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The Vertical Illusions of Batters

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For many decades, batters have maintained that a high, hard fastball can accelerate and rise suddenly as it nears the strike zone. They claim the ball appears to "jump" a foot or more with an explosive burst of speed. For example, in describing Dwight Gooden, Tony Gwynn states, "He rears back and throws you that high-rising fastball whenever he needs a big pitch" (Gwynn and Rosenthal, 1992). The rising fastball is often called, "smoke," "cheese," or "express."

According to principles of physics, a rising fastball (in the strike zone) is impossible unless delivered with a low side-armed or underhand release (Karnavas, Bahill and Regan, 1990; Bahill and Karnavas, 1993). Regardless of the delivery, all pitches must decelerate and all are in a free fall during flight. Yet, most batters claim the explosive riser can be thrown by pitchers with an overhand or three-quarter delivery. This widespread belief has persisted in spite of the recognition by some coaches that such a pitch cannot occur (House, 1994; Thrift and Shapiro, 1990; Mike Scioscia quoted by Will, 1990).

A related phenomenon is the curve or sinker that appears to "drop off the table." This is described as a sharp, downward break and sudden deceleration as the pitch nears the strike zone. Like the rising fastball, the breaking pitch contradicts the laws the physics - the trajectory of every spinning pitch is smooth with no sudden changes.

As these phenomena must be perceptual illusions, what is causing them?

WHAT THE BATTER DOES DURING THE PITCH

The timeline of the batter's activities during the pitch has been described by Watts and Bahill (2000) and Adair (2002). During the early phase of the ball's flight, the batter gathers sensory information about the pitcher's release point and the trajectory of the ball (Baker, Mercer, and Bittinger, 1993; Schmidt and Ellis, 1994). Concurrently, the batter compares this information with mental models of previous pitches he or she has experienced (Bahill and Karnavas, 1993; Gray, 2003). A model with characteristics that appear to be consistent with the current pitch will be used in predicting the location and time of contact.

After the observational phase, the batter computes where and when the ball will make contact with the bat. In addition, the swing/take decision is made in this second phase. Once this decision processing is complete, the batter begins the swing of the bat (and decision making occurs only with respect to checking the swing). Upon completion of the pitch, the batter gathers final information and compares it with the predictions.

In this scenario, the batter uses information gathered in the first part of the pitch to estimate time until contact and the height of the ball at contact. The batter must determine the pitch speed in order to estimate the height of the ball (the ball is in a free fall throughout its flight - the longer the pitch is in the air, the farther it falls). Underestimation of pitch speed results in anticipation that the potential contact point is lower than it actually is and can produce the illusion of the rising fastball. An analogous explanation of the breaking pitch is based on speed overestimation (Karnavas, Bahill, and Regan, 1990; Bahill and Karnavas, 1993).

EYE TRACKING STRATEGIES

The angle of the ball's trajectory with the batter's line of sight increases during the flight of the ball. Consequently, even on pitches of moderate speed, the image velocity increases until the batter can no longer maintain the image on the fovea of the eye. Thus, the batter cannot use smooth pursuit eye movement to track the pitch the entire distance to the contact point.

To compensate, batters use one of two strategies in tracking the pitch (Bahill and LaRitz, 1984). *The optimal learning strategy* allows the batter to see the ball hit the bat. The batter tracks the ball over the early part of its trajectory with smooth pursuit eye movement, then makes a saccade (leap) to a predicted point of bat-ball collision. The batter continues to follow the ball with peripheral vision, letting the ball catch up to the foveae. The batter then resumes smooth pursuit tracking with the image of the ball on the foveae. It is called an optimal learning strategy because the batter predicts where the contact point will be, and sees the ball's position when it contacts (or fails to contact) the bat. The batter uses this feedback to make better predictions when the pitcher throws a similar pitch.

The optimal hitting strategy does not allow the batter to see the ball hit the bat. With this strategy, the batter tracks the ball with smooth pursuit eye movements and falls behind late in the pitch. It is called the optimal hitting strategy because the batter keeps the eyes on the ball longer. This should allow late adjustments to the swing/take decision. We have no evidence that batters voluntarily switch between these two strategies.

Either strategy allows the batter to track the ball with smooth pursuit long enough to start the swing. Then, the momentum of the bat does not allow the batter to alter the timing or height of the swing - the only change the batter can make during the swing is to check it by pulling the bat toward the rear shoulder. Therefore, neither tracking strategy allows an adjustment for greater accuracy during the swing.

With respect to monitoring the actual height of the pitch when it reaches the potential contact point, the optimal hitting strategy might be inferior because the batter cannot see the ball at this point but must infer its position by where the ball is caught – several feet behind the contact point. Since experienced catchers catch the ball with glove moving toward the center of the strike zone (to influence the umpire), the batter could be misled in judging the height of the pitch.

