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Predicting a Baseball's Path

A batter watches the pitcher's motion plus the spin on the ball to calculate when and where it will cross the plate

A. Terry Bahill, David G. Baldwin and Jayendran Venkateswaran

Imagine being at the center of the most dramatic moment in baseball. It's the bottom of the ninth inning of the seventh game of the World Series—two outs, the tying run on second, the winning run on first, and you are the batter. Everything depends on you. The trouble is: The most fearsome pitcher in baseball stands on the mound. He has an awesome assortment of pitches: fastball, change-up, curveball, slider and knuckleball. You want any advantage that you can get in predicting where each pitch will go.

With the crowd going wild and sweat pouring from your every pore, you have to concentrate on the ball that is about to be launched in your direction. You must gather as much information about the pitch as quickly as you can in order to make crucial decisions.

As we will show, you get just a few hundreds of milliseconds to figure out what kind of pitch—perhaps traveling at almost 100 miles per hour—is heading toward the plate. In that instant, you must observe the ball's spin and predict how it will move on its way to the plate. It's a daunting computational task. Luckily, we can describe a few clues for you to use. And you will need them soon, because that fearsome pitcher is rocking back on his pivot leg. In a split second, his arm will swing through a great arc and send a baseball hurtling your way.

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The Physics of a Pitch

Before you have to figure out the World Series–winning or –losing pitch, let's learn more about the entire process. A pitcher stands on the mound and throws a baseball—a bit under three inches in diameter and covered in leather—toward home plate, which is 60.5 feet away from the pitcher's rubber on the mound. A strike must cross the plate, which is just 17 inches wide, at a height that is roughly between a batter's knees and armpits. An extremely fast pitcher can throw a baseball that reaches 95 miles per hour, maybe a little faster. At that speed, a ball reaches home plate in less than half a second. On the way from pitcher to home plate, though, several forces determine a baseball's trajectory.

As soon as a pitcher releases a ball, it's in gravitational free fall, whether it's a blistering fastball or a gentle change-up. A 95-mile-per-hour fastball drops 1.7 feet between the pitcher's release point and the point of a bat-ball collision. Slower pitches fall more. A 75-mile-per-hour curveball, for instance, drops 5.7 feet. Clearly, a ball's pathway to the plate also depends on other forces.

A pitcher cannot control gravity, but he can put spin on a pitch. During the nearly two centuries that baseball has been played, pitchers have invented more than a dozen pitches, and each is characterized by its specific spin rate, spin direction and forward velocity. A pitcher controls these characteristics by assuming a grip and wrist movement devised to provide a given trajectory.

Spin on a ball creates a so-called *Magnus force.* In the mid-1850s, German physicist and chemist Gustav Magnus was one of the first scientists to study this effect. Imagine watching any ball moving right to left with topspin—meaning that the top of the ball rotates in the direction of flight. Air flows smoothly around the ball until it gets to about one o'clock on the top and four o'clock on the bottom. At those positions, called *separation points,* the airflow changes into a turbulent wake that deflects upward with this spin. The physics behind this force can be explained in a couple ways. The first invokes *Bernoulli's principle,* postulated by 18th-century Swiss mathematician, Daniel Bernoulli. When a ball with topspin is placed in moving air, the movement of the ball and its seams slows down the air flowing over the top of the ball and speeds up the air flowing underneath it. According to Bernoulli's equation, the point with lower speed—the top—has higher pressure and the point with higher speed—the bottom—has lower pressure. This difference in pressure produces the Magnus force, which pushes the ball downward. This model has not been validated experimentally.

The second—and probably better—model of the Magnus force has been validated by wind-tunnel tests. It involves the principle of *conservation of momentum*. With topspin, the wake of turbulent air behind the ball is deflected upward. Anyone can prove that a body moving in air goes the opposite direction of the deflected air, which conserves momentum. With a driver aware of your plan, put your hand out

Al Tielemans/Sports Illustrated

Figure 1. As a professional pitcher releases a baseball, a batter gets little time to decide whether or not to swing. A pitch could be a 95-mile-per-hour fastball right down the pike, a curveball that "breaks" low and away, a slider that drifts away, a knuckleball that goes wherever it wants or a ball that takes a number of other trajectories. With so much to decide in so little time, a batter needs every possible advantage in determining where a pitch will go. As the authors explain, a batter can tell a lot from how a ball spins as a pitcher (here, Roger Clemens) releases it.

