

## Notes

### TWO HOURS: MAY 6, 2017

1 *an estimated 13 million people*: Take all audience estimates with a grain of salt, but 13.1 million is Nike's official tally of viewers tuned into the live stream on Twitter, Facebook, and YouTube during the race. Another 6.7 million watched the video over the following week, and that number doesn't include China, where a substantial (but untracked) audience watched.

2 *What would happen, Joyner wondered*: "Modeling: Optimal Marathon Performance on the Basis of Physiological Factors," *Journal of Applied Physiology* 70, no. 2 (1991).

2 "A lot of people scratched their heads": This and other details are from multiple conversations with Joyner, but he repeats this quote here: Michael Joyner, "Believe It: A Sub-2 Marathon Is Coming," *Runnersworld.com*, May 6, 2017.

3 *published an updated paper*: Michael Joyner et al., "The Two-Hour Marathon: Who and When?," *Journal of Applied Physiology* 110 (2011): 275–77; the thirty-eight responses followed in the same issue.

3 *Runner's World magazine asked me*: "What Will It Take to Run a 2-Hour Marathon?," *Runner's World*, November 2014.

3 *biggest sports brand in the world*: The Forbes Fab 40 pegs Nike's brand value at \$15 billion, well ahead of ESPN in second place.

### CHAPTER 1: THE UNFORGIVING MINUTE

7 *If you can fill the unforgiving minute*: From the poem "If—," by Rudyard Kipling, in *Rewards and Fairies* (London: Macmillan, 1910).

7 *the quintessential "nearly man."*: Sebastian Coe, "Landy the Nearly Man," *Telegraph*, January 26, 2004.

7 *"four-minute mile is beyond my capabilities"*: As quoted in Neal Bascomb, *The Perfect Mile* (London: CollinsWillow, 2004). This definitive account is also the source of subsequent details about Landy's races.

9 *Ernest Shackleton's ill-fated Antarctic expedition*: Alfred Lansing, *Endurance* (New York: Basic Books, 1959).

10 *"the struggle to continue against a mounting desire to stop."*: Marcora cites this as the definition of an "effortful cognitive process," drawing on a definition of stamina from Roy Baumeister et al. in "The Strength Model of Self-Control," *Current Directions in Psychological Science* 16, no. 6 (2007).

10 *LeBron James's biggest foe*: Cork Gaines, "LeBron James Has Played More Minutes Than Anyone in the NBA Since 2010, and It Isn't Even Close," *Business Insider*, June 4, 2015; Tom Withers, "LeBron James Pushes Himself to Total Exhaustion in Win Over

Hawks,” Associated Press, May 25, 2015; Chris Mannix, “Do LeBron, Cavaliers Have Enough Left in the Tank to Survive NBA Finals?,” *Sports Illustrated*, June 12, 2015.

10 “*Negative Acceleration Phase*.”: Jimson Lee, “From the Archives: Maximal Speed and Deceleration,” March 17, 2010, and “Usain Bolt 200 Meter Splits, Speed Reserve and Speed Endurance,” August 21, 2009, SpeedEndurance.com; Rolf Graubner and Eberhard Nixdorf, “Biomechanical Analysis of the Sprint and Hurdles Events at the 2009 IAAF World Championships in Athletics,” *New Studies in Athletics* 1, no. 2 (2011).

10 *Bolt’s 9.58-second world-record race*: Bolt’s late-race surges can be partly explained by the fact that he reaches a higher top speed, which means that even if his *relative* deceleration in the final 20 meters is the same as everyone else’s, he’ll continue to pull away. But expert consensus is that he’s also uniquely good at late-race “speed maintenance.”

11 *Even in repeated all-out weightlifting efforts*: I. Halperin et al., “Pacing Strategies During Repeated Maximal Voluntary Contractions,” *European Journal of Applied Physiology* 114, no. 7 (2014).

