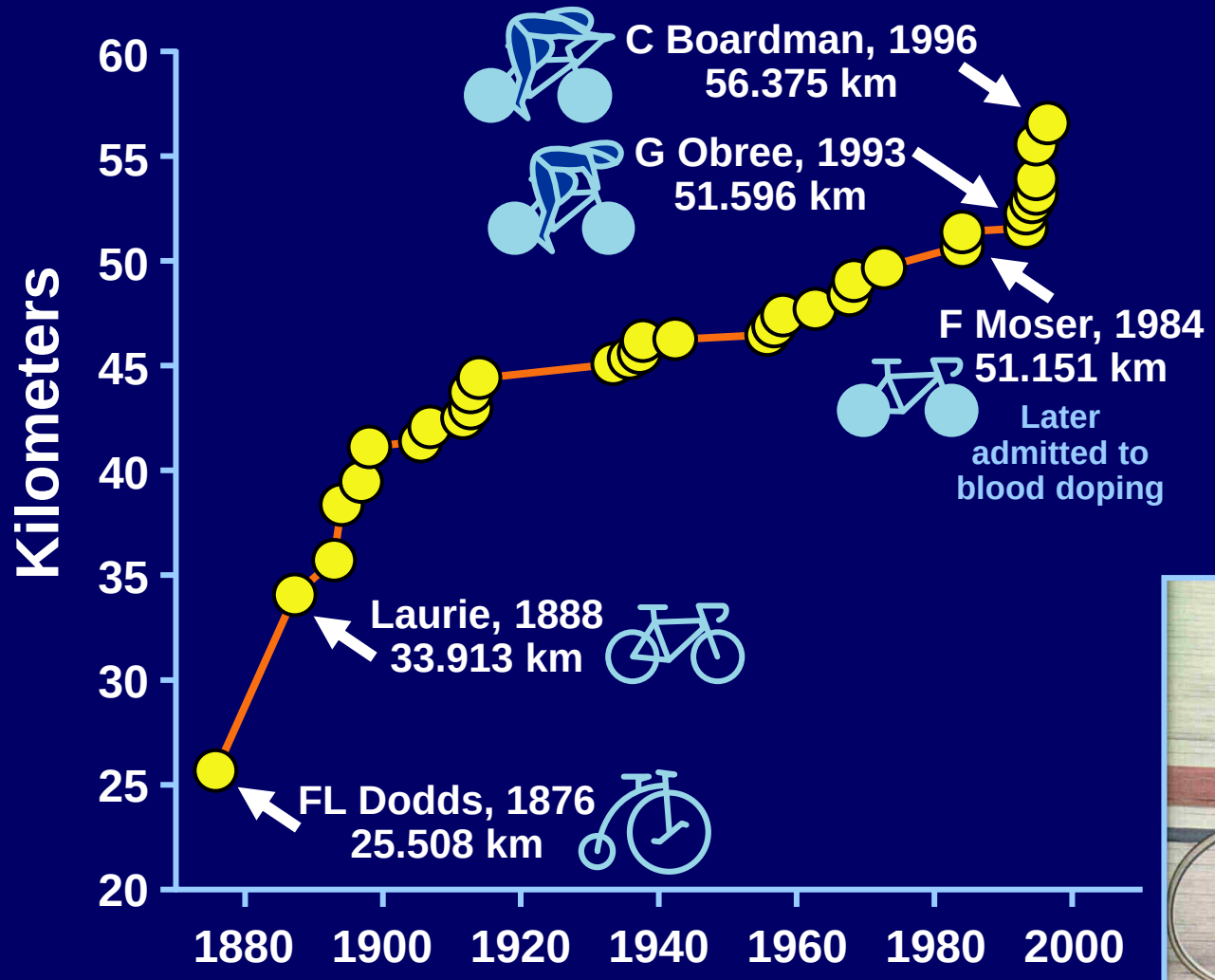
1. Athlete
2. Course
3. Environmental conditions

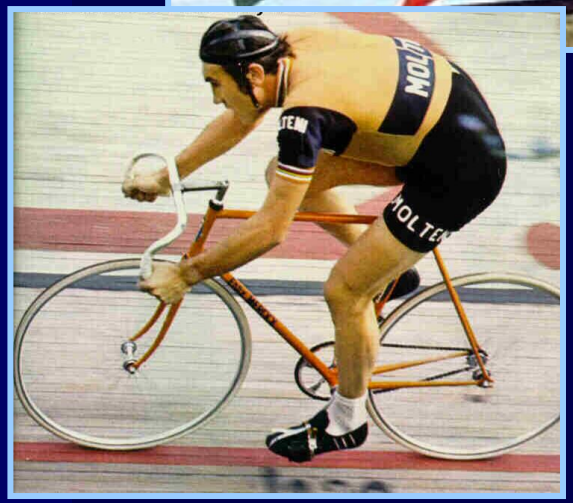
Pacing/Drafting ~ 2 Minutes?
Kipchoge - INEOS vs Berlin &

2:15:25	Paula Radcliffe
2:17:01	Mary Keitany
2:17:08	Ruth Chepngetich
2:17:18	Paula Radcliffe
2:17:41	Worknesh Degefa
2:17:42	Paula Radcliffe
2:17:56	Tirunesh Dibaba

The Same Story For Cycling

World Cycling Hour Record 1876-1998





MAYO CLINIC

CP1278619-77

Get Better Equipment:
1943 Dutch Warmerdam 4.78m (~15-8)

Recognize The Limits of Forecasting: *Who Would Have Predicted This?*

http://www.eia.gov/todayinenergy/ 1-2016

The Shoes ~ 80s

- Kipchoge vs Berlin
- Kosgei vs the women's list & Radcliffe's 2:15:25

Problems With Drug Testing

- Avoid false positives
- Gene variants and renal excretion of testosterone metabolites
- False negatives with urine tests for EPO
- Intellectual issues associated with urine testing for short acting peptide hormones
- Whole classes of releasing factors and designer drugs
- Criminal convictions of athletes who have “passed” hundreds tests but were clearly using drugs while tested
- Self-taught clinical pharmacologists