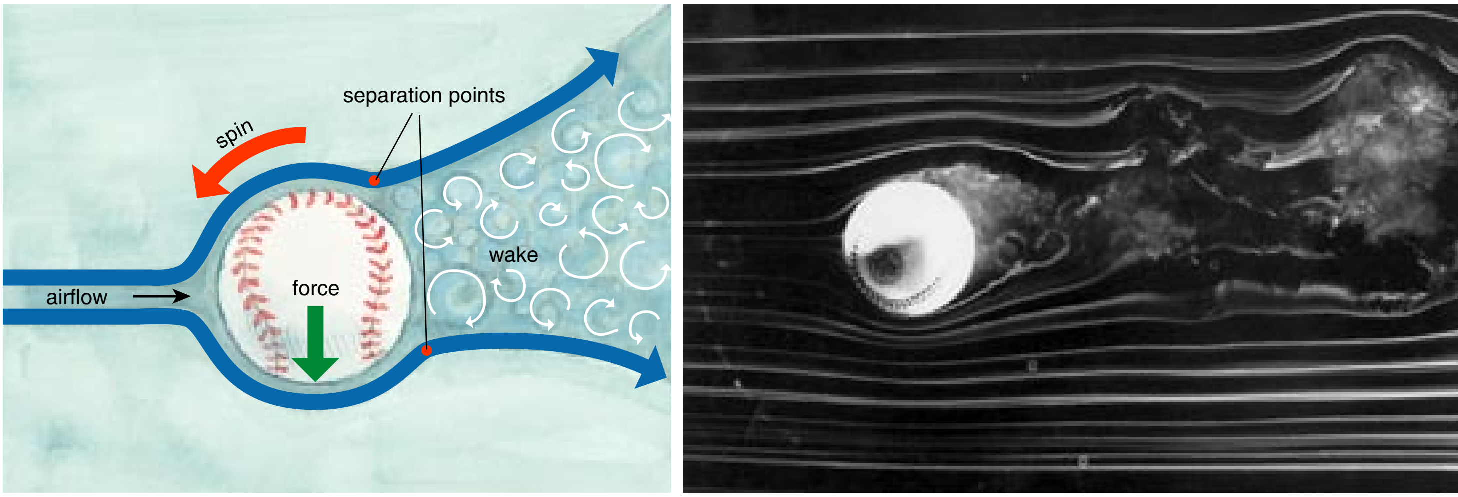

Figure 2. Magnus force determines a ball's trajectory. The diagram at left shows a baseball as if it is spinning counterclockwise and moving right to left. Air flows smoothly around the ball until it gets to about one o'clock on the top and four o'clock on the bottom. At those locations, called separation points, the airflow changes into a turbulent wake, as seen in the erratic flow behind the ball photographed in a wind tunnel *(right)*. With this spin, the wake deflects upward, which pushes the ball downward. (Photograph taken by F. N. M. Brown, courtesy of the University of Notre Dame.)

the window of a moving car, and tilt it so that air is deflected downward; your hand will be pushed upward. Now, let's relate that to a baseball with topspin moving horizontally in air. Before the ball interacts with the air, all the momentum is horizontal. Afterward, the air in the wake has upward momentum. The principle of conservation of momentum requires that the ball have downward momentum, which makes it go down.

Of course, a pitcher can put a wide variety of spins on a ball. A couple of easy "hand" rules reveal which way a spinning ball will travel. The so-called angular right-hand rule reveals the spin axis of a pitch. If you curl the fingers of your right hand in the spin direction, your extended thumb will point in the direction of the spin axis. For instance, if a ball is spinning in a counterclockwise direction when viewed from above—as in a right-handed pitcher's curveball or a left-handed pitcher's screwball—the thumb will be pointing upward.

Once you know the spin axis, you can find the spin-induced deflection with the coordinate right-hand rule. Point the thumb of your right hand in the direction of the spin axis, and point your index finger in the direction of forward motion of the pitch. Bend your middle finger so that it is perpendicular to your index finger. Your middle finger will be pointing in the direction of the spin-induced deflection. In our example of a pitch with a counterclockwise spin when viewed from above, your middle finger will be pointing toward first base.

Get a Grip

A pitcher varies the direction of the deflection by varying the angle of the spin axis. The spin rate and forward velocity of the ball determine the magnitude of the deflection. To fine-tune his abilities, a major-league pitcher practices even when not really throwing. A pitcher with time to kill tosses a ball into his glove to practice various grips. The pitcher develops a wrist movement and a grip that is specific for each of the pitches in his repertoire.

For a fastball, a pitcher snaps the wrist directly forward, releasing the ball with symmetrical force from the tips of the index and middle fingers.

