IOP Concise Physics

Science in the Arena

Explanations and analyses of performances and phenomena in sport

Blane Baker

Chapter 10

Special topics

Novel questions arise every day in sport, often as a result of technological advances and emergence of new generations of extraordinary athletes. Many of the questions that stimulate our curiosity require scientific approaches to find suitable answers. Using the principles and habits of mind developed thus far give us the framework for answering contemporary scientific questions in the wide world of sport.

Need for speed

Our fascination with fast motions probably dates to prehistoric eras when sprinting and launching various weapons with great speed and accuracy were necessary for survival. Moreover, since ancient times, we have celebrated the ability of athletes to run quickly by declaring winners of particular races as 'the fastest runners in the world.'

Given our natural curiosity and awe of great sprinters, we, as observers, might ask: what makes them unique? In order to pursue this question, a quick glance back at the concept of speed is useful. Average speed is defined as the ratio of the distance covered to the time interval, required to travel that distance. In a particular competition, a sprinter who runs a given distance in the least amount of time wins the race—and generates the greatest average speed. With a view toward generating maximum speed, we will address what physical attributes make certain athletes extraordinarily fast.

One of the first studies to examine how human speed depends on the anatomy of an athlete was conducted in the 1970s by Hoffmann and co-workers [1]. Their work examined the stride lengths of 56 male athletes and 23 female athletes and revealed a linear correlation between average stride length L and a sprinter's height H. Linear relations take the form $y = mx$, so that $L = cH$, where c represents a constant of proportionality. In addition to showing this linear correlation, Hoffmann's studies found constants of proportionality of 1.14 for female sprinters and 1.13 for male sprinters. Recent analyses of modern, elite sprinters by the present author also have

doi:10.1088/2053-2571/aadd43ch10

found linear correlations between L and H—but with slightly higher proportionality constants [2].

To extend the results of Hoffmann and to show the unique abilities of elite sprinters, two basic quantities are required—average stride length and average stride frequency. Average stride length refers to the average length of a stride during a race and is found by dividing the race distance by the number of strides taken during the race. Average stride frequency refers to the average number of strides taken per time interval and is found by dividing the number of strides taken during a race by the race time. Clearly, both quantities depend upon the number of strides taken, so the two are not independent of one another; nevertheless, their product is equivalent to the average speed. In order to develop significant speed, an elite sprinter must have both a sufficiently long stride, together with sufficiently rapid 'turnover' of the legs.

To examine numerical values of these quantities, a complete analysis of Usain Bolt's stride characteristics is undertaken, using data from his world record performance during the 2008 Olympics in Beijing. In these games, Bolt, whose standing height is 1.96 m, sprinted to victory in the 100 m dash in a time of 9.69 s while taking 41 strides to complete the race. With these numbers in hand, average stride length, average stride frequency, and the proportionality constant relating average stride length and standing height can be calculated quite readily.

Average stride length L is determined by dividing distance covered by the total number of strides, so in Bolt's case average stride length is 2.44 m (100 m/41 strides). Average stride frequency is found by dividing the number of strides by the race time; average stride frequency for Bolt is 4.23 strides per second (41 strides/9.69 s). Amazingly, Bolt's strides are slightly greater than 2.4 m (7.9 feet) each and occur at rates over 4 (strides) per second.

For completeness, the constant of proportionality relating average stride length and standing height H is found using the relation $L = cH$; c for Bolt is $L/H = 1.24$. For comparison, constants for other elite, modern-day sprinters have been determined to be in the range of 1.24–1.27. Knowing these constants and how they vary over time and from sprinter to sprinter are important for developing training regimens and modeling sprinters' improvement. The relation between L and H, determined for Bolt and other modern-day sprinters, agrees with previous work and confirms what might be expected: a taller sprinter takes longer strides when sprinting along a track.

