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The Effect of Fastball Backspin Rate on Baseball Hitting Accuracy

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The effectiveness of fastballs of equivalent speed can differ; for example, one element of this difference could be due to the effect of rate and orientation of ball spin on launched ball trajectory. In the present experiment, baseball batters' accuracy in hitting fastballs with different backspin rates at a constant ball velocity of 36 m/s was examined. Thirteen skilled baseball players (professionals, semiprofessionals, and college varsity players) participated in the study. The movements of bat and ball were recorded using two synchronized high-speed video cameras. The Pearson product-moment correlation coefficient (r) was calculated and used to analyze the relationship between ball backspin rate and the vertical distance between ball center and sweet spot at the moment of ball-bat impact. Ball backspin rate was positively correlated with increases in the distance from the optimal contact point of the swung bat (sweet spot) to the actual point of contact ($r = .38$, $P < .001$). Batters were most effective at the usual backspin rate for the ball velocity used. The decrease in accuracy of the batter's swing that was observed when the fastball's backspin deviated from the usual rate likely occurred because experienced batters predict ball trajectory from perceived ball speed.

Keywords: ball spin rate, batting performance, pitch trajectory

Successful hitting in baseball involves a quick perception and reaction, as well as a powerful and accurate swing. It takes only 450 ms for a 40 m·s^{-1} (90 mph) fastball to reach home plate. Since signal processing in the central nervous system and muscle activation require about 150 ms,[1] a batter has only the first 300 ms within which to make a decision about whether and where to swing. Once a decision to swing is made, the batter must accelerate a 0.9 kg bat to a speed of about 30 m·s^{-1}.[2] This is accomplished by sequential muscle actions that start with the legs, are followed by trunk movements, and terminate with arm activity.[3] Concurrently, for a successful hit to even be possible, the batter must guide the bat such that contact with the ball is made within a small area around the "sweet spot."[4–6] This is the area where the most efficient transfer of a bat's energy occurs and is typically the area between 100 and 200 mm from the top of the bat, and with a width of about 50 mm.[4,6,7] An ideal flight angle of the batted ball is produced only when the location of ball center at the point of ball-bat contact ranges from the sweet spot to about 25 mm above the sweet spot, in a direction perpendicular to the bat's long axis.[4] Since the diameter of a baseball is only 74 mm, making a clean hit is a very difficult feat.

To understand and improve hitting performance, many of the relevant physical and physiological variables have been quantified. These include ground reaction force,[8,9] movement kinematics and kinetics,[2,9–11] surface electromyography (EMG),[12,13] as well as the effects of bat grip,[14] and bat velocity.[11,15,16] These studies have largely clarified bat swing mechanics. However, in addition to having a functional swing, a successful batter must also guide the bat to a particular location at just the right time to make a clean hit. Relatively few studies relate bat control to batting accuracy. Gray[17] arranged a batting simulation and used elite hitters to demonstrate that spatial accuracy of ball-bat impact is strongly related to the speed of the pitch. Batters tend to swing over the ball at slow speeds and under the ball at high speeds.[17]

Over the course of a season, the pitch most frequently thrown is the four-seam fastball. Fastballs are commonly evaluated by their velocity, location, and movement. However, the more astute spectators are also aware that, even with roughly equivalent speeds, some pitcher's fastballs are much more effective.[18] While batters often vehemently claim that the successful hurlers have pitches that rise, a rising fastball is exceedingly unlikely, given the limitations on a pitcher's ability to put backspin on the ball.[18] One reason for the appearance of a rising ball (termed "hop") is because the batter underestimates the speed of a fastball. From the initial characteristics of each

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pitch, the batter formulates a predicted location for the ball's arrival. When the ball is near the plate and is higher than expected, it appears to jump up, or "hop."[18] Another reason for the appearance of a rising ball involves differences in trajectories of pitched baseballs of equivalent speed. This variation is caused by differences in the rate of backspin, an effect created by the Magnus force. This force opposes the gravitational force and as backspin increases, the drop of a fastball decreases.[19–22] A numerical simulation study[22] indicates that the decrease in drop produced by this force at home plate is quite significant. For a pitch with a velocity of 39 $m \cdot s^{-1}$ (87 mph), a ball with a backspin rate of 40 rotations per second (rps) will arrive 70 mm higher than a ball with a backspin rate of 30 rps. Indeed, such range of variation in the ball backspin rates exists among both collegiate and professional baseball pitchers' fastballs.[23]

However, while batters' ardent statements support the likelihood that backspin has an impact on batting performance, the impact of trajectory change due to an increase in the rate of backspin on hitting performance has not been quantified. Therefore, this study was conducted to test the hypothesis that an increase in ball backspin rate of a fastball would result in a greater distance between the sweet spot to ball center at the moment of ball-bat contact. To test this hypothesis, elite batters attempted to hit balls launched from a pitching machine at a constant speed, but with different backspin rates.

Methods

Subjects

All thirteen subjects were males and were skilled baseball field players. Age, height, and body mass (mean ± SD) were 24 ± 4 years, 1.74 ± 0.04 m, and 71 ± 5 kg, respectively. One player was a professional, one was a former professional, seven were semiprofessionals, and four were division-one college varsity players. The mean years of baseball experience was 15 ± 4 years (range, 10–25 years). Seven subjects batted right-handed, and six batted left-handed. Written consent forms were obtained from all participants. The study was approved by the Human Ethical Committee of Waseda University.