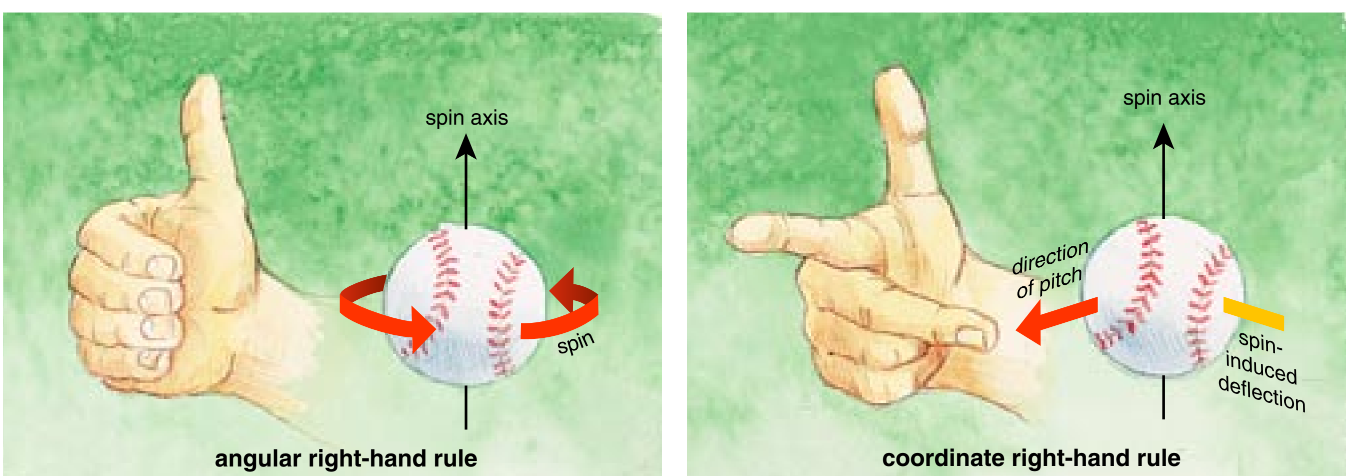

Figure 3. Right-hand rules reveal a ball's trajectory. The angular right-hand rule *(left)* reveals the spin axis of a pitch. Curl the fingers of your right hand in the spin direction, and your extended thumb points in the direction of the spin axis. Next, apply the coordinate right-hand rule *(right)*. Point your right thumb in the direction of the spin axis and your index finger in the direction of forward motion of the pitch. Then bend your middle finger so that it is perpendicular to your index finger; your middle finger now points in the direction of the spin-induced deflection.

Figure 4. Fastballs are generally gripped in two ways. If a pitcher grips the ball across the seams *(left)*, it appears that four seams pass in front as the ball makes one revolution. This is called a "four-seam" grip. If a pitcher grips a fastball with the seams *(middle)*, it's called a "two-seam" grip because only two seams appear from the front during a revolution. Also, a pitcher can throw a change-up, which reaches just 60 to 70 miles per hour, by using a fastball delivery but shoving the ball into the palm of his hand—a so-called palmball *(right)*.

A fastball delivered with an overhand arm motion produces backspin. That is, the ball's top surface spins back toward the pitcher, and the bottom spins forward. The Magnus force will "lift" such a pitch. More accurately, it decreases the distance the ball falls due to gravity.

To throw a fastball, a pitcher can grip the ball in different ways, which are described by the position of the fingers relative to the ball's seams. Actually, the ball has a single continuous seam—made up of 108 stitches that hold together two smooth pieces of leather—but this seam curves to fit the surface of a sphere. If a pitcher grips the ball across the seams, it appears that four seams pass in front as the ball makes one revolution. Hence, this is called a "four-seam" grip. If a pitcher grips a fastball with the seams, it's called a "two-seam" grip because only two seams appear on the front during a revolution.

Most pitching coaches recommend a four-seam grip for the fastball. They presume that a seam perpendicular to the trajectory of the pitch encounters greater air resistance than the smooth surface of the ball. Therefore, they speculate that a four-seam fastball encounters greater air resistance than a two-seam fastball, which might create a stronger Magnus force on the ball. Pitchers assume this produces a greater lift on the overhand fastball.