13 *the prospects of a sub-two-hour marathon*: For the analogy to the four-minute mile, see Claire Dorotik-Nana, “The Four Minute Mile, the Two Hour Marathon, and the Danger of Glass Ceilings,” PsychCentral.com, May 5, 2017. For skeptical takes, see Robert Johnson, “The Myth of the Sub-2-Hour Marathon,” LetsRun.com, May 6, 2013; and Ross Tucker, “The 2-Hour Marathon and the 4-Min Mile,” *Science of Sport*, December 16, 2014.

13 *Spanish star José Luis González became the three hundredth man*: According to the list maintained by the National Union of Track Statisticians, <https://nuts.org.uk/sub-4/sub4-dat.htm>.

14 *TV coverage of the 1996 Trials is on YouTube*: <https://www.youtube.com/watch?v=8dSLUVmK1Ik> (but please don’t watch it; it wasn’t my finest hour).

14 “*It should be mathematical*.”: Michael Heald, “It Should Be Mathematical,” *Propeller*, Summer 2012.

#### CHAPTER 2: THE HUMAN MACHINE

17 *After fifty-six days of hard skiing*: Details of Worsley’s 2009 expedition and Shackleton’s 1909 expedition are from Worsley’s 2011 book, *In Shackleton’s Footsteps*, unless otherwise noted.

17 *just 112 miles from the South Pole*: the figure is often reported as “97 miles” because Shackleton (and Worsley) reported their distances in nautical miles, which are about 15 percent longer than the more familiar statute miles. All mile distances in this book are statute unless otherwise noted.

18 “*The decision to turn back*.”: From an archived interview broadcast on BBC *Newsnight* on January 26, 2016: <https://www.youtube.com/watch?v=O3SMkxA08T8>.

18 *between 6,000 and 10,000 calories per day*: Timothy Noakes, “The Limits of Endurance Exercise,” *Basic Research in Cardiology* 101 (2006): 408–17. See also Noakes in *Hypoxia and the Circulation*, ed. R. C. Roach et al. (New York: Springer, 2007).

19 *an account of their research on lactic acid*: W. M. Fletcher and F. G. Hopkins, “Lactic Acid in Amphibian Muscle,” *Journal of Physiology* 35, no. 4 (1907).

19 *what’s found inside the body is actually lactate*: L. B. Gladden, “Lactate Me-

tabolism: A New Paradigm for the Third Millennium,” *Journal of Physiology* 558, no. 1 (2004).

19 *Berzelius noticed that the muscles of hunted stags*: This anecdote shows up in many modern textbooks (e.g., *The History of Exercise Physiology*, ed. Charles M. Tipton, 2014) but proved unexpectedly hard to trace. Berzelius first published the observation of lactic acid extracted from the muscles of slaughtered animals in 1808 (in his Swedish book *Föreläsningar i Djurkemien*, p. 176), but many chemists didn’t believe it. When the German chemist Justus von Liebig tried to claim credit for the discovery in 1846, Berzelius wrote an indignant response pegging the year of his own observation as 1807 (*Jahresbericht über die Fortschritte der Chemie und Mineralogie*, 1848, p. 586). But Berzelius himself never published the claim that the amount of lactic acid depended on the severity of pre-death exercise. Instead, this observation, attributed to Berzelius, first appears in the 1842 textbook *Lehrbuch der physiologischen Chemie*, by Carl Lehmann, on p. 285. In 1859, the physiologist Emil du Bois-Reymond wrote to Lehmann asking for the source of this statement; Lehmann replied that he had received a personal letter from Berzelius himself reporting that the muscles of hunted animals contained more lactic acid than normal, while animals whose legs were immobilized in splints before death had less lactic acid (reported in *Journal für praktische Chemie*, 1859, p. 240; reprinted in the 1877 book *Gesammelte Abhandlungen zur allgemeinen Muskel- und Nervenphysik* with a footnote describing the exchange of letters on p. 32.).

19 *chemists were still almost a century away*: An oft-cited benchmark in the understanding of acids is Svante Arrhenius’s definition, an extension of work that earned him the 1903 Nobel Prize in Chemistry.

