SAMPLE CHAPTER

PERFECTION POINT

The Fastest Man, the Highest Jump, and the Search for the Limits of Athletic Performance

The host and creator of the Emmy Award-winning show *Sport Science* uses hard data and scientific research to uncover the absolute limits of human performance.

Raw Speed:
How fast can a human run?

Even if you've never seen a track meet or run a local 10K or could care less about sports altogether, give even a moment's thought to the limits of human potential and you have to wonder: How fast is it possible for someone to move over flat ground using nothing but his own two legs?

Running has ceased to be very useful in modern society.

If we want to move rapidly, we have bicycles, skateboards, roller blades, cars, trains and airplanes to do most of the work for us. On those rare occasions when we do need to run on our own two feet, it's usually away from something, like a nasty dog, a rain shower or someone trying to serve a summons, so almost all the running we're familiar with takes place in sports: baseball, football, tennis, basketball, soccer. In all of those, there are advantages to being able to run well, like getting to the ball, basket or goal faster than the other guy. Running is a means to an end.

Running just to run is a different story. As little of it as most of us actually do, running for its own sake still seems to hold a certain fascination, probably because it's an elemental combination of strength and speed that echoes what is likely the oldest form of competition known to humankind: "Hey! Beat you to the corner!" Nobody had to teach your five-year old to shout that to his buddy as they headed home from kindergarten. It's basic, requires no equipment, ends quickly and definitively and the rules are as simple as you can get: We're both *here*; whoever gets *there* first, wins.

Simple head-to-head running contests soon led to bunches of people competing at the same time, and before too long somebody got around to wondering who would win if

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everybody on the planet ran against everybody else. It would be tough to arrange a race like that, but timed races under controlled conditions do a pretty good job of answering the question to everyone's satisfaction. For any given distance — mile, 10K, marathon, whatever — we assume that the current world record holder would win if all 6.7 billion of us toed the start line at the same time.

Which brings us to the question of running's perfection point: What is the fastest possible speed that anyone could ever run?

And how would we find out? There are dozens of different competitive running events, but the most fascinating of all, and the most popular among fans and the general public, is also the simplest and the shortest. It's the 100-meter sprint, and whoever holds the world record gets the most coveted title in sports: *The fastest man on earth.*

It's not just hype, either. It's the literal truth, and it doesn't mean only on the day of the race. The world record holder at this distance is almost certainly the fastest human who ever lived. As of August, 2008, that's Usain Bolt of Jamaica, and if he were to run the 100m in a neighborhood with a 25 mph speed limit, he'd get a speeding ticket.

In 1912, the world record for the 100m sprint was held by Don Lippincott of the United States. His time was 10.6 seconds. It would be 66 years before Jim Hines, another American, managed to do it in under ten seconds. Bolt's current world record is 9.69.

It keeps getting faster, but it can't get faster forever. Once we've optimized the conditions, the equipment and the athlete himself, there can't be any more improvement. Somewhere, there is a limit.

* * *

The athlete standing at the start line of the 100-meter sprint is six feet, two inches tall and weighs 192 pounds, only 4% of it in fat. Most of his height is in his legs; his tailor would measure his inseam at 40 inches.

His calf muscles are 6 inches in cross section at their thickest part and consist of 65% fast-twitch and 35% slow-twitch fibers. The ratio is slightly less (55%/45%) for his quadriceps, the large muscles in his thighs, which are 12 inches wide. Specialized training has built up the power-generating capacity of his hip flexors to just shy of the point where they would damage his tendons.

The athlete's super lightweight shoes are perfectly matched to the track surface, with carbon fiber spikes at the toe and mostly empty space in the heel. The total weight of the shoe is 87 grams. He wears aerodynamic sunglasses, no jewelry and a skintight track suit surfaced with thousands of tiny dimples. His head is shaved bald.

On race day there is a breeze at his back of two meters per second, about 4.4 mph, the maximum allowable under Olympic standards. The track in the hills above the Moroccan city of Marrakesh is at an altitude of 3,276 feet, and the straight stretch used for the 100m sprint faces west; when the race begins at 8:00 a.m. the morning sun will be low in the sky behind him, not in his eyes. The barometric pressure is 29.14 inches of mercury, the humidity is a desert-dry 11% and the temperature is 82 degrees Fahrenheit. Because of his fast times in the semis, he's been assigned to Lane Four for today's final. The other lanes are occupied by runners who look exactly like him and are capable of running the same speed.

Directed to take his place, he kneels and plants his feet against the starting blocks, leans forward and positions his fingertips on the track surface just behind the start line. Then he lets his knees settle on the track and wills himself to stillness. When the starter calls "Ready!" he comes off his knees, raises his hips high in the air and leans forward on his fingertips.

His reaction time to the gun is perfect. The sensors built into the starting blocks detect an increase in pressure exactly a tenth of a second after the gun goes off. Just under 1.4 seconds later he's 10 meters down the track, moving at 9 mph and still hunched over, still accelerating.

At 20 meters, he sees the other runners in his peripheral vision. They're all ahead of him. Concerned, he grits his teeth and concentrates, making sure to maintain his perfect running form even as he slams the pedal to the floor and begins to assume a more upright position. By the time he gets just past the halfway point of the race he's fully upright, covering more than eight feet of ground with every step and traveling at a blistering 27.2 mph. That's the top speed of which he's capable. He isn't going to get any faster, and now that his speed has stabilized, he risks devoting some small portion of his concentration to checking his peripheral vision again.

He's still in last place.

The athlete doesn't panic, doesn't waste precious mental energy trying to make up the deficit between himself and the other runners. He has a plan, he knows his competitors and he knows that they can't get any faster, either. But while he knows all of that, his challenge now is to make himself believe *it. He has to bank on the fact that he can hang on to his high speed for a longer time than the others can hang on to theirs. If he does that, he can win.*

At the 80m mark he's still in last place. But he's closer to the leader now, and gaining on him. Less than eight seconds have elapsed since the start of the race. For the first time he feels a strain in his shoulders as his arms pump madly to counterbalance the shift from one foot to the other and back again, almost give times per second. He also feels himself slowing down, and pours every last ounce of energy he has into his legs, not to regain *higher speed but to minimize the rate at which he's decelerating. At 90m he's neck-and-neck with the frontrunners. They know he's there, and he knows they know, and he also knows that they're every bit as tough, determined and talented as he is.*

At that point his mind pulls completely away from them. The white strip indicating the finish line is the only thing in his line of vision. He has nothing at all left in the tank, but somewhere deep down in his gut he finds a drop of gas he never knew was there and seizes on it, forcing it into his afterburner and feeling it ignite. It works; he's a hair's breadth ahead of the others and can see them react to it. But he does, too. Energized by his lead, his adrenal glands give up their final wisp of epinephrine and wring the last measure of power out of his nearly-spent muscles.