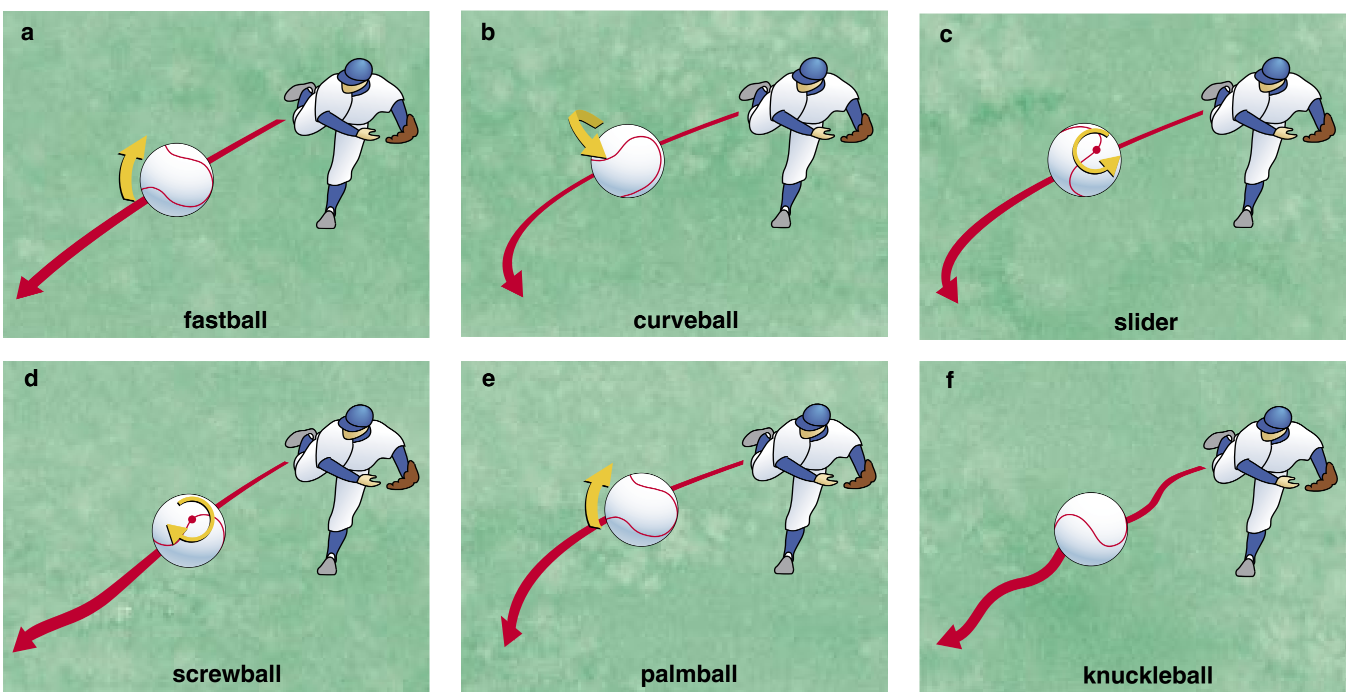

Figure 5. Pitches with different spins follow different trajectories. A fastball *(a)* usually rotates with underspin and drops some on the way to the plate because of gravity. A curveball *(b)* spins at roughly a 45-degree angle to its trajectory and breaks down and away from the batter. A slider *(c)* rotates around a point at the upper right, as seen by a batter, and breaks about half as much as a curve. A screwball *(d)* is basically a mirror image of a slider. A palmball *(e)* spins like a fastball but drops more on the way to the plate because of its reduced velocity. Finally, a knuckleball *(f)* wobbles slightly—not even completing one revolution on its way to the plate—and follows a trajectory that can be difficult for a batter to predict. (All descriptions assume a right-handed pitcher and right-handed batter.)

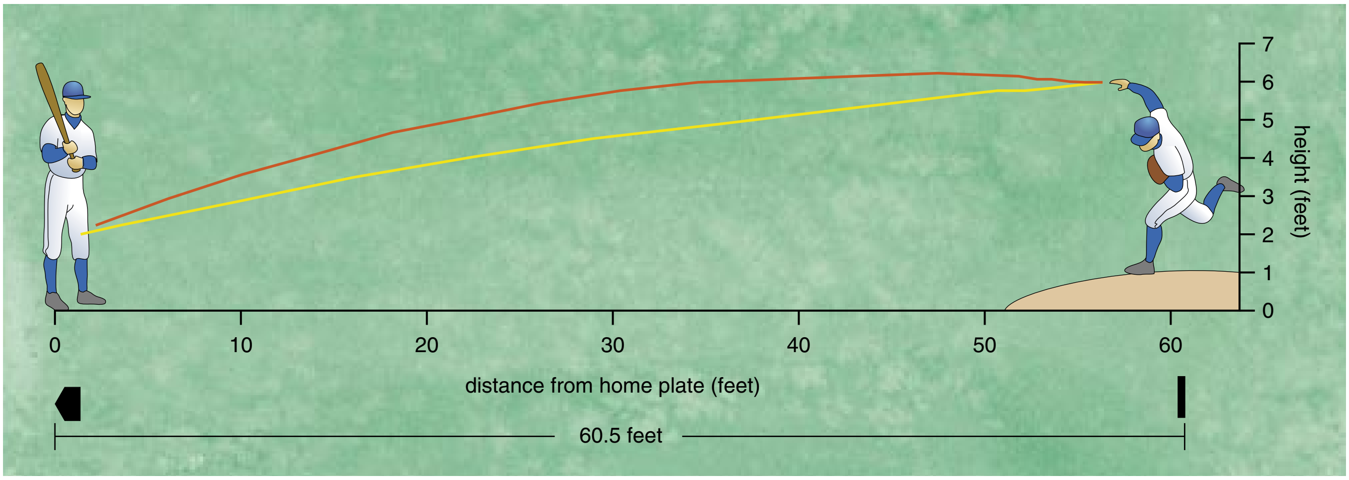

Figure 6. Launch angle also provides a clue about a pitch. Here the 95-mile-per-hour fastball *(yellow)* is launched downward at a 2.3-degree angle, whereas the 60-mile-per-hour palmball *(red)* is launched upward at a 2.4-degree angle. A good major league batter can distinguish the difference between these angles.

Indeed, pitchers have written that the four-seam grip is more effective than the two-seam grip in producing rising fastballs. However, wind-tunnel tests have shown no significant differences in lift between two- and four-seam orientations. Two of us (Baldwin and Bahill) have explained that the perceived rise of the four-seam fastball is probably a perceptual illusion.

A fastball, though, can experience more than an upward deflection. Any delivery that varies from directly overhand will create some spin at an angle to horizontal, which generates some lateral deflection. Moreover, sidearm or "submarine" fastballs tend to have some topspin so these pitches sink more than they would due to gravity alone.