19 *Berzelius himself subscribed to the idea of a “vital force”*: Berzelius’s views on vitalism were actually quite nuanced and evolved over time, as discussed in Bent Søren Jørgensen, “More on Berzelius and the Vital Force,” *Journal of Chemical Education* 42, no. 7 (1965).

20 *German scientists collected their own urine*: Dorothy Needham, *Machina Carnis* (Cambridge: Cambridge University Press, 1972).

20 *measure lactate in real time*: Linda Geddes, “Wearable Sweat Sensor Paves Way for Real-Time Analysis of Body Chemistry,” *Nature*, January 27, 2016. It’s not yet clear, though, how closely lactate levels in sweat correspond to what’s happening in your bloodstream or muscles.

20 *first to complete the 320-meter circuit*: Christopher Thorne, “Trinity Great Court Run: The Facts,” *Track Stats* 27, no. 3 (1989). There are different schools of thought on the “correct” route around the courtyard, so Fletcher’s corner-cutting shouldn’t be taken as a mark against his character.

21 *the importance of oxygen was confirmed*: Leonard Hill, “Oxygen And Muscular Exercise as a Form of Treatment,” *British Medical Journal* 2, no. 2492 (1908).

22 *He ultimately made twenty-two attempts*: “Jabez Wolffe Dead: English Swimmer, 66,” *New York Times*, October 23, 1943.

22 “[E]very living being has from its birth a limit”: T. S. Clouston, “Female Education from a Medical Point of View,” *Popular Science Monthly*, December 1883, p. 215, cited by John Hoberman in *Athletic Enhancement, Human Nature, and Ethics* (New York: Springer, 2013), p. 263.

22 *he hated his name*: William Van der Kloot, “Mirrors and Smoke: A. V. Hill, His Brigands, and the Science of Anti-Aircraft Gunnery in World War I,” *Notes & Records of the Royal Society* 65 (2011): 393–410.

23 *In 1923, Hill*: A. V. Hill and Hartley Lupton, “Muscular Exercise, Lactic Acid, and the Supply and Utilization of Oxygen,” *Quarterly Journal of Medicine* 16, no. 62 (1923). Details in subsequent paragraphs are also from this paper unless otherwise noted.

23 *“it may well have been my struggles and failures”*: A. V. Hill, *Muscular Activity* (Baltimore: Williams & Wilkins, 1925).

23 *an eighty-five-meter grass loop in Hill’s garden*: In Hill’s 1923 QMJ paper, he describes the experiments taking place “around a circular grass track 92½ yds. (84½ metres) in circumference.” Hugh Long, a coauthor and experimental subject in Hill’s Manchester studies, recalls “running up and down stairs, or round the professor’s garden while at intervals healthy samples of blood were withdrawn from my arms”; quoted in “Archibald Vivian Hill. 26 September 1886–3 June 1977,” *Biographical Memoirs of Fellows of the Royal Society* 24 (1978): 71–149.

23 *“reaches a maximum beyond which no effort can drive it”*: Hill, *Muscular Activity*, p. 98.

24 *an analysis of world records*: A. V. Hill, “The Physiological Basis of Athletic Records,” *Nature*, October 10, 1925. For Hill’s ideas on muscle viscosity, see *Muscular Movement in Man* (New York: McGraw-Hill, 1927). For details of the hacksaw blade timing system, see Hill’s article “Are Athletes Machines?,” *Scientific American*, August 1927.

26 *He rode a Harley, taught needlepoint to prison inmates*: Stefano Hatfield, “This Is the Side of Antarctic Explorer Henry Worsley That the Media Shies Away From,” *Independent*, January 31, 2016.

27 *“As you probably are the first to reach this area”*: Edward Evans, *South with Scott* (London: Collins, 1921).

27 *a botched “scientific” calculation*: Lewis Halsey and Mike Stroud, “Could Scott Have Survived with Today’s Physiological Knowledge?,” *Current Biology* 21, no. 12 (2011).

28 *On November 13, he set off on skis*: Details of Henry Worsley’s Shackleton solo trip are from the daily audio dispatches he posted at <https://soundcloud.com/shackletonsolo> (the last five days have been removed). Further background details about his trip are at [shackletonsolo.org](http://shackletonsolo.org).