The final stride that carries him to the finish line is his 43rd step of the race. It takes a high-speed camera to determine that he won, by a hundredth of a second. His time of 8.99 seconds makes this the fastest hundred ever run.

It's the fastest that will ever be *run.*

The year is 2909 and we've reached the limit.

* * *

On the face of it, a time of 8.99 seconds is absurd. Nobody familiar with the sport of running would believe that such a time is even remotely feasible, nor is a top speed of 31.15 mph.
It is feasible. We're going to prove it.

* * *

Why does the 100m produce the fastest speed?

Let's say you wanted to find out the fastest you could possibly run over flat ground. To do that, you'd accelerate quickly in order to pour as much energy as possible into gaining velocity and not waste it covering distance. There's not much strategy: Just put the hammer down and give it everything you've got. Somewhere around the 55-meter mark, you're going to hit the top speed of which you're capable. That's what 100m sprinters do. For the remaining 40 or so meters, they just try to slow down as little as possible.

In a 200m or longer race, you'd never hit that top speed. If you did, you'd run out of gas a few seconds later and finish dead last, by an embarrassingly wide margin. So the 100m record holder is rightly considered to be the fastest man on earth because that race mimics exactly what you'd do if your goal was to reach your maximum possible velocity.

Like a presidential candidate winning the popular vote but losing the election because of too few electoral votes, it's possible to win a 100m race even if one of your competitors hits a faster top speed than you. That can happen if you come out of the blocks a little earlier than he did or accelerate more quickly or decelerate less at the end. If that seems odd, consider this: In a 100m race between the world's best human runner and the world's fastest race horse, the human will win easily. Even though the horse will eventually hit a higher top speed, it can't accelerate as quickly, so it doesn't reach its highest speed until the last part of the race and by then it's too late. Add just another 30m, though, and the horse would leave the human in the dust

So in a technical sense, "the fastest man on earth" isn't necessarily the one who hit the highest top speed; it's the one who covered the full 100m distance more quickly. But the two are so closely correlated — the runner who wins is almost always the same as the one who hit the highest top speed — that we're quite safe using the 100m sprint as the gold standard in exploring the perfection point of human foot-powered speed. Whatever top speed is reached in the fastest possible 100m is going to be the top speed reachable, period. What will that speed be? Using purely statistical methods, some scientists have developed models that predict the theoretically fastest possible 100m times. While that might sound like some fairly dubious speculation, three things make those models fairly credible.

The first is that several different researchers who arrived at their conclusions independently of one another are in very close agreement. The generally accepted conclusion is that we'll max out at 9.44 seconds, somewhere between 250 and 500 years from now.

The second thing that makes the models credible is that they've done a very good job of accurately predicting the progressive improvement of actual world record results thus far. Being able to predict things is the hallmark of a good scientific theory, and the more far-out the prediction, the better it makes the theory look if the prediction works. By doing nothing more than sitting in his study, Albert Einstein came up with the Theory of Relativity, which other scientists had a hard time believing. One of the things the theory predicted is that light could be bent by gravity, which nobody believed, either. Fourteen years after the theory was published, a British scientist named Arthur Eddington took advantage of a full eclipse to see what would happen to light from a star as it passed close to the sun on its way to earth. Not only did the powerful gravity of the sun bend the light, it did it by the precise amount Einstein had predicted.

Eddington sent a famous telegram to the Royal Astronomical Society that read "Relativity is right!" and Einstein became an instant celebrity.

The third reason we have for trusting the statistical models is perhaps the most compelling of all. We know the exact 10m split times for pretty much every major race since the advent of electronic timing. For those not officially published, we can figure it out as long as the race was captured on tape or film. Since we know the exact number of frames per second of the camera, it's a simple matter to count how many frames it took to shoot each 10m segment. Once we do that, we can select the fastest splits ever run for each of those segments. For example, the fastest that the first ten meters has ever been covered, including reaction time, was 1.69 seconds by Raymond Stewart at the 1991 World Cup in Tokyo. Bruny Surin's time of one second flat for meter 10-20 at Sevilla in 1999 is the fastest ever for that segment. The best time for the third 10m segment is Maurice Greene's 0.89 seconds at Stockholm the same year.
If we do that for all ten segments of the 100m sprint and add them up? It comes to 9.44 seconds, the exact time predicted by the statistical models as the fastest time possible.

Obviously, that doesn't mean that anyone today is capable of running that time. The splits include those of runners who were monsters off the block but didn't have high top speed, others who reached high speed but took too long to get there, and others who got going pretty good but faded quickly. All of those skew the results by giving us phenomenal splits that no single sprinter could put together in one race. It would be like trying to calculate the fastest possible marathon by adding up the best ever one-mile splits, including a 3:50 by some professional miler who wanted to be able to say he had the lead for a few minutes and then took another five hours to finish the remaining 25.2 miles.