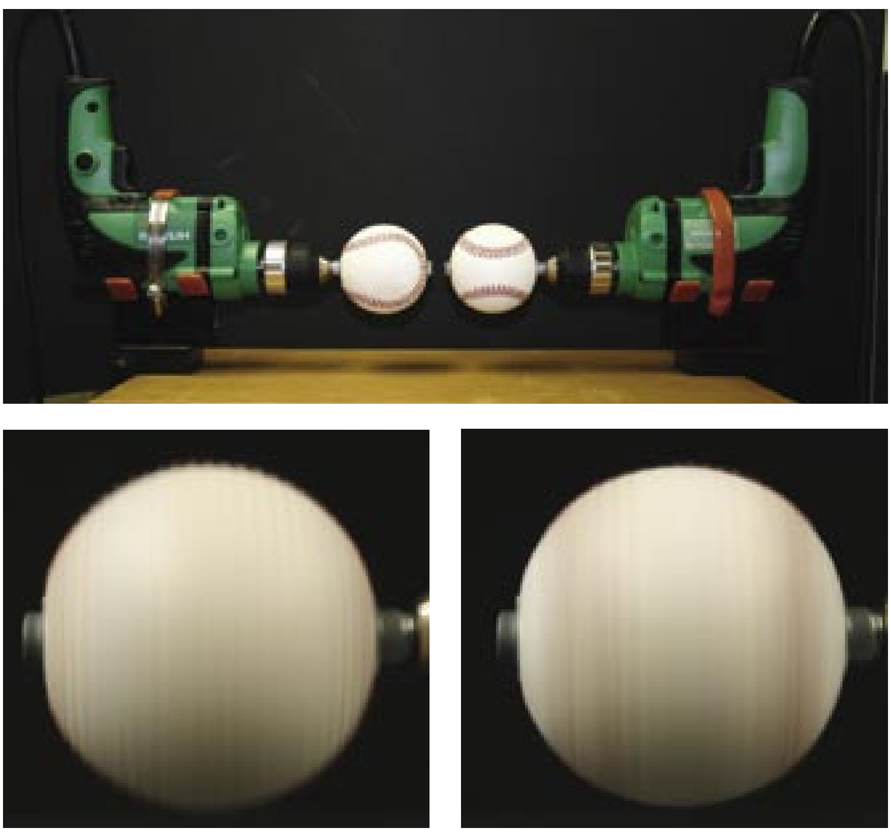

Figure 7. Grip affects the appearance of a pitch, especially a four- versus a two-seam fastball. The authors skewered baseballs on bolts in the four- *(upper left)* and two-seam *(upper right)* orientations, and chucked them in electric drills that rotated at 1,200 revolutions per minute—the typical spin rate for a fastball. The four-seam fastball appears to be a gray blur with thin vertical red lines *(lower left)*. A two-seam fastball exhibits two big red stripes, each about three-eights of an inch wide *(lower right)*. (See also Bahill video, bibliography.)

A Catalog of Curvatures

Even more options arise when it comes to a curveball. First, a pitcher grips the ball with his middle finger lined up along, or just inside, one of the seams where the leather makes a roughly circular shape on the surface of the ball, and his index finger lies right beside the middle one. In general, a pitcher rotates his wrist as the ball is released to throw a curveball. This causes four seams to appear per revolution if you could watch the ball from directly in front as it heads toward the plate; thus this pitch is also generated by a four-seam grip. The index and middle fingers roll to the front or side of the ball, imparting greater spin. An overhand curve produces topspin, resulting in a downward deflection usually referred to as a "drop." In other words, a ball drops more than it would due to gravity alone. If a pitcher applies spin with a vertical axis, as on a toy top, the ball curves horizontally, and concurrently falls due to gravity. This "flat" curve is thrown by pitchers using a sidearm delivery.

Most pitchers adopt what is called a "three-quarter delivery," swinging the arm through an arc that is roughly halfway between vertical and horizontal. This applies sidespin and topspin components to a curve. For a right-handed pitcher, the ball curves diagonally from upper right to lower left. The speed of a curveball varies from around 70 to 80 miles per hour, and the spin rate has been measured at up to 2,000 revolutions per minute.

The drop in a curve usually gives a hitter more trouble than the sideways deflection, because of the shape of the bat and the horizontal orientation of the swing. A bat's sweet area—the place that can hit a ball most effectively—is about 4 inches long but only one-third of an inch high. As a result, a vertical drop is more effective than a horizontal deflection at taking the ball away from the bat's sweet area, because the batter has a smaller margin of error vertically. On the other hand, a horizontal curve can be just as hard to hit as a dropping one when thrown to a batter of like handedness—that is, right-hander to right-hander or left-hander to left-hander. Anyone who has stood in the batter's box—even facing a good high school pitcher—soon learns that it is easier to hit a curve that is deflected toward you instead of one bending away. Apparently, the batter finds it harder to judge the horizontal location of the pitch as it curves away. Also, a batter tends to flinch a bit from a curveball that is aimed at him and then "breaks" toward the outside corner of the plate.

Another horizontally deflected pitch is called a "slider." It travels faster than a curveball, but spins less and, consequently, only deflects about half as much as an ordinary curveball. A pitcher throws a slider somewhat like a pass in football. He takes a fastball grip and rolls his wrist slightly during the delivery. That makes a pitcher's finger pass toward the outside of the ball—sometimes called "cutting the ball"—and that creates some lateral spin. A slider's axis of rotation usually points up and to the left from the perspective of a right-handed pitcher. This causes the ball to drop a little and curve from the right to the left.

The curveball and slider bend away from the pitcher's throwing-arm side, whereas a screwball deflects the other way. That is, if a right-handed pitcher throws a screwball, it curves toward a right-handed batter. In the early 1900s, Christy Mathewson—a longtime New York Giant and member of the Hall of Fame—developed this fadeaway pitch. One of Mathewson's biggest rivals, Hall of Famer Mordecai "Three-Fingered" Brown, threw a natural screwball because he lost part of his index finger on his pitching hand in a farm-machine accident when he was a child. In the 1930s, New York Giant Carl Hubbell made the screwball popular once more. Of the pitches described in this article, pitchers throw the screwball the least. It requires difficult twisting of the hand, forearm and elbow that puts the pitcher's fingers on the inside and top of the ball at the point of release.

No matter which way a curving pitch goes, once it starts to move, a batter can predict the trajectory with some confidence. Not so with a knuckleball. A hurler grips this pitch with his knuckles on a smooth part of the ball or his fingertips dug into a seam. Then, he holds his wrist rigid, basically pushing the ball, which reduces any spin. This pitch travels slowly—only about 60 miles per hour—and a good one revolves less than one time on its way to the plate. That spin is unpredictable, as is the ball's trajectory. For example, Hoyt Wilhelm—a Hall of Famer who was one of the greatest knuckleballers—threw a knuckler that was described as following a corkscrew path, attaining multiple deflections during its flight.