29 *“we don’t do it because it is useful . . .”*: Hill, *Muscular Movement in Man*.

29 *funded by Britain’s Industrial Fatigue Research Board*: See author notes in A. V. Hill, C.N.H. Long, and H. Lupton, “Muscular Exercise, Lactic Acid, and the Supply and Utilization of Oxygen,” *Proceedings of the Royal Society B* 96 (1924): 438–75.

29 *established in 1927*: Charles Tipton, ed., *History of Exercise Physiology* (Champaign, IL: Human Kinetics, 2014).

29 *Citing Hill’s research as his inspiration*: David Bassett Jr., “Scientific Contributions of A. V. Hill: Exercise Physiology Pioneer,” *Journal of Applied Physiology* 93, no. 5 (2002).

30 *blood sugar levels in Harvard football players*: Alison Wrynn, “The Athlete in the Making: The Scientific Study of American Athletic Performance, 1920–1932,” *Sport in History* 30, no. 1 (2010).

30 *“New Records in Human Power”*: S. Robinson et al., “New Records in Human Power,” *Science* 85, no. 2208 (1937).

30 *As MIT historian Robin Scheffler recounts:* “The Power of Exercise and the Exercise of Power: The Harvard Fatigue Laboratory, Distance Running, and the Disappearance of Work, 1919–1947,” *Journal of the History of Biology* 48 (2015): 391–423.

30 *thirteen workers died of heat exhaustion:* A. D. Hopkins, “Hoover Dam: The Legend Builders,” *Nevada*, May/June 1985; Andrew Dunbar and Dennis McBride, *Building Hoover Dam: An Oral History of the Great Depression* (Las Vegas: University of Nevada Press, 2001).

31 *The most notorious of these wartime studies:* Todd Tucker, *The Great Starvation Experiment* (Minneapolis: University of Minnesota Press, 2006).

32 *“there is good reason for not trusting the subject’s . . .”:* Henry Longstreet Taylor et al., “Maximal Oxygen Intake as an Objective Measure of Cardio-Respiratory Performance,” *Journal of Applied Physiology* 8, no. 1 (1955).

32 *“men must have certain minimum physiological requirements”:* W. P. Leary and C. H. Wyndham, “The Capacity for Maximum Physical Effort of Caucasian and Bantu Athletes of International Class,” *South African Medical Journal* 39, no. 29 (1965).

32 *“. . . more in athletics than sheer chemistry,”:* Hill, *Muscular Movement in Man*.

32 *“those qualities of resolution . . .”:* A. V. Hill, C.N.H. Long, and H. Lupton, “Muscular Exercise, Lactic Acid, and the Supply and Utilization of Oxygen—Parts IV–VI,” *Proceedings of the Royal Society B* 97 (1924): 84–138.

33 *on the verge of dropping out:* From interviews with Michael Joyner; see also Ed Caesar, *Two Hours* (New York: Penguin, 2015).

35 *what pushed him over the edge:* Worsley’s widow, Joanna Worsley, has suggested that a burst ulcer triggered the infection that killed him: Tom Rowley, “Explorer Henry Worsley’s Widow Plans Antarctic Voyage to Say a ‘Final Goodbye,’” *Telegraph*, January 7, 2017.

36 *“did Worsley not realize . . .”:* Jill Homer, “Henry Worsley and the Psychology of Endurance in Life or Death Situations,” *Guardian*, January 26, 2016.

36 *“The machinery of the body . . .”:* Hill, *Muscular Movement in Man*.

36 *“I said, now hold on . . .”:* Quotes are from my visit to Noakes’s lab in Cape Town in 2010.