BATTERS' PREDICTIONS AND THE RISING FASTBALL

Although retinal image information provides an accurate cue for the time until contact, it provides poor cues for absolute distance to the ball and for its line-of-sight speed (Bahill, Karnavas, and Regan, 1990). Classical stereoscopic depth perception is of little help in this regard. Although this system provides a precise indication of relative depth (i.e. the difference between the x-axis distances of two objects imaged near the fovea), it provides little indication of absolute distance. In tracking the pitched ball, the batter has one object, the ball, imaged on the fovea. Therefore, the batter cannot measure the distance to the ball or the pitch speed; the batter can only estimate them.

Bahill and Karnavas (1993) present the following psychophysical explanation for the rising fastball. Although retinal image information provides an accurate cue for the ball's time until contact, it provides poor cues for absolute distance to the ball and for its line-of-sight speed (Bahill, Karnavas, and Regan, 1990). Therefore, the batter can only approximate pitch speed and the time since release of the pitch. The batter uses these data in conjunction with his or her experience (mental models of past pitches) to estimate the distance to the ball. The batter then uses this estimate and the ball's retinal image velocity to estimate the vertical velocity. From the vertical velocity and the time until contact, the batter can estimate how far the ball will fall in the last one-third of its flight, thereby predicting the height of the ball at the potential contact point.

Figure 1a and Table 1 illustrate the results of simulation studies of 95 and 90 miles per hour (mph) fastballs (Karnavas, Bahill, and Regan, 1990). These simulations include the effects of gravity and aerodynamic forces of lift and drag. In these studies, both pitches were launched one degree upward with 1500 revolutions per minute (rpm) of backspin. As shown in Figure 1d, the distance from the front of the pitcher's rubber to the plate's back vertex is 60.5 feet. The pitcher released the ball about five feet in front of the rubber. Therefore, the simulated release point was 55.5 ft away from the vertex. We assume the batter's head was aligned with the front of the plate and the bat hit the ball about 1.5 ft forward of the head. The plate measures 17 inches from back vertex to front edge. Thus, the bat-ball collision point was assumed 3 ft in front of the vertex (represented by bottom row values of Tables 1 and 2). The pitcher's release point was assumed six feet high.

Now consider an example of a visual judgment error. Suppose the pitcher throws a series of 90 mph pitches, followed by a 95 mph fastball. Assume the batter uses a 90 mph mental model to interpret retinal image information about the 95 mph pitch. Suppose the batter tries to estimate the ball's vertical speed 200 msec after the ball left the pitcher's hand. The actual pitch (a 95 mph fastball) would be 28.6 ft from the vertex of the plate (Table 1). By subtracting 1.5 ft (the distance forward from vertex to the batter's eye alignment) from 28.6, we get 27.1 ft as the distance from the ball to the batter's eyes. At this distance, its vertical velocity of 6.4 ft/sec (derived from gravitational effects) would produce a retinal velocity of 13.3 deg/sec. The actual height of the ball at the potential impact point is 3.56 ft (Table 1).

However, if the batter thinks the pitch is a 90-mph fastball, this model would translate to a pitch 28.5 feet away (30.0 – 1.5) at 200 msec after release. At this distance, a retinal image velocity of 13.3 deg/sec would indicate the vertical velocity was about 6.7 ft/sec. The batter would think the ball was falling farther than it really was. The batter would predict the height at impact to be 3.33 ft and would tend to swing under the ball. Therefore, if the batter made a saccadic jump to the predicted point of contact, this point would be below the ball when the ball caught up with the eye, and the ball would seem to jump upwards - in this example by three inches. This error of visual judgment could be avoided if the batter had an accurate visual cue to the ball's absolute distance or its speed, but the batter has no direct optical sense for these two important parameters.

BATTERS' PREDICTIONS AND THE BREAKING PITCH

Spinning baseballs follow smooth parabolic trajectories. The 90-mph fastball of Table 1 and Figure 1 falls more than 2.5 ft in its flight to the plate. A plot of this vertical distance as a function of time would be parabolic. In the first, second, third, and fourth 100 msec periods, the ball falls 3.8, 6.2, 8.3, and 10.3 inches, respectively. The ball drops progressively more in each period, but it follows a smooth parabolic trajectory (in agreement with Adair, 2002). The drop can be enhanced with the addition of a vertical Magnus force due to topspin on the ball.

Table 2 shows the results of simulations of 80 and 75-mph drop curves (defined as pitches with pure topspin). Both were launched upward at an angle of 2.5 degrees with 1900 (rpm). We used a formula from Watts and Bahill (2000) to calculate the downward force due to spin.