Tricking a batter, though, takes more than throwing the right curves. Changing the speed of pitches also plays a large role. Even if a pitcher could throw 100-mile-per-hour fastballs for nine innings, major league hitters would time the pitches and turn potential strikes into home runs. So, pitchers also use a change-up—just an off-speed straight pitch—that can be thrown in several ways. One of the most common change-up techniques is the palmball, which is thrown by shoving the ball into the palm of the pitcher's hand. This reduces the whipping action of the wrist, and even with a fastball delivery the velocity of the pitch drops to 60 or 70 miles per hour.

Keep Your Eye on the Ball

As a pitcher delivers a ball, a batter gets a few clues for developing a mental model of the pitch. For example, the angle of the pitching arm provides vital information about the upcoming trajectory of the pitch. Arm angle varies through a continuum that includes overhand, three-quarters, sidearm and submarine. Consequently, the height of the release point varies from over six feet off the ground to just one foot. The release point also varies for different pitches.

Another clue for the ball's impending behavior is the launch angle. To go through the strike zone, a 95-mile-per-hour fastball must be launched downward at a 2-degree angle, whereas a 60-mile-per-hour change-up must be launched upward at a 2-degree angle. A major league batter can distinguish the difference between these angles. An good major-league batter might even be able to distinguish the difference in launch angle between a fastball and a curveball.

A batter can also look for how the pitcher holds the ball as he releases it. With the knuckler, a batter will see two or three knuckles sticking up above the ball as a pitcher releases it. If a pitcher throws a curveball and a batter has keen eyesight, he might be able to see the index and middle fingers roll

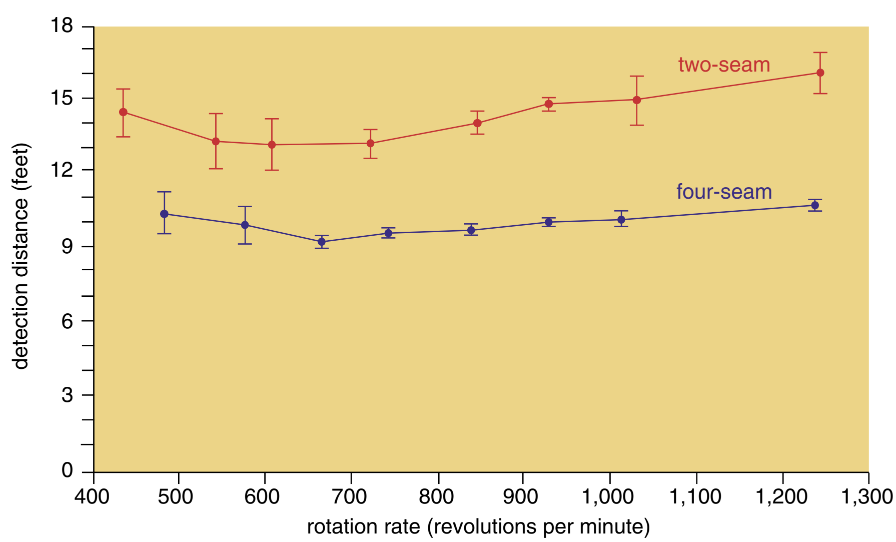

Figure 8. Simulated two-seam fastball *(red)* can be detected more easily than a simulated four-seam fastball *(blue)*. The authors varied the rotation speed of baseballs oriented like two- and four-seam fastballs in the drills, and asked a non-athlete with ordinary vision when he could see the two-seam stripes and the thin red lines on a four-seam fastball. At all rotation speeds, the subject saw the stripes of the two-seam fastball at a greater distance.