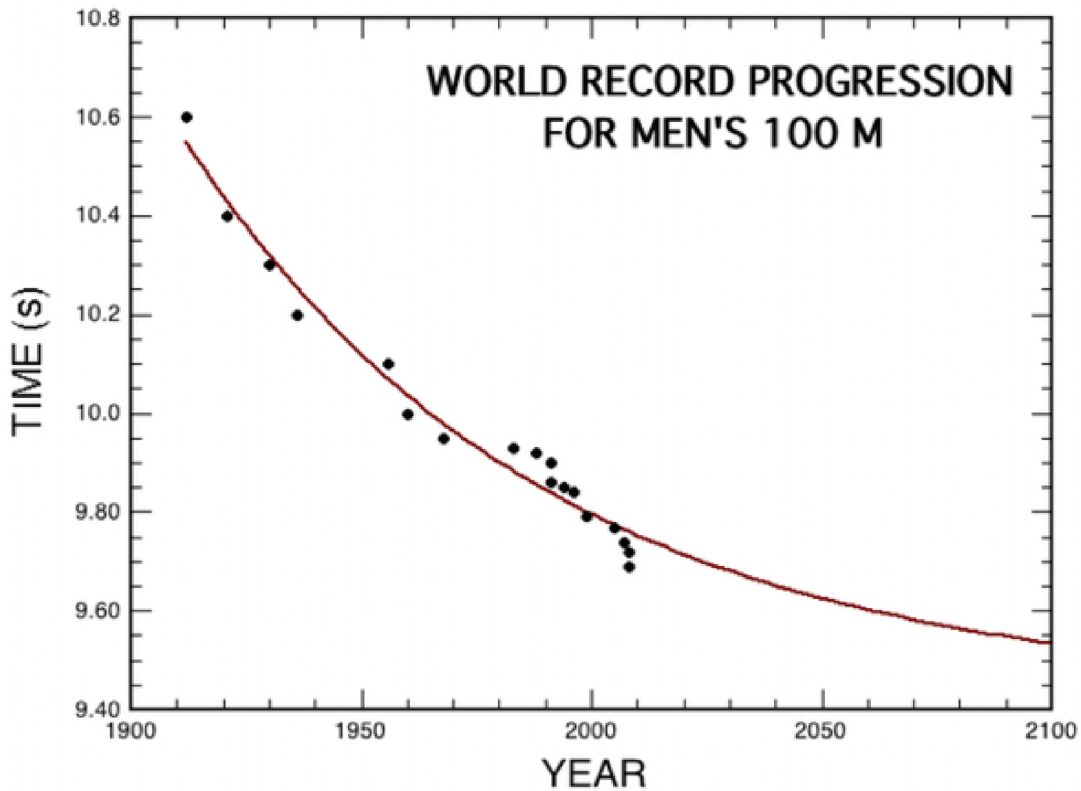
But the 100m numbers are different. Each of the athletes who ran those splits was a serious competitor on the world stage who was trying to win, not a showoff like the annoying marathon "rabbits" who purposely burn themselves out staying out front for the first few miles so they can get on television. So while adding up the ten fastest splits doesn't give us a plausible estimate of what's achievable today, it does provide a good reasonableness check of the prediction models for what's possible.

Add that to the other two pieces of evidence that strongly confirm the predictive accuracy of the models and you have an impeccably logical, utterly scientific and thoroughly validated estimate of 9.44 seconds for the ultimate 100m sprint.

There's just one problem. And it has a name: Usain "Lightning" Bolt.

The Jamaican running phenom must not have gotten the memo about what the researchers predicted because his string of 100m sprints in 2008 not only trashed the world record, they trashed the prediction models, too. According to nearly all of them, we shouldn't have seen his Beijing Olympics time of 9.69 seconds until the year 2030.

Here's a graphic look at how badly Bolt shifted what started out as a nice, neat statistical curve. The two lowest dots below the curve in years 2007-8 are his:



I asked University of Pennsylvania mathematician Reza Noubary, author of a textbook on sports statistics, what Bolt's Beijing performance did to the theoretical lower limit. Noubary is the researcher who came up with an "ultimate record" of 9.44 seconds.

"With this new data," he said with a deadpan expression, "the predicted fastest 100-meter time would probably go down a little bit."

No kidding. Or, maybe the models are just plain wrong. Back in 2000 Jonas Mureika, a physicist at Loyola Marymount University in Los Angeles, approached the problem in a completely different way. He developed a statistical model using techniques drawn from seismology and accurately predicted a Bolt-like time by 2009. But nobody knew about his results because he decided not to publish his conclusions. Why?

Because he didn't believe them. "The record then was about 9.79," Mureika told me, "and my model predicted these crazy times, that by 2009 the record would be down in the high 9.6s. I thought that was crazy. It's not going to progress that fast."

After Beijing, he must have felt like Einstein did when the legendary theoretician stumbled onto the fact that the universe was expanding but didn't believe his own numbers. When it turned out that he was right, Einstein called it the biggest mistake of his career. "Every day that I think about that," Mureika laments in similar fashion, "I kick myself. That's my penitence for doubting the numbers."

Despite the success of Mureika's model, we have to remind ourselves that it's a purely numerical analysis and, as Mark Twain once put it, "There are lies, damned lies and statistics." Mathematical models have to be tempered with physical reality. Otherwise, you can end up with technically true but nevertheless dubious conclusions. On average, everyone in the world has one breast and one testicle, but that's not an especially useful piece of information.

Peter Weyand, a physiologist at Southern Methodist University in Dallas who is an expert on the biomechanics of running, believes that mathematical models such as Mureika's can't really predict how fast humans might eventually run.

"Predictions like that are fun," he told me, "but it's not a scientifically valid approach, because they assume that everything that has happened in the past will continue in the future." That doesn't work in the stock market and it doesn't work in sports, either. "Mathematical models can't predict what's going to happen at the extreme edges of athletic performance," Weyand observed, "the freaky phenoms that surprise us all."

Weyand is right. The statistical approach isn't going to work for us. We need a more direct method of answering our question.

In the fictional description of the fastest possible 100m at the beginning of this chapter, our runner took 8.99 seconds to complete the distance. Let's take a look at how we got there.

* * *

The most scientifically credible way to arrive at a realistic prediction of the fastest hundred that could ever be run is to start with the fastest that's already *been* run and then apply what we know about physiology, physics and the lore of the track to figure out how much faster it's physically possible to get.

But we're not interested in assembling a Frankenstein with the legs of a weightlifter, the height of an NBA center and the upper body of an anorectic ballerina. Our goal is to imagine a perfect yet perfectly plausible sprint specialist who has all the benefits of genetics, nutrition, training, mental discipline and the knowledge acquired by his predecessors.
For a race so simple — start at Point A and get to Point B as fast as you can — the hundred is surprisingly complex. It consists of four distinct phases:

1- Reacting to the gun
2- Getting out of the blocks
3- Accelerating to top speed
4- Hanging on for dear life at the end

To predict the ultimate time, we'll use Usain Bolt's record-breaking 100m sprint at the 2008 Beijing Olympics as our starting point, then break it down into these phases. For each phase, we'll look at how much better Bolt would have done if the conditions had been more favorable. That will give us a new starting point, one that still doesn't take into account the athlete himself getting any better.

Then, we'll consider how much faster it's possible for a sprinter to be. If we factor that into the ideal race conditions we came up with in determining our starting point, we will have arrived at the fastest 100m sprint it's possible for a human to run.

We're going to assume that the sprint takes place under race conditions. Without direct and visible competition, times would be far slower. Send Bolt down a track solo and he wouldn't have a prayer of coming anywhere close to a record time. As a matter of fact, he wouldn't even have a respectable time. At those speeds, there's simply no way to gauge how fast you're going other than in comparison to what your competitors are doing. It's why the center lanes are so coveted and are always assigned to those with the fastest preliminary heats. They give the athlete the best view of as many of the other runners as possible. If Bolt hadn't had Richard Thompson of Trinidad and Tobago pushing him from Lane Four, it's not likely he would have run as well as he did.

Phase 1: Reacting to the Gun

The first order of business for the 100m runner is to start running as soon as the timing clock does.