#### CHAPTER 3: THE CENTRAL GOVERNOR

37 *Diane Van Deren needed to cover 36 miles:* The Mountains-to-Sea Trail run is recounted in Mackenzie Lobby Havey, “Running from the Seizures,” *Atlantic*, December 12, 2014; and Chris Gragtmans, “Diane Van Deren’s Record-Setting MST Run,” *Blue Ridge Outdoors*. Her background story is told in Bill Donahue, “Fixing Diane’s Brain,” *Runner’s World*, February 2011; John Branch, “Brain Surgery Frees Runner, but Raises Barriers,” *New York Times*, July 8, 2009; Hoda Kotb, *Ten Years Later* (New York: Simon & Schuster, 2013).

39 *Noakes started out as a collegiate rower:* most biographical details are from my interviews with him, with additional information from his 2012 memoir (with Michael Vlismas), *Challenging Beliefs*.

39 *gathering of sports scientists before the 1976 New York Marathon:* “The Marathon: Physiological, Medical, Epidemiological, and Psychological Studies,” whose proceedings were published in volume 301 of the *Annals of the New York Academy of Sciences* in 1977.

39 *the case of Elanor Sadler*: Noakes's initial report, "Comrades Makes Medical History—Again," appeared in *SA Runner* in September 1981. The case first appeared in a scientific journal in 1985: T. D. Noakes et al., "Water Intoxication: A Possible Complication During Endurance Exercise," *Medicine & Science in Sports & Exercise* 17, no. 3 (1985).

40 *a handful of deaths*: An exact count of deaths due to hyponatremia during endurance exercise is hard to pin down, but one 2007 study tallied eight confirmed and four suspected cases: Mitchell Rosner and Justin Kirven, "Exercise-Associated Hyponatremia," *Clinical Journal of the American Society of Nephrology* 2, no. 1 (2007).

40 *the limits might reside in the contractility*: T. D. Noakes, "Implications of Exercise Testing for Prediction of Athletic Performance: A Contemporary Perspective," *Medicine & Science in Sports & Exercise* 20, no. 4 (1988).

40 *Lore of Running, a 944-page doorstopper*: The book has gone through many editions. The fourth edition, published in 2002, has 944 pages.

40 *the J. B. Wolfe Memorial Lecture*: "Challenging Beliefs: Ex Africa Semper Aliquid Novi," *Medicine & Science in Sports & Exercise* 29, no. 5 (1997).

41 *Gage was "no longer Gage."*: "Recovery from the Passage of an Iron Bar through the Head," *Publications of the Massachusetts Medical Society* 2, no. 3 (1868).

42 *"You must have just come through those tornadoes back there,"*: Quoted in Havey, "Running from the Seizures."

42 *"is the hardest thing I have ever done."*: Quoted in "900+ Miles Later, Diane Van Deren Reaches Jockey's Ridge," [greatoutdoorprovision.com](http://greatoutdoorprovision.com), 2012.

43 *"Well, shit—I don't feel pain?"*: Quoted in Kotb, *Ten Years Later*.

43 *"I could be out running for two weeks,"*: Quoted in Andrea Minarcek, "Going the Distance," *National Geographic*, December 2009/January 2010.

43 *largest, oldest, and most prestigious ultra-race*: First run in 1921, Comrades earned a place in the Guinness record books in 2010 with 16,480 starters and 14,343 finishers within the twelve-hour time limit. In 2000, prior to Guinness certification, more than 20,000 people finished, according to the official results at [www.comrades.com](http://www.comrades.com).

45 *in a 1998 paper he coined the term "central governor,"*: In "Maximal Oxygen Uptake: 'Classical' versus 'Contemporary' Viewpoints: A Rebuttal," *Medicine & Science in Sports & Exercise* 30, no. 9 (1998), Noakes writes: "a new physiological model is proposed in which skeletal muscle recruitment is regulated by a central 'governor' specifically to prevent the development of a progressive myocardial ischemia that would precede the development of skeletal muscle anaerobiosis during maximum exercise."

45 *Alan St. Clair Gibson*: See, for example, T. D. Noakes, A. St. Clair Gibson, and E. V. Lambert, "From Catastrophe to Complexity: A Novel Model of Integrative Central Neural Regulation of Effort and Fatigue During Exercise in Humans," *British Journal of Sports Medicine* 38, no. 4 (2004).