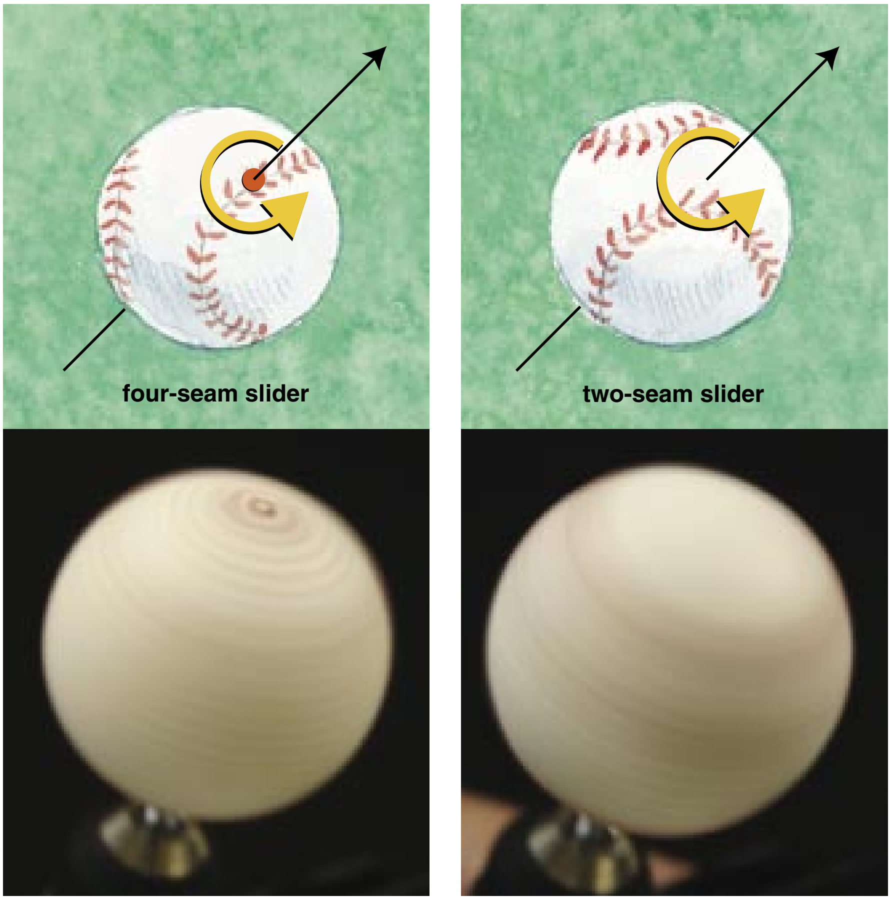

Figure 9. Two- and four-seam sliders also look different to a batter. The four-seam grip used for a slider causes the axis of rotation to exit the ball through a seam *(upper left)*. With a two-seam grip, the axis of rotation exits the ball through an open patch of white leather *(upper right)*. As a result, the four-seam slider creates a red dot at the upper right as seen by a batter *(lower left)*, but there is no dot with the two-seam slider *(lower right)*. So a four-seam grip works to a pitcher's advantage on a fastball, but a two-seam grip works better for a slider.

across the face of the ball as the pitcher snaps it off. These are examples of information about the kind of pitch that will be coming a batter's way.

A batter's best source of information, however, is the way the ball is spinning immediately after its release. How much spin a batter can distinguish, though, depends on his dynamic visual acuity, which is the ability to perceive moving objects. (An optometrist, on the other hand, measures a person's static visual acuity, which is the ability to perceive information in nonmoving objects, such as letters on a page. Moreover, a person's static visual acuity is not correlated with his dynamic visual acuity.) A batter needs excellent dynamic visual acuity to track and predict the flight of a baseball. Experienced athletes have better than average dynamic visual acuity, partly because athletes are selected for this ability and partly because it can be improved with training. Nonetheless, our survey of major-league hitters revealed considerable variation in their ability to see the spin on a pitch. Batters with good dynamic visual acuity can see the spin on the ball; those with poor dynamic visual acuity cannot. To get a feel for the range in dynamic visual acuity, consider that most of us can read the label on a phonograph record turning at 33 revolutions per minute, but this would be about the limit of our capabilities. The great Boston Red Sox hitter, Ted Williams, could read one turning at 78 revolutions per minutes, which is far beyond the dynamic visual acuity of the average person.

And Here's the Pitch …

At last, the moment of truth arrives. The pitcher launches his body down the mound at you, and his arm suddenly whips out from behind him. And there is his hand releasing the pitch. The ball is in the air, spinning and telling you everything you need to know.

As you brace for the pitch, you must evaluate it quickly—extremely quickly. You must determine its speed and spin in about one-seventh of a second. In the next one-seventh of a second, you decide whether to swing and—if you decide yes—where and when to swing. That leaves just one-seventh of a second—if the pitch is a fastball—to swing the bat.

In the rest of this article, we will concentrate on the first roughly 150 milliseconds (about one-seventh of a second) after the release. In that time, a batter tries to determine the direction and rate of spin to predict the magnitude and direction of a ball's deflection. The appearance of the pitch, however, depends on a pitcher's grip. For example, a two-seam fastball does not look like a four-seam fastball, although the speed and spin rates of these pitches are the same.

To prove this, we skewered baseballs on bolts in the four- and two-seam orientations. The bolts were chucked in electric drills and rotated at 1,200 revolutions per minute—the typical spin rate for a fastball—which was measured with a stroboscope. Both visual observation and photographs show that a four-seam fastball appears to be a gray blur with thin vertical red lines about one-seventh of an inch apart and running perpendicular to the spin axis. These lines are the individual stitches of the baseball, but even Ted Williams could not see the individual stitches. By comparison, a two-seam fastball looks different. It exhibits two big red stripes, each about three-eighths of an inch wide, which are created by the spinning seams. (For simplicity, our drill-driven fastballs modeled an overhand delivery. The more common three-quarter arm delivery would tilt the axis of rotation by 45 degrees.) Those stripes provide easily perceived information for the batter to determine the angle of the spin and then predict the direction of the resulting deflection. Therefore, the big difference between the two- and four-seam fastballs is that—because of the visibility of vertical red stripes—the batter might be able to more quickly and easily perceive the spin direction on the two-seam version.

A video of drills spinning four- and two-seam fastballs shows the difference even more dramatically. Moreover, the difference in appearance of the four- and two-seam orientations is even more apparent for spinning baseballs in our laboratory than it is in this video. Those differences made us think that something in addition to the big red stripes distinguishes the two- from the four-seam pitches. We hypothesized that the difference might relate to the *critical flicker-fusion frequency*.