In the old days, the man with the starting pistol stood off to the side and fired away, which was simple enough. But with races being won or lost by as little as one or two hundredths of a second, it's not that simple anymore. If the starter is standing in the infield ten feet from Lane One, he's thirty-six feet away from the runner in Lane Nine. Sound travels about a thousand feet per second in air at sea level, so when the gun goes off, the sound will reach Lane Nine .025 seconds after Lane One, which may not sound like much but it would have meant the difference between second and third in Beijing. (Incidentally, if you sit in the stands down at the finish line, the sound of the gun won't reach you until nearly a third of a second after it goes off. By the time you hear it, the runners will already have left the blocks. That's why hand-timers in the old days were trained to start their stopwatches when they saw a puff of smoke from the pistol.)

One solution might be to place the starter in the middle lane far behind the runners, but that's not so simple, either. The gun also starts the clock, and there would have to be a calculation of how long the sound took to get to the racers, which would involve factoring in the temperature, humidity, wind speed and barometric pressure. While such a start might be fair to the runners in terms of who won, it would make the determination of whether a world record was set somewhat problematical. And in these days of multi-million dollar endorsements it wouldn't just be an academic issue, either. In 2001, pro golfer Casey Martin went all the way to the Supreme Court over whether he should be allowed to ride a cart in tournaments because of his bad leg, so it's not much of a leap to imagine a runner filing suit over whether sound waves bouncing off a television camera gave an unfair advantage to the guy in Lane Three. (Martin won his case, by the way.)

The solution that seems to satisfy everybody is having a small speaker placed behind each set of blocks that transmits the sounds of the starter's pistol to every runner at the same time. The blank round in the pistol still sets of a satisfyingly loud report for the benefit of the crowd, but that sound reaches the athletes after the ones from the speakers, so it doesn't matter. So that's it for the reaction time issue, right? Everybody hears the gun at the same time and off they go?

Not quite. What happens if someone goes early? That's called a false start, and we need a way to detect when it happens. It used to be done by the starter, who watched the runners as he pulled the trigger and used his own judgment. Now it's done automatically, using pressure sensors built into the starting blocks. They detect exactly when the runner pushes off. If he does that before the gun goes off, it's a false start. So now are we done with this part of the race? Not just yet. There's another problem. International rules require that each runner take off in reaction to the sound of the gun. If instead he guesses when the gun is going to be fired, kicks off based on that and happens to hit it just right, he's technically guilty of a false start. But how do we know what's in someone's mind?

We don't. What we do know, or think we know, is the shortest interval of time over which it's possible to hear the gun and push off the blocks. In international competition, that's assumed to be a tenth of a second, or 100 milliseconds. React faster than that and it's a false start. This happened to American Jon Drummond in the 2003 IAAF World Championships when he was disqualified for leaving the blocks 53 msec seconds after the gun. (Drummond wasn't happy with the decision and didn't do much for the sport, or for his fellow athletes who were waiting for the restart, by lying down on the track and refusing to leave for nearly twenty minutes.) A short time later in a different heat, Asafa Powell was disqualified for an 86 msec start. Powell's legitimate finishing time in an earlier heat was the fastest time of the meet, so imagine his frustration when he was tossed out.

This stuff really matters. In 1991, Carl Lewis false started during a 100m race. Nervous about getting disqualified if he did it again, he got off the blocks in the restart in a dismal 166 msec. Leroy Burrell's reaction time was 117 msec. Subtract the reaction times from the finishing times and it turns out Lewis covered the distance in 9.76 seconds vs. Burrell's 9.78, but Burrell won because he was faster off the blocks and reached the finish line first.

While all of this sounds somewhat complicated — and it is, if you're actually participating in a race or trying to produce one on a world stage — determining the perfection point for this part of the hundred is very easy. Or at least it's easy if you accept the assumption that 100 msec is the fastest possible "legitimate" reaction time to the starting gun. If you do, we're done: Our perfect race starts with a reaction time of exactly 100 msec and we move on to the next phase. But can we make that assumption?

Typical elite sprinter reaction times are in the range of 120-160 msec. The fastest legitimate start on record was Jon Drummond's perfect 100 msec in Monaco in 1993. A year before that, Bruny Surin clocked 101 msec during a World Cup semi-final, which would seem to prove that Drummond's reaction time wasn't a one-off anomaly.

But if 100 msec has been demonstrated in actual race conditions, who's to say that 99 isn't possible? Or 98, or 90?

There's no solid rationale for accepting 100 msec as the absolute threshold of human ability. For one thing, "100" is an awfully arbitrary number. When you see numbers that round, it's a warning that there's not a lot of scientific precision behind them. For another, limits like that are nothing more than a challenge, just as the four-minute mile was. When elite athletes smell barriers, they go into overdrive attempting to crack them. You can bet that sometime in the not-too-distant future there is going to be a string of sub-100 msec reaction times in important 100m races, followed by a great hue and cry, a handful of lawsuits and a redefinition of "false start." For all we know, there are a bunch of Drummonds and Surins already out there who are capable of consistent 90 msec reaction times but are too fearful of disqualification to push themselves. Take the psychic shackles off and what can we expect? Hard to say, although we do know that there is an absolute bottom limit at around 75 ms based on the chemistry of nerves and muscles.

But the .10-second standard is universally accepted, and that makes it very easy to determine the perfection point for this phase of the ultimate 100m. As test pilots are fond of saying, "You can only *tie* the record for lowest altitude." We're going to assume that our ideal athlete nails the current standard of a tenth of a second. Anything longer than that isn't perfect, and anything less would disqualify him.

Now that we know what the perfect start is, and also know that it's achievable in a real-world race because it's been done (by Jon Drummond), let's return to Usain Bolt's performance in Beijing. At 0.17 seconds, his reaction time to the gun was downright pedestrian for a world-class sprinter. In fact, it was the second *slowest* among the eight men in the field. For our purposes in determining the fastest possible 100m, we can adjust his reaction time to the Olympic minimum of .10 seconds.

We can't always make adjustments like that. For example, we talked about the speed at which various segments of the race have been run by others. To say that Bolt could conceivably run the first 10m segment as fast as the fastest ever is not legitimate, because doing that would affect the rest of his race, as you know if you've ever gone out too fast in a 10k and then faded. Similar factors come into play for the other segments as well.

But reaction time is different. It doesn't take any extra effort, so it's perfectly reasonable to say that if a sprinter reacts faster, he'll finish faster.

Had Bolt gotten off the line at the Olympic standard of .10 seconds instead of .17, his final time would have been 9.62. That's the first adjustment we're going to make in trying to arrive at the 100m perfection point.