45 *Frank Marino*: See, for example, "Anticipatory Regulation and Avoidance of Catastrophe During Exercise-Induced Hyperthermia," *Comparative Biochemistry and Physiology—Part B* 139, no. 4 (2004).

46 *a critical threshold of about 104 degrees Fahrenheit*: B. Nielsen et al., "Human Circulatory and Thermoregulatory Adaptations with Heat Acclimation and Exercise in a Hot, Dry Environment," *Journal of Physiology* 460 (1993): 467–85; J. González-Alonso et al., "Influence of Body Temperature on the Development of Fatigue During Prolonged Exercise in the Heat," *Journal of Applied Physiology* 86, no. 3 (1999).

46 *cyclists started at a slower pace*: R. Tucker et al., “Impaired Exercise Performance in the Heat Is Associated with an Anticipatory Reduction in Skeletal Muscle Recruitment,” *Pflügers Archiv* 448, no. 4 (2004).

46 *puzzlingly low lactate levels*: T. D. Noakes, “Evidence That Reduced Skeletal Muscle Recruitment Explains the Lactate Paradox During Exercise at High Altitude,” *Journal of Applied Physiology* 106 (2009): 737–38.

46 *swish a carbohydrate drink*: J. M. Carter et al., “The Effect of Carbohydrate Mouth Rinse on 1-h Cycle Time Trial Performance,” *Medicine & Science in Sports & Exercise* 36, no. 12 (2004).

46 *supposedly crippling levels of dehydration*: Lukas Beis et al., “Drinking Behaviors of Elite Male Runners During Marathon Competition,” *Clinical Journal of Sports Medicine* 22, no. 3.

46 *brain-altering drugs like Tylenol*: A. R. Mauger et al., “Influence of Acetaminophen on Performance During Time Trial Cycling,” *Journal of Applied Physiology* 108, no. 1 (2010).

48 *pacing patterns of almost every world record*: R. Tucker et al., “An Analysis of Pacing Strategies During Men’s World-Record Performances in Track Athletics,” *International Journal of Sports Physiology and Performance* 1, no. 3 (2006).

49 *“If they caught you breaching, . . .”*: This and other details from Micklewright’s talk at the Endurance Research Conference at the University of Kent in September 2015.

49 *Micklewright had more than a hundred schoolchildren*: D. Micklewright et al., “Pacing Strategy in Schoolchildren Differs with Age and Cognitive Development,” *Medicine & Science in Sports & Exercise* 44, no. 2 (2012).

50 *finish times of more than nine million marathoners*: Eric Allen et al., “Reference-Dependent Preferences: Evidence from Marathon Runners,” *Management Science* 63, no. 6 (2016).

51 *“produced a brainless model of human exercise performance.”*: T. D. Noakes, “Testing for Maximum Oxygen Consumption Has Produced a Brainless Model of Human Exercise Performance,” *British Journal of Sports Medicine* 42, no. 7 (2008).

51 *“In the parlance of my North American colleagues.”*: Roy Shephard, “The Author’s Reply,” *Sports Medicine* 40, no. 1 (2010).

52 *a disciplinary hearing*: Bill Gifford, “The Silencing of a Low-Carb Rebel,” *Outside*, December 8, 2016.

52 *video of a Rube Goldberg-esque contraption*: <https://www.youtube.com/watch?v=L8SghDfyo-8>; E. B. Fontes et al., “Brain Activity and Perceived Exertion During Cycling Exercise: An fMRI Study,” *British Journal of Sports Medicine* 49, no. 8 (2015).

52 *Other researchers have tried electroencephalography*: L. Hilty et al., “Fatigue-Induced Increase in Intracortical Communication Between Mid/Anterior Insular and Motor Cortex During Cycling Exercise,” *European Journal of Neuroscience* 34, no. 12 (2011).

#### CHAPTER 4: THE CONSCIOUS QUITTER

55 *Marcora’s thirteen-thousand-mile motorcycle ride*: To hear Marcora himself spinning tales from this trip, check out his podcast appearance on the Adventure Rider Radio Motorcycle Podcast from May 15, 2015, <https://adventureriderpodcast.libsyn.com/>.