Seeing and Concealing

As the frequency of a blinking light increases, the light appears to flicker and then, at a certain frequency, it appears to be continuously illuminated. This transition point is the critical flicker-fusion frequency, which is measured in hertz (Hz), where 1 Hz equals one pulse per second. For a person in a baseball park, this frequency is probably between 40 and 50 Hz. Television screens present a different frame 60 times per second, or 60 Hz, and the pictures do not flicker. The time indicator on your VCR, on the other hand, probably blinks once a second, which clearly produces what is perceived as a blinking sequence. (At the beginning of the 20th century, movies were called "the flicks," because the 24 Hz–frame rate produced flickering images.)

A typical major-league fastball completes about 1,200 revolutions per minute, or 20 per second. For a two-seam fastball, the pair of seams that straddle the narrow isthmus of the ball would cross the field of view once on each rotation. These seams lie so close together that they probably appear as a single item. Therefore, the frequency of this pulse would be around 20 Hz, which is below the critical flicker-fusion frequency, and perhaps the ball would appear to flicker, giving the batter a clue about the spin. A batter might not have to compute the spin rate to determine whether the pitch is a fastball or curveball. Instead, he just has to determine from the flickering if the ball has topspin—a curveball—or backspin—a fastball. That could help a batter quickly predict the movement of a ball.

In contrast, each of the seams of a four-seam fastball would cross the field of view once per rotation. That produces a frequency of 80 Hz, which is above the critical flicker-fusion frequency. Therefore, a ball would not flicker, and a batter would not have this extra clue about spin. A batter would have to guess if a pitch were a curveball or a fastball. If he guesses curveball when it is really a fastball, he will expect a pitch to be slower than it actually is. Therefore, he will also expect the ball to fall farther than it actually will. Consequently, when he discovers that the pitch is higher than he predicted, he might perceive a rising fastball. This could be the reason that pitchers often say the four-seam fastball rises.

One of us (Venkateswaran) measured how far away a non-athlete with ordinary vision could see the stripes of a simulated two-seam fastball compared with the thin red lines on a four-seam fastball. The two-seam stripes showed up at roughly 16 feet versus 10 feet for the thin lines on a four-seam fastball. Professional baseball players undoubtedly have better dynamic visual acuity than this subject and can probably see the red stripes much farther away. For a professional fastball, the batter's swing starts when the ball is about 19 feet from the plate. Information gathered after this point would be of no help for that pitch.

The two-seam versus four-seam grip might also give the batter clues about the slider. For example, we surveyed 15 former major-league hitters about what they remembered about a slider. Eight remembered seeing a dot in the upper-right quadrant of the ball for a slider thrown by a right-handed pitcher. They remembered seeing this telltale sign that a pitch was a slider.

To study this, we went back to our drills. We bolted one ball to spin the way it would for a slider from a four-seam grip and another to spin as it would from a two-seam grip. The four-seam grip used for a slider causes the axis of rotation to exit the ball through a seam, which creates the perception of a red dot. With a two-seam grip, the axis of rotation exits the ball through an open patch of white leather, which eliminates a red dot. Generally, pitchers use the same grip for the fastball and slider to avoid tipping off the pitch, so using a four-seam grip works to the pitcher's advantage on a fastball, but presents a distinguishing feature on a slider.

The grip employed for a knuckleball reduces the spin rate, and the grip used for the palmball reduces the forward velocity of the ball. A knuckleball baffles a batter because of the ball's erratic behavior. Even though a batter might see the knuckleball grip as the pitcher releases the ball, this information will not help a batter much. The palmball has the same spin axis as the fastball but it has a slower spin rate and might be spotted quickly.

Physical tests show negligible differences in deflection magnitude between the two- and four-seam fastballs, curveballs or sliders. The big differences seem to be psychological—specifically perceptual. The batter can see the two red stripes and the flicker of the two-seam fastball and palmball, the two red stripes of the two-seam curveball and the red dot on a four-seam slider. All of these clues alert the batter to the type of spin on the ball and help him predict its movement.

In conclusion, the pitcher should use a four-seam grip for fastballs and curveballs to remove the perceptual clue of the two red stripes and the flicker. Then, he should use the two-seam grip for the slider, to remove the clue of the red dot. These techniques could make a fearsome pitcher even more difficult to hit. But if you're in luck, he hasn't read this article.

Bibliography

Adair, R. K. 2002. *The Physics of Baseball*. New York: HarperCollins.

Bahill, A. T., and D. G. Baldwin. 2004. The rising fastball and the perceptual illusions of batters. In *Biomedical Engineering Principles in Sports,* ed. G. Hung and J. Pallis. New York: Kluwer Academic.

Bahill, A. T., and T. LaRitz. 1984. Why can't batters keep their eyes on the ball? *American Scientist* 72:249–253.

Bahill, A. T. Baseball video. http://sie.arizona.edu/sysengr/baseball/2Seam-4Seam-Video.AVI

Baldwin, D. G., and A. T. Bahill. 2004. A model of the bat's vertical sweetness gradient. In *Proceedings of the 5th Conference of Engineering of Sport*, ed. M. Hubbard, R. D. Mehta and J. M. Pallis. Sheffield, UK: International Sports Engineering Association.

Nathan, A. L. personal Web site. http://www.physics.uiuc.edu/People/Faculty/profiles/Nathan/

Selin, C. 1959. An analysis of the aerodynamics of pitched baseballs. *The Research Quarterly* 30(2):232–240.

Watts, R. G., and A. T. Bahill. 2000. Keep Your *Eye on the Ball: Curve Balls, Knuckleballs and Fallacies of Baseball.* New York: W. H. Freeman.

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