Phases 2 & 3: Getting Out of the Blocks and Accelerating

We're going to combine these two aspects of the race both for the sake of simplicity and because, as we'll soon see, there's not much to be gained by considering them separately.

As complicated as the rules are governing the start, once you get going there are only two rules left: Stay in your own lane and don't take drugs.

An athlete in the 100m sprint has two jobs once he's out of the starting blocks. The first is to accelerate his body as quickly as he can to the highest speed he can, and the second is to slow down as little as possible once he gets there. It's his muscles that provide the force that gets him going, and it's friction that tries to slow him down. Let's start with how he gets up to speed. If you analyze the dozen or so fastest 100m races, you won't find any correlation at all between who covered the most distance in the first step and who won the race. After all, a fly could get out of the blocks faster than Bolt but it's not going to beat him to the finish line. This is why we combined our consideration of the start and accelerating. While there's certainly a benefit to honing technique, it doesn't pay to go overboard on maximizing the kick out of the blocks because a sprinter who adopts a weightlifter's training regimen — repetitive squatting with heavy weights to build up the calves and thighs — just to enhance the initial push off risks compromising the rest of his race. He might launch himself like a human cannonball when the gun goes off, but his leg muscles will be so overdeveloped that he won't be able to move them fast enough down the stretch.

Let's turn to accelerating down the track. We'll use Usain Bolt at the Beijing Games as our example again. Except for reaction time, he's about the best example to use when talking about any aspect of the hundred. He went from zero to 25 mph in two seconds. That's the same acceleration you get in a Maserati Ghibli II (which has a top speed of 162 mph).

There's a simple relationship among acceleration, force and mass, so knowing that Bolt's mass on race day was 90 kilograms tells us how much force he was generating. But in addition to generating enough force to get his mass moving, which is the same whether he's on earth or in outer space, the earthbound athlete has the added problem of friction. A good way to understand friction is to talk about baseball.

What does a baseball commentator mean when he tells us excitedly that a pitcher just launched a 100-mph fastball? He's referring specifically to the speed recorded by a radar gun at the moment the ball leaves the pitcher's hand. That's not the same speed at which it crosses the plate, because once it's flying freely through the air, the air itself gets in the way.

Air may not seem like much of an obstacle when you're walking to the corner for the morning paper at two mph, but at higher speeds it starts to feel more and more like molasses. A space shuttle on its way to returning to earth from orbit hits the upper atmosphere at 15,000 mph. Fifteen minutes later it's down to less than 250 mph. The only thing that slowed it up was air resistance, and the friction is so immense that the shuttle would heat up and vaporize if it weren't protected by a layer of thermal tiles.

Things aren't quite so dramatic on the ground, but they still make a difference. A Nolan Ryan fastball might be moving at 100 mph when it leaves his hand, but once it's on its way the air goes to work on it. A baseball loses about one mph for every ten feet it travels. By the time Ryan's heater reaches the plate, it's only going about 93 mph.

Air resistance and other forms of friction play a part in many athletic events involving speed, as does gravity. If a cyclist in the Tour de France didn't have these factors to worry about, he could pedal his way up to a good clip and just coast through the rest of the race. But a cyclist has to battle air and gravity as well as friction from the moving parts of his bike.

On level ground, nearly all of a cyclist's energy goes into overcoming air resistance. Two-time Olympic cyclist John Howard wondered what would happen if you could eliminate it entirely. He mounted a wind-breaking shield on the back of a race car and rode his bicycle behind it, so that he was effectively riding in zero wind. He quickly got up to such a high speed that he couldn't turn his pedals fast enough, even in his top gear. So he went home and built a special bike with enormous gears, then tried it again. Using only the power of his legs but without any air resistance to fight, he hit 152 mph. A few years later **Fred Rompelberg of the Netherlands gave it a whirl and got up to 170 mph.**

Air resistance impacts the 100m sprint as well. The force with which air impedes the motion of a moving body is called aerodynamic drag, and it increases with increasing speed. Unfortunately for runners— and for race car drivers, airplane pilots and cyclists as well — drag increases as the square of the speed. That means that when you double the speed, you quadruple the drag. A marathon runner hits a top speed of around 13 mph. A 100m sprinter gets up to twice that speed, and therefore experiences four times more drag from the air than the marathoner. So anything that reduces his aerodynamic drag will play a big part in the finishing time.

One way to do that is to run with a tailwind. Olympic and international standards allow for a "following" wind of up to 2 meters/sec, or about 4.4 mph. That's not exactly a hurricane: It's the speed of a brisk walk, and is less than what you feel coming out of the air conditioner in your car on its lowest setting. Because the sprinter is moving much faster than that he's never going to feel an actual tailwind, but what he will feel is less of a headwind. The impact is not trivial. Tyson Gay clocked 9.68 seconds at the Olympic trials in Oregon two months before Bolt ran 9.69 in Beijing, but he wasn't credited with the record because the following wind was 4.1 m/sec, more than twice the "legal" limit, like your air conditioner on medium. Without that wind he would have run only 9.78, barely beating Maurice Greene's 1991 record of 9.79.

But when Bolt broke the world record in Beijing, there wasn't a breath of wind. That's virtually unheard of in an outdoor race. Among the twelve fastest 100m times ever, all but one was run with a tailwind, including a 1.7 m/sec breeze behind Bolt himself when he broke his first record in New York three months before Beijing.

Every meter per second of following wind knocks approximately five one-hundredths of a second off a 100m sprinter's time. Had there been a breeze in Beijing just slightly faster than the one Bolt had in New York, he might have chopped .09 seconds off his time. Add that adjustment to the one we made for his slow reaction time and we're down to a very plausible 9.53 seconds as the basis for determining the perfection point

There is also an Olympic standard for the maximum altitude of the track, because the thinner the air, the less the resistance, as any golfer who plays on a mountain course knows. The standard is 1,000 meters (another suspiciously arbitrary, round number), or 3,276 feet. Official races can be run at higher altitudes, but the results are marked with an "A," which renders any records suspect. At the 1968 Games in Mexico City, which is over 7,000 feet high, world records were broken by large margins in all three sprint distances, the 100m, 200m and 400m. In the long jump, another event in which aerodynamic drag is a critical factor, Bob Beamon utterly destroyed the world record with an astonishing leap of over 29 feet, a mark that wouldn't be surpassed for 23 years.

The track at the Beijing Games was only 209 feet above sea level. Using standard corrections for 100m finishing times at various altitudes, we can assume that, had Bolt been running on a track at the allowed maximum altitude instead of in Beijing, he would have taken another .06 seconds off his time. That gets us down to 9.47 seconds.