Consider the 75-mph pitch. The ball falls 2.4 inches between 100 and 200 msec, and 7.7, 12.7, and 17.5 inches in the following 100 msec periods. Once again, the ball drops more in each period, but it still follows a smooth parabolic trajectory. This is a gradual curve rather than a sharp break. To undergo a sharp downward break a 75-mph curve would have to drop 2.4 inches in the early 100-msec period, but more than 17.5 in the last 100 msec.

To explain the breaking pitch, we will suppose the pitcher threw the 75-mph drop curve of Table 2. It would drop 25 inches in the last 150 msec before contact. However, if the batter overestimated the pitch speed and thought it was 80 mph, the batter would expect it to fall 21 inches in the last 150 msec. Thus, if the batter took his eye off the ball 150 msec before the projected time of contact, and saw it again when it arrived at the potential contact point, he would think that it broke downward 4 inches. Therefore, we suggest that the apparent break of some pitches might result from the overestimation of pitch speed in the batter's mental model - the opposite of the explanation for the rising fastball.

EXPERIMENTAL ASSESSMENT OF THE MODEL

To assess the model, Bahill and Karnavas (1993) ran experiments using a pitching machine. They threw 450 pitches to seven subjects: three adults and four boys aged 9, 11, 11 and 13. Pitching speed was set at 50 mph, with an occasional 55 mph pitch. The number of 50 mph pitches between these fast pitches was 3, 4, 5, or 6, chosen randomly. An observer (who did not know the pattern of pitches) recorded the relationship of bat and ball when the ball crossed the plate. The outcomes of the fast pitches and the two pitches before and two after were averaged, as shown in Figure 2. These results, statistically significant, show that on fast pitches batters swung below the ball, indicating they underestimated the speed of the pitch. This vertical error in judgment associated with error in speed estimation supports the illusion model.

PITCHERS' TACTICS

The pitcher's tactics are to select a pitch different from the batter's predictive model and to provide adequate vertical movement of the pitch (since vertical movement is more effective than horizontal). The most important factor in pitch selection is the change of speeds. Warren Spahn is quoted by Will (1990) as saying, "Hitting is timing. Pitching is upsetting timing." As a manager, Ted Williams[1] exhorted his pitchers to never let a batter see consecutive pitches of the same speed. Pitching coach Johnny Sain[2] expressed the same maxim, adding that the pitcher should work rapidly to allow the batter to retain a mental image of the previous pitch. In following this advice, pitchers amplify speed differences; thereby increasing the likelihood the batter will misjudge the vertical movement of the ball (Bahill and Baldwin, 2003). These tactics contribute to vertical illusions of batters.

CONCLUSIONS

Vertical illusions are caused by misjudgment of the ball's distance and speed coupled with accurate but misunderstood feedback about the prediction error. That is, the batter predicts the height of the potential contact point inaccurately, sees how far off the prediction was, and then misinterprets this error to be a phenomenon of the ball's flight. The likelihood the batter will undergo an illusion is increased by pitching tactics designed to confound the batter's judgment of pitch speed and pitch height at contact. The illusion is not directly related to the effectiveness of the pitch, however; commitment to the swing takes place before the batter experiences an illusion.

NOTES

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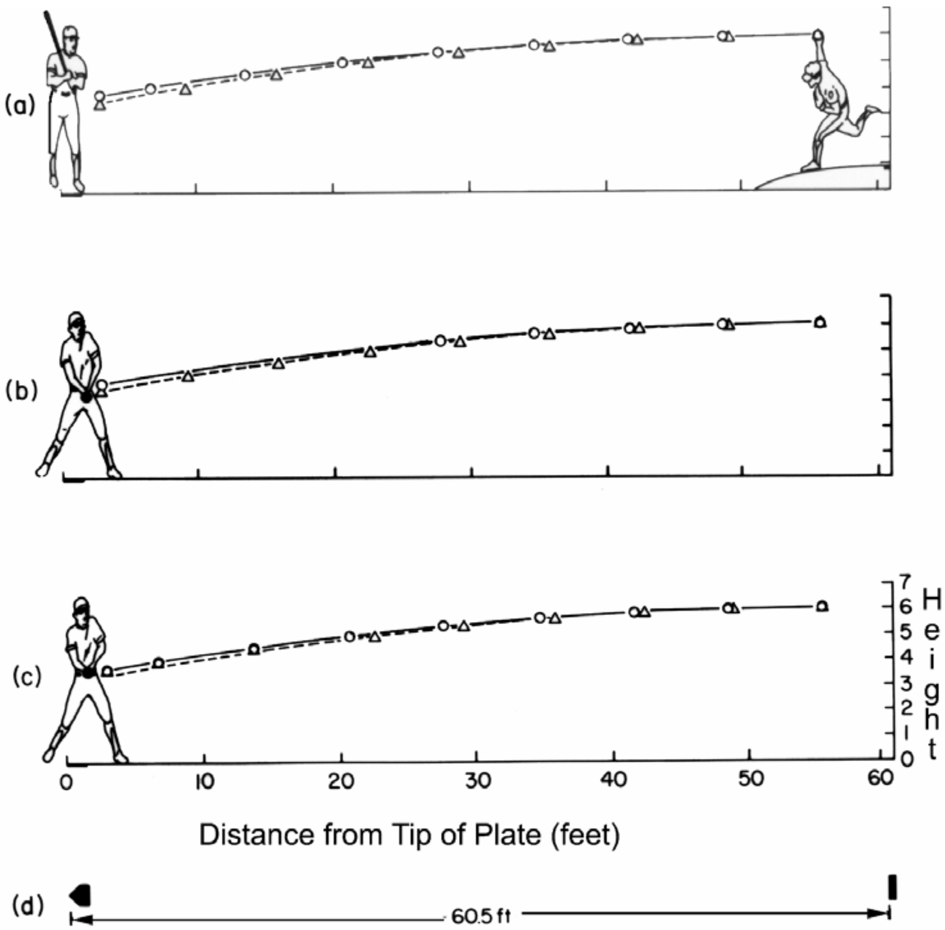