Procedure

The subjects were asked to hit thirty fastballs launched at a height of 1.6 m by a two-wheel ball pitching machine (M100, The Jugs Company Japan Ltd., Japan) located at a distance of 17 m. The batters were instructed to hit the balls in the same way that they would try to hit pitches in a game situation. Launched ball velocity was kept constant at 36 $m \cdot s^{-1}$ (81 mph) as measured with a radar gun (The Jugs Company Japan Ltd., Japan). Although the ball machine was randomly set to generate ball spin rates of 30, 40, and 50 rps (typical backspin rate of a 36 $m \cdot s^{-1}$ fastball is ~30 rps[24]), the entire set of 390 trials were treated as a continuum due to the spin rate deviations from the set values. For consistent ball projections, we fed balls to the machine with the same seam orientation. To maintain consistent ball heights at the instant of impact, before each trial we measured the drop of the baseball for each of the backspin rates used. By combining this information with a previous calibration of the effect of alteration of the anterior-posterior tilt angle setting, we were able to make a separate mark on the tilt adjustment handle for each backspin rate. This allowed us to deliver pitches with different backspin rates that arrived at the plate at very nearly the same height. The batters were not aware of this process.

After sufficient warm-up and practice hitting, the batters took their thirty hits. An aluminum bat (SC900 Victory Stage Dream King; length = 850 mm; weight = 0.9 kg; Mizuno, Japan), and official Japan amateur league baseballs (2OH100, Mizuno, Japan) were used. The subjects were instructed to place their trailing (back) foot in their preferred position and to keep the same foot position during all the trials. A 10-min break was given after 15 trials to minimize the influence of fatigue.

Data Collection

The movements of bat and ball were recorded using two synchronized high-speed video cameras (Trouble Shooter, Fastec Imaging, USA) with a frame rate of 1000 Hz and an exposure time of 0.1 ms. Camera 1 was placed 6 m away from home plate at a right angle to the line between the center of the pitching rubber and the center of home plate, and camera 2 was placed 6 m behind home plate to provide a rear view of the hitting movement (Figure 1). To establish the actual spin rate of the ball just after ejection from the pitching machine, the spin rate was determined from images taken by camera 3 (Trouble Shooter, Fastec Imaging, USA) for 150 ms after the ball's ejection. Camera 3 had a frame rate of 1000 Hz, an exposure time of 0.1 ms and was located 2 m behind the pitching machine. Ball backspin rate was determined from the images by counting the number of frames in one rotation of the ball. Hitting motion for 300 ms before and 300 ms after ball-bat impact was recorded. Launched ball linear velocity was obtained from digitized data taken from 5 ms to 1 ms before the moment of ball-bat impact. Reflective tape was attached to the top of the bat and 450 mm down from the top of the bat to aid in data analysis.

Data Analysis

The image data of bat top, bat grip, and launched ball were digitized and analyzed using a motion analysis system, Frame Dias IV (DKH, Japan). The three-dimensional coordinates were obtained with the direct linear transformation (DLT) method. The right-hand orthogonal reference frame was defined by X_{global}, Y_{global}, and Z_{global}-axes with the origin at the top of home plate (Figure 1). The Y_{global}-axis was directed from home plate to the pitcher's plate, and the Z_{global}-axis indicated a vertically

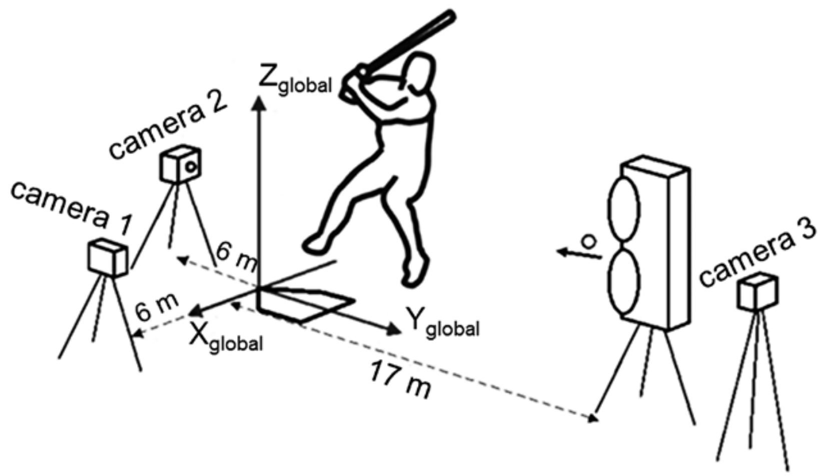

Figure 1 — Experimental setup and the space-coordinate system (X_{global}, Y_{global}, and Z_{global}) with its origin at the rear point of home plate.

upward direction. The X_{global}-axis was defined as the cross product of the Y_{global} and Z_{global}-axes. For analysis of left-handed batters, a left-hand coordinate system with the same Y_{global} and Z_{global}-axes as the right-hand coordinate system was used. For calibration, poles with three reference markers (0 m, 0.75 m, and 1.5 m from the bottom) were vertically set at nine different locations within a 1.5 m × 1.5 m square on the ground. A recording of the calibration points with cameras 1 and 2 was conducted both before and after the batting tasks. To test the accuracy and reliability of this measurement method, one investigator digitized two reference markers on a swung bat for five frames on two separate occasions. The standard