This is why the purely statistical models are almost certainly wrong. Our estimate of 9.47 seconds is not a theoretically fastest time for a human. It's just what Usain Bolt could actually have done had he reacted more quickly to the gun and raced with the strongest legal tailwind on the highest legal track. It doesn't assume that he's any stronger than he was that day in Beijing. So while we've just demonstrated that 9.47 could be done right now, the statistical models predict that it won't happen for another 200-400 years.

And we're not done yet.

Phase 4: Hanging on at the End

Cranking up to 25 mph from a standing start took Bolt two seconds. Squeezing out just an additional 2 mph to get him to his top speed of 27 mph took him another four seconds. Since he was probably creating roughly the same amount of force during all of that time, why did it take so long to accelerate from 25 to 27 mph?

There are a number of reasons. The first has to do with aerodynamic drag again. From 5 to 10 mph the drag on his body quadrupled, then it quadrupled again on his way to 20 mph. By the time he reached that speed, a lot of the force he was generating went toward just overcoming the air resistance at the higher pace, along with a little to overcoming friction. There's not much left after that to produce acceleration as well.

Another reason is that there are limits to how fast muscles can move. Olympic weightlifting champion Hossein Rezazadeh of Iraq can generate enough force in his legs to stand upright from a squatting position while holding a 578-pound barbell to his chest. That's a lot more force than any runner is ever going to create, but that doesn't mean Rezazadeh is going to be competing in any sprints very soon. Aside from being far too heavy, he couldn't move his legs fast enough.

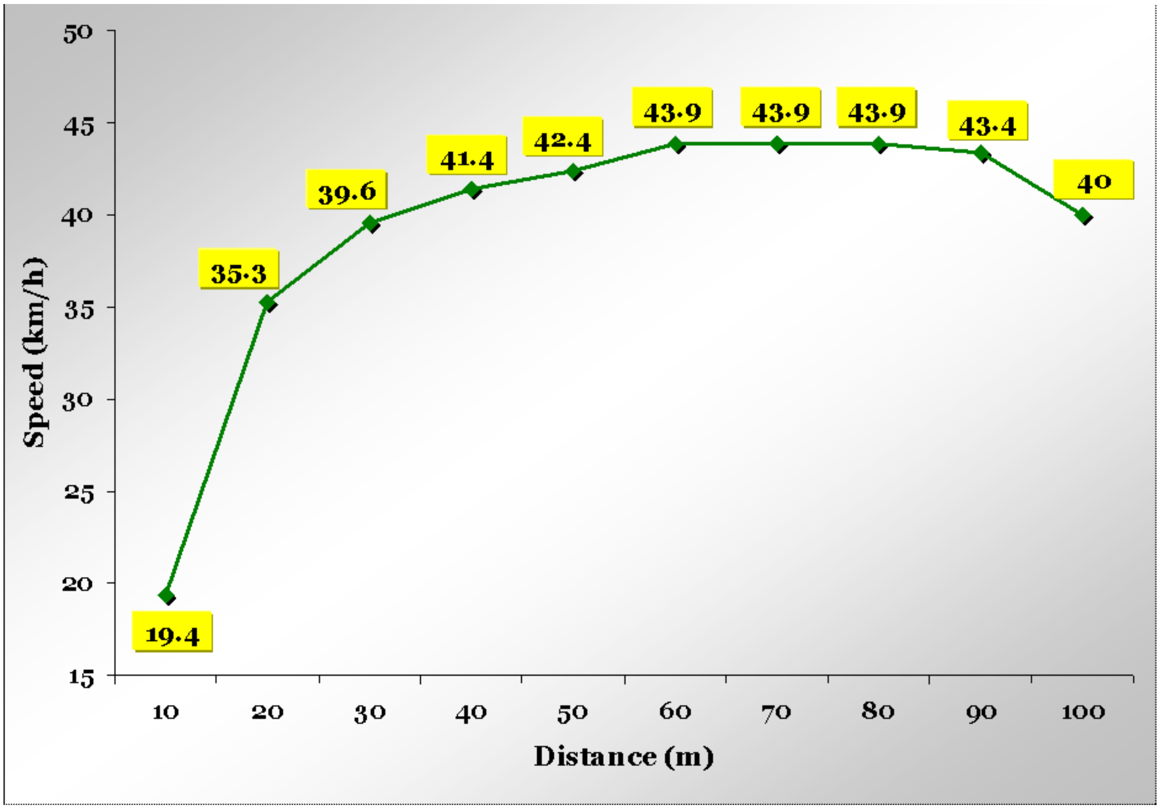
But even a sprinter can move his legs only so fast. He not only has to push off powerfully with each leg, he then needs to get that leg forward as quickly as possible to get ready for the next step. The muscles required to do that are different from the ones that supply the pushing power and, unlike in the ostrich, the fastest animal on two legs (that's not a joke: the ostrich can run *twice* as fast as a good 100m sprinter, or about 50 mph, and keep it up for half an hour), they're not well developed in humans. We also don't have an ostrich's muscle tendon units that act like springs to help that rear leg move forward.

Once a sprinter reaches the limit of how fast he can take individual steps, the best he can do if he's got power in reserve is to use it to increase his stride length so he can cover more ground with each step. World-class sprinters typically take 43 or 44 steps over the course of a 100m. Usain Bolt needed only 41 in Beijing, covering well over eight feet with every step in the middle of the race. That's about the distance from the floor to the ceiling of an average size room.

Bolt hit his top speed of about 44 m/sec, or 27 mph, somewhere after the 50m mark, which is where most sprinters reach their top speed. About 10 or 20 meters later, they begin slowing down. While it's difficult to tell exactly how fast they're moving at any point in the race, we know their splits — the time they took to complete each 10-meter segment — with great accuracy. Here are the splits from 50 through 90 meters for seven record-breaking 100m sprints (reaction time is included in the 0-10m segment):

	Ben '88	Carl '88	Mo '99	Mo '01	Tim '02	Asafa '05	BOLT '08
RT	0.132	0.136	0.162	0.132	0.104	0.150	0.165
0-10m	1.83	1.89	1.86	1.83	1.89	1.89	1.85
10-20m	1.04	1.07	1.03	1.00	1.03	1.02	1.02
20-30m	0.93	0.94	0.92	0.92	0.91	0.92	0.91
30-40m	0.86	0.89	0.88	0.89	0.87	0.86	0.87
40-50m	0.84	0.86	0.88	0.86	0.84	0.85	0.85
50-60m	0.83	0.83	0.83	0.83	0.83	0.85	0.82
60-70m	0.84	0.85	0.83	0.83	0.84	0.84	0.82
70-80m	0.85	0.85	0.86	0.86	0.84	0.84	0.82
80-90m	0.87	0.86	0.85	0.89	0.85	0.85	0.83
90-100m	0.90	0.88	0.85	0.91	0.88	0.85	0.90
TIME	9.79	9.92	9.79	9.82	9.78	9.77	9.69
		Courtesy of SpeedEndurance.com					

Two things pop out right away. The first is that Bolt had the fastest 10m split in history, at 0.82 seconds. (This despite the fact that Ben Johnson and Tim Montgomery were disqualified for using performance enhancing drugs.) The second is that he had *three* of those in a row. What shocked the experts more than anything else was not how fast he was moving, but for how long he was able to hold onto his top speed. As the next graph shows, for a 50m stretch starting at the 40m mark, Bolt never dropped below 42 km/hr, or 26 mph.