57 *I drove 120 miles through Australia’s Blue Mountains*: I wrote about this trip

and my subsequent experience with Marcora's brain endurance training in the October 2013 issue of *Runner's World*.

57 *among the New York Times—reading public*: Nicholas Bakalar, "Behavior: Mental Fatigue Can Lead to Physical Kind," *New York Times*, March 9, 2009. The study was S. M. Marcora et al., "Mental Fatigue Impairs Physical Performance in Humans," *Journal of Applied Physiology* 106, no. 3 (2009).

58 "... the single best indicator of the degree of physical strain," Gunnar Borg, "Psychophysical Bases of Perceived Exertion," *Medicine & Science in Sports & Exercise* 14, no. 5 (1982).

60 *a 1986 experiment by French researcher Michel Cabanac*: "Money Versus Pain: Experimental Study of a Conflict in Humans," *Journal of the Experimental Analysis of Behavior* 46, no. 1 (1986).

60 *a similar mind-over-muscle demonstration*: S. M. Marcora and W. Staiano, "The Limits to Exercise Tolerance in Humans: Mind over Muscle?," *European Journal of Applied Physiology* 109, no. 4 (2010).

61 *a bewilderingly complex slide taken from a recent paper*: Chris Abbiss and Paul Laursen, "Models to Explain Fatigue During Prolonged Cycling," *Sports Medicine* 35, no. 10 (2005).

62 *Angelo Mosso conducted a series of experiments*: A 1904 translation of *La Fatica* is available at <https://archive.org/details/fatigue01drumgoog>. For further context, see Camillo Di Giulio et al., "Angelo Mosso and Muscular Fatigue: 116 years After the First Congress of Physiologists: IUPS Commemoration," *Advances in Physiology Education* 30, no. 2 (2006).

63 *Mosso's insights were mostly forgotten*: Tim Noakes argues that Mosso's ideas were supplanted by those of A. V. Hill: "Fatigue Is a Brain-Derived Emotion That Regulates the Exercise Behavior to Ensure the Protection of Whole Body Homeostasis," *Frontiers in Physiology*, April 11, 2012.

63 *The torch passed instead to psychologists*: Nick Joyce and David Baker, "The Early Days of Sports Psychology," *Monitor on Psychology*, July/August 2008.

63 *An 1898 study by Indiana University psychologist Norman Triplett*: "The Dynamogenic Factors in Pacemaking and Competition," *American Journal of Psychology* 9, no. 4 (1898).

64 *a famous 1988 experiment*: Fritz Strack et al., "Inhibiting and Facilitating Conditions of the Human Smile: A Nonobtrusive Test of the Facial Feedback Hypothesis," *Journal of Personality and Social Psychology* 54, no. 5 (1988).

64 *record the activity of facial muscles*: H. M. de Morree and S. M. Marcora, "The Face of Effort: Frowning Muscle Activity Reflects Effort During a Physical Task," *Biological Psychology* 85, no. 3 (2010), and "Frowning Muscle Activity and Perception of Effort During Constant-Workload Cycling," *European Journal of Applied Psychology* 112, no. 5 (2012).

64 *subsequent study by Taiwanese researchers*: D. H. Huang et al., "Frowning and Jaw Clenching Muscle Activity Reflects the Perception of Effort During Incremental Workload Cycling," *Journal of Sports Science and Medicine* 13, no. 4 (2014).

64 *legendary sprint coach Bud Winter*: Tex Maule, "It's Agony, Upsets and Hopes," *Sports Illustrated*, June 15, 1959.



65 *cyclists who were shown sad faces rode*: A. Blanchfield et al., “Non-Conscious Visual Cues Related to Affect and Action Alter Perception of Effort and Endurance Performance,” *Frontiers in Human Neuroscience*, December 11, 2014.

66 *tested a simple self-talk intervention*: A. Blanchfield et al., “Talking Yourself Out of Exhaustion: The Effects of Self-Talk on Endurance Performance,” *Medicine & Science in Sports & Exercise* 46, no. 5 (2014).