So what makes an elite sprinter unique? The answer depends on the individual sprinter's physical characteristics and abilities. In Bolt's case, his stride length surpasses those of other elite sprinters by about 10% due to his tall stature (1.96 m or 6 feet, 5 inches). His average stride frequency, however, is somewhat less than other outstanding sprinters but still in the range of elite sprinters. Other sprinters like Maurice Greene who are of shorter stature rely more on stride frequency to generate substantial speeds. Extraordinary sprinters need both sufficiently long stride lengths and sufficiently rapid stride frequencies in order to compete on the world stage—yet no two sprinters are exactly alike.

The irony of Bolt's extraordinary sprinting performances is that his sprinting times could have been reduced even further—not by running any faster but by coming out of the blocks more quickly. In his 2008 Olympic race, for example, his reaction time was 0.165 s, as compared to 0.13 s for the next-worst sprinter. (Reaction time refers to the delay between the sound of the gun and the first motion of the sprinter.) By reducing his reaction time to 0.13 s, he could have decreased his 100 m race time to 9.655 s.

Beyond starting more quickly, Bolt could have reduced his race time by an additional 0.1 s in the 2008 Olympics by continuing to sprint through the finish line rather than reducing his speed while showboating. Finally, in a scenario in which he could take full advantage of maximum tail winds of 2.0 m s^{-1} in a particular race, he would reduce his time by an additional 0.1 s. Under such ideal conditions, his ultimate 100 m time would be lowered to 9.455 s—an achievement thought impossible only 20 years ago. While fascinating to consider, our speculation here is now hindsight in light of Bolt's retirement after the 2016 Olympics in Rio de Janeiro.

Extreme, extreme sports

On June 3, 2017, Alex Honnold reached the apex of pure rock climbing by scaling El Capitan, a nearly 3000 foot granite wall in Yosemite National Park, without the aid of ropes or other safety gear. He completed this historic free solo climb in less than four hours with no spectators present, except for a small team of filmmakers who documented his feat for National Geographic. Honnold had trained for this breathtaking climb for more than a year in venues across the United States, China, Europe, and Morocco. He had attempted the free solo climb the previous November but stopped after less than an hour when conditions were deemed unfavorable. The climbing world responded to Honnold's extraordinary achievement by comparing the free soloing of El Capitan to landing on the Moon. To appreciate his feat, it is worth noting that other climbers who have ascended El Capitan along the same Freerider route as Honnold have received significant acclaim and media coverage. The difference of course is that those climbers used ropes for safety and generally climbed with partners.

Free soloing of a rock face is remarkable both for the physical and mental challenges it presents. From a physical perspective, the ascent requires essentially lifting the body from the base of the rock face to the summit in a series of climbing maneuvers. During these maneuvers the climber performs work, leading to an increase in potential energy PE. For Honnold the potential energy mgh attained is 6.5×10^5 J, where $m = 73$ kg, $g = 9.8$ m s^{-2}, and $h = 914$ m; this PE change is equivalent to 4300 baseballs traveling at 100 mph (44.7 m s^{-1}). Beyond the large energy demand, the climb also requires some extremely difficult feats including balancing on a matchbox-wide ledge and dangling in the air with only a fingertip hold. In preparation for such extreme climbs, Honnold follows a rigorous training regimen, which includes hanging for an hour each day using only a fingertip hold.

As evidence of Honnold's thirst for new challenges, he and climbing partner, Tommy Caldwell, set a new record for speed climbing El Capitan on June 7, 2018. Using ropes the pair scaled the rock face along the Nose in 1 h, 58 min, and 7 s. Even before their latest record-setting climb, the pair had broken the previous record of 2 h and 19 min twice in the preceding two weeks. One of the former record-holders, Brad Gobright, was quoted in Outside Magazine, 'It's the proudest speed climbing ascent to have happened in the history of U.S. rock climbing.' The pair has not said whether or not they will attempt to break their own record, but Honnold has indicated that he thinks the limit of human potential for this climb is in the range of an hour and a half.

References

[1] Hoffman K 1971 Stature, leg length, and stride frequency *Track Technique* **46** 1463–9

[2] Shinabargar A J, Hellrich M and Baker B 2010 What makes Usain Bolt unique as a sprinter? *Phys. Teacher* **48** 365