When Bolt hit his top speed just past halfway through the race, one of two things was going on: He was either moving his legs as fast as he could and therefore additional power wasn't going to do him any good, or he was putting out as much power as he could possibly generate and it wasn't enough to make his legs move faster. Where would a future athlete go from there?

To find out, I consulted with sports medicine specialist Dr. Bassil Aish, chief medical advisor for "Sport Science." Former team physician for UCLA football, track and field, soccer and swimming, Dr. Aish is one of the world's foremost researchers and authorities on the science of running. I asked him to speculate about the ultimate sprinter and explain his thinking.

While there is a relatively straightforward relationship between muscle mass and strength assuming ideal oxygen utilization, the situation gets vastly more complex when you also consider speed, weight and endurance, and even more convoluted when you get into fast-twitch vs. slow-twitch fibers. Make the muscle bigger and it gets stronger, which is good for a weightlifter, but in a runner there's a point where it becomes so heavy or unwieldy that it becomes less flexible and decreases the speed of contraction, thereby actually slowing him down. Get the wrong mix of fiber types and the marathoner might be happy but the sprinter could be a dud.

Aish has calculated the ideal muscle mass and fiber ratio for a marathon runner. We asked him to do it for a 100m sprinter. It turned out to be a harder task than he first thought, because of important differences in muscular demand between the acceleration and high-speed phases of the race. The explanation of how he conducted his analysis is very technical and difficult to convert into a specific speed prediction, so I asked him to express his conclusions about the "ideal sprinter" via comparison to Usain Bolt.

"He's fairly close," Aish reported back, "but there's plenty of room for improvement." How much room, exactly? "A sprinter who achieved ideal proportions," he says, "could accelerate to a high enough speed and hold it for a long enough time to cover run the 100m distance 3.7% faster than Bolt could."

Aish stressed that this didn't mean that the overall result of the race would be 3.7% faster than Bolt's Beijing time, because that would depend on the track conditions, wind, elevation and reaction time getting out of the blocks. His conclusion was only that, once underway, under identical conditions, the ideal sprinter will cover the distance 3.7% faster than Bolt.

It's a dramatic conclusion, but it comes with a caveat.

"We're talking about something that might happen a thousand years from now," Aish warned. "That's thirty generations. At the rate that humans are evolving, we're not the same species we were even two hundred years ago, and we're definitely not going to be the same species a thousand years from now."

In other words, we may never know if he's right because our genetic makeup could change enough by then to make his calculations irrelevant. So we need to keep in mind that we're talking about the limits of humans as we know them, because there's no sure way to predict where they're going.

It would seem that we now have all the data we need to calculate the perfection point, but we're still not quite ready because we haven't yet dealt with the single most extraordinary — and downright bizarre— aspect of Bolt's Olympic race:

He wasn't even trying his best.

We know that because of what happened at the end.

* * *

Look at the previous graph and notice how much slower Bolt ran the last ten meters than the previous sixty. The reason?

Eighty meters into the race Bolt looked to the side to check out Richard Thomson, who was in second place and fading fast. Bolt, realizing that he now had the race won, dropped his arms and began celebrating, not only coasting his way to the finish and high-stepping across it but thumping his chest for good measure.

It made for wonderful theatre, and was one of the most talked about moments of the entire Games, but what's important for our purposes is that Bolt literally quit racing with nearly 20 meters remaining. Even the most conservative experts agree that he could have gone a tenth of a second faster if he'd kept the hammer down instead of showboating.

Hans Eriksen and his colleagues at the Institute of Theoretical Astrophysics at the University of Oslo went even further. They considered factors such as Bolt's position, acceleration and velocity in comparison with second-place finisher Thompson. Their conclusion? Had the Jammin' Jamaican not slowed down to start celebrating before the finish, he could have gone 9.55.

Much as we're tempted to use that lower figure, we won't, precisely *because* Eriksen took into account Bolt's position relative to Thompson's. Had Bolt reacted to the gun faster, he wouldn't have been as far behind in the early part of the race and therefore might not have been as motivated to pick up the pace. So it would be unscientific to simply take Eriksen's analysis at face value and make an adjustment of .15 seconds. On the other hand, it does give us firm grounds for accepting the .10-second estimate of what Bolt's exuberant display cost him in the end.

Now we're ready to do the final calculation.

The Perfection Point — Adding It All Up

We start with Bolt's actual finish time of 9.69 seconds.

From that we subtract .07 seconds to account for his poor start and get him down to the Olympic reaction time standard.

Next we subtract .09 seconds because that's the advantage he would have had with a "legal" wind at his back.

The track was far lower than the allowable standard of 3,276 feet. That cost him another .06 seconds which we can subtract.

Then we take off the .10 seconds that his celebratory showboating added to his time. We now know what Bolt's time would have been had all the conditions been ideal: 9.37 seconds.

Let's pause for a reality check, because those of you familiar with the sport of running are probably already shaking your heads. Listen to NBC commentator Ato Boldon, winner of four Olympic medals in the 100m and 200m sprint and one of the keenest observers of the sport:

"You put the wind he had in New York behind the 9.69 here," Boldon said the day after the race, "and we could be down in the 9.5s, except that he shut down with 20 meters to go. So now, I'm like, is that in the 9.4s? It's mind-boggling."

There's more. Asafa Powell was 25 when he set the world record that Bolt broke. (He actually broke it twice: the first time was three months before the Olympics, in New York, in a time of 9.72 seconds.) Maurice Green was 25 when he set his record, Leroy Burrell 27, Donovan Bailey 29, Carl Lewis 30.

When Bolt stunned the world in Beijing, he was only 21, making him the youngest record holder ever. And in case I forgot to mention it, the 100m isn't even Bolt's specialty. The 200m is. He didn't start running the hundred until the year before the Beijing Olympics, and when he set that world mark of 9.72 in New York, it was only the fifth time he'd raced that distance. To say that he's got plenty of time and plenty of potential to get even faster is an understatement. All of which makes the 9.37-second adjusted time seem a little less impossible.

And we're not even going to talk about the fact that one of Bolt's shoes was undone when he ran in Beijing.

With 9.37 as our starting point, all that's left is to factor in how much faster than Bolt a future athlete might be. Based on what we know about muscle weight, strength and mobility, Prof. Aish told us that the greatest possible physiological improvement we can expect is 3.7%.

Apply that to our adjusted starting point of 9.37 seconds and it brings us to 9.02 seconds.

And now, at last, it seems that we're done. We've run out of reasons to think a 100m race could get any faster. There are simply no more sources of additional speed.

Except one. And this is where we're going to leave the safe arena of science and venture into the netherworld of pure speculation. Because there's something special about that predicted time of 9.02 seconds that's impossible to ignore.

* * *

In the middle of the 19th century two men working for Sir George Everest set out to measure the height of the world's tallest mountain. Their result after nine solid years of incredibly precise and painstaking work? 29,000 feet. *Exactly* 29,000 feet. Sir George knew they were right but was so afraid that people would assume that such a round number was just a guess that he arbitrarily slapped on another two feet before he published it. Mt. Everest's official elevation of 29,002 feet stood for nearly a hundred years.

Round numbers might invite suspicion but they're also irresistibly tantalizing. The world wasn't mesmerized by the quest for a 4:01 mile or a 3:59. It was "The Four Minute Mile." A 99.8 mph fast ball is an extremely impressive pitch, but it doesn't get a roar from the crowd. An even hundred does. When Wilt Chamberlain broke the all-time record for points by one player in a basketball game in 1962, there was still time left on the clock, so his teammates did everything they could to help him get to 100 points. That's the mark everyone remembers, and hardly anyone can recall what the previous record was.

At some point in the future, athletes are going to begin edging very close to the time we so carefully derived for the 100m perfection point: 9.02 seconds. When they do, a nearby round number is going to raise a very big question in the minds of athletes and track-and-field fans the world over: Is it possible to break nine seconds?

Science says no. Nine seconds isn't possible because 9.02 is the calculated perfection point and how can you get better than perfect?

I don't know. But we can.

To get from 9.02 seconds to sub-9 in the hundred, a .03% improvement in performance is needed, a third of one percent. It's actually a pretty large figure at the thresholds we're talking about, but the history of human breakthroughs tells us it doesn't matter. If you look at other barriers that were previously labeled "unbreakable" and then examine how far we went beyond them, you'll see that being less than one percent away from anything in sports practically guarantees that we're going to get there eventually.

As late as 1999 no woman had ever broken 2:20 in the marathon. The world record stood at 2:20:43. Less than four years later, Paula Radcliffe ran the London Marathon in 2:15:25, an improvement of 3.2% over that seemingly impenetrable barrier. The difference between the four-minute mile that Roger Bannister cracked in 1954 and the current world record represents an improvement of 7%. In the mid-1950s, going under ten seconds in the 100m sprint was considered impossible, but Usain Bolt's Beijing time of 9.69 is more than 3% better than what turned out to be a psychological rather than physical brick wall. So is going from 9.02 to 8.99 in the 100m, an improvement of only .03%, really that hard to believe?

It isn't, but where could it come from? Maybe from a muscle spasm, or a mid-race gust of wind that doesn't register on the official meters, or an equipment improvement. Maybe our improvement factor of 3.7% is wrong. Maybe it will come from nothing more than population growth: Right now there are about 6.8 billion people in the world but in fifty years there will be ten billion, giving us a 50% larger pool to draw our best runners from. Maybe it will come from new technology: NASA spent $80 billion over eight years getting us to the moon, so surely $800 million in R&D over *800* years by the likes of Nike and Reebok can shave another .03 seconds off the 100m.

I don't know where we'll find that last three hundredths of a second, but what I do know is this: Come that close to a number like 9.0 and betting against it will be like betting against the sun rising in the morning. By 1954 the record for the mile had hovered around 4:02 for many years. Had it been 4:13 we might not have seen four minutes broken in our lifetimes. If our calculated perfection point for the 100m had come to 9.23 seconds or 9.17 or even 9.12, I would have left it at that and bet everything I had on the science.

But at 9.02 seconds, it's simply not an option for the species to leave it lying there. If we ever get to 9.02, we're going to break 9.0. We can't say when it will happen — the perfection point isn't about a detailed schedule of predicted world records, just the absolute limit — but it will, because our desire to overcome seemingly insurmountable obstacles may not be quantifiable but it's still a bigger factor than any of the others we've considered.

There's an obvious logical fallacy in arguing that something is possible based only on the fact that we thought it wasn't. "They laughed at Columbus" is a frequently-invoked rationale for some pretty dumb notions. A human is never going to run as fast as an ostrich or high-jump over the goal posts at the Superdome or lift a Volkswagen over his head. But that's not the argument here, because nobody has ever come close to doing those things.

The argument is that, at least in sports, how close we are to a barrier is sometimes all we need to know about whether it's possible to break it. Ten percent away and it's anyone's guess. Less than one percent and it's a virtual certainty, for no other reason than it's in our nature to find a way, as Bannister, Radcliffe, Sir Edmund Hillary, Charles Lindbergh, Roger Maris and countless others did.

When a gauntlet like that is thrown before the human race, it's impossible for us to resist and it's inconceivable that we'll fail.

The perfection point for the 100m sprint is 8.99 seconds. For a fraction of a second at the 55-meter mark, the athlete will be moving at 27.2 mph.

Unless the species itself changes, it's the fastest a human will ever run.

Perfection Point: The Fastest Man, the Highest Jump, and the Search for the Limits of Athletic Performance
by John Brenkus • 9780061845451 • On Sale: 8/31/2010 • Trim: 6 x 9 • PP: 288 • $26.99 ($34.99 Can.)

Update: On August 16, 2009, Usain Bolt ran the 100m in Berlin in a much-anticipated race that included American record holder Tyson Gay. This time there was no slowing down and no show-boating. In the same stadium that saw Jesse Owens embarrass Adolph Hitler in 1936, Bolt ran his heart out all the way to the finish and utterly destroyed the record he'd set the year before in Beijing, leaving the track world in shock and reporters nearly speechless. His time was 9.58 seconds, an incomprehensible .11 faster than his Olympic performance. ESPN track and field expert Larry Rawson's breathless comment: "It's like he's thirty years before his time."

Actually, he's pretty much right where we predicted he should be.