67 *caffeine pills*: F. C. Wardenaar et al., “Nutritional Supplement Use by Dutch Elite and Sub-Elite Athletes: Does Receiving Dietary Counseling Make a Difference?,” *International Journal of Sport Nutrition and Exercise Metabolism* 2, no. 1 (2017).

68 *his famous “marshmallow test”*: Walter Mischel et al., “Delay of Gratification in Children,” *Science* 244, no. 4907 (1989); also B. J. Casey et al., “Behavioral and Neural Correlates of Delay of Gratification 40 Years Later,” *PNAS* 108, no. 36 (2011).

69 *tax their subjects’ response inhibition*: B. Pageaux et al., “Response Inhibition Impairs Subsequent Self-Paced Endurance Performance,” *European Journal of Applied Physiology* 114, no. 5 (2014).

70 *professionals were significantly better at the Stroop task*: K. Martin et al., “Superior Inhibitory Control and Resistance to Mental Fatigue in Professional Road Cyclists,” *PLoS One* 11, no. 7 (2016).

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73 *ushered through security into the Nike Sport Research Lab*: My full account of the build-up to Nike’s Breaking2 race, “Moonshot,” was published in the June 2017 issue of *Runner’s World*. Further commentary and reporting is collected at [www.runnersworld.com/2-hour-marathon](http://www.runnersworld.com/2-hour-marathon).

74 *tests secretly conducted at the University of Colorado*: The study was performed in Rodger Kram’s group: Wouter Hoogkamer et al., “New Running Shoe Reduces the Energetic Cost of Running,” presented at the American College of Sports Medicine annual meeting in Denver, May 31, 2017.

75 *100 seconds over the course of a two-hour marathon*: C. T. Davies, “Effects of Wind Assistance and Resistance on the Forward Motion of a Runner,” *Journal of Applied Physiology* 48, no. 4 (1980).

76 *running directly behind another runner can eliminate*: L.G.C.E. Pugh, “The Influence of Wind Resistance in Running and Walking and the Mechanical Efficiency of Work Against Horizontal or Vertical Forces,” *Journal of Physiology* 213 (1971): 255–76.

77 *Shalane Flanagan, the second-fastest women’s marathoner*: David Epstein noted Flanagan and Hall’s early exposure to high altitude in *The Sports Gene* (New York: Current, 2013).

78 *aid tables every five kilometers*: the IAAF Road Running Manual ([www.iaaf.org](http://www.iaaf.org)) says “water shall be available at suitable intervals of approximately 5km.”

CHAPTER 5: PAIN

83 *the very first stage of the 2014 Tour de France*: Kenny Pryde, “Marcel Kittel Wins Opening Stage of Tour de France,” *Cycling Weekly*, July 5, 2014; Mike Fogarty, “Now I Am Officially the Biggest Climber in the Tour de France”—Jens Voigt,” [firstendurance.com](http://firstendurance.com), July 6, 2014.

83 *coined when a Danish television reporter*: “The Origin of ‘Shut Up, Legs!’” *Bicycling*, <http://www.bicycling.com/video/origin-shut-legs>.

84 “. . . pain as a state of mind to be combated . . .”: “Jens Voigt: The Man Behind the Hour Attempt,” *Cycling Weekly*, September 17, 2014.

84 *Freund published a telling study*: Wolfgang Freund et al., “Ultra-Marathon Runners Are Different: Investigations into Pain Tolerance and Personality Traits of Participants of the TransEurope FootRace 2009,” *Pain Practice* 13, no. 7 (2013).

85 “*The beauty of it lies in its simplicity*,”: from Jens Voigt, *Shut Up, Legs!* (London: Ebury Press, 2016).

85 *The first official Hour record*: Michael Hutchinson, “Hour Record: The Tangled History of an Iconic Feat,” *Cycling Weekly*, April 15, 2015. See also Michael Hutchinson, *The Hour* (London: Yellow Jersey, 2006), which recounts his own crack at the record.

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