Figure 1 (a). Computer simulation of the trajectory of a 95-mph fastball (solid line and circles) and a 90-mph fastball (dashed line and triangles). The slower pitch takes longer to get to the plate and therefore drops more. (b) Computer simulation of the trajectory of a 95-mph fastball (solid line and circles), and the batter's mental model of this trajectory (dashed line and triangles) when the batter underestimated the speed of the pitch by 5 mph. (c) The same simulation as Figure 1b, except that when the ball was 20 feet in front of the plate, the "batter" realized his mental model was wrong and corrected it, thus putting his mental model triangles on the 95 mph trajectory. (d) Physical dimensions for adult baseball. [From Karnavas, Bahill and Regan, 1990].

Table 1. Trajectories of Fastballs

Time Since Release (msec)	95 mph fastball Distance (ft)	Height (ft)	Speed (mph)	90 mph fastball Distance (ft)	Height (ft)	Speed (mph)
0	55.5	6.00	95.0	55.5	6.00	90.0
50	48.6	5.86	93.3	49.0	5.86	88.5
100	41.8	5.67	91.7	42.5	5.68	87.0
150	35.2	5.43	90.2	36.2	5.44	85.6
200	28.6	5.15	88.6	30.0	5.16	84.3
250	22.2	4.83	87.2	23.8	4.84	82.9
300	15.8	4.46	85.7	17.8	4.47	81.6
350	9.6	4.05	84.4	11.9	4.05	80.4
400	3.4	3.59	83.1	6.0	3.59	79.2
404	3.0	**3.56**	83.0			
426				3.0	**3.33**	78.6

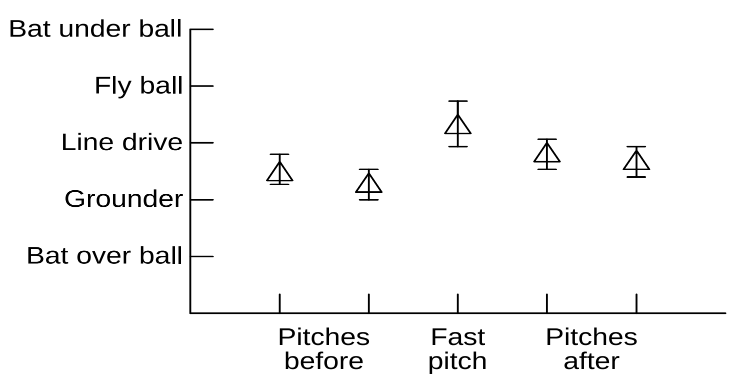

Figure 2. Averaged data from seven batters, showing that when an unusually fast pitch was thrown most batters swung under the ball. The triangles are the mean values and the vertical bars are the 95% confidence intervals. [From http://www.sie.arizona.edu/slides/risingFastball © 2003, Bahill.]
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Table 2. Trajectories of Drop Curves				
	80 mph		75 mph	
Time Since Release (msec)	Distance (ft)	Height (ft)	Distance (ft)	Height (ft)
0	55.5	6.00	55.5	6.00
50	49.7	6.20	50.0	6.18
100	44.0	6.28	44.7	6.25
150	38.3	6.24	39.4	6.20
200	32.7	6.09	34.1	6.05
250	27.2	5.83	29.0	5.78
300	21.9	5.47	23.9	5.41
350	16.5	4.99	18.8	4.93
400	11.3	4.41	13.9	4.35
450	6.11	3.73	9.0	3.67
480	3.0	**3.27**		
500			4.2	2.89
513			3.0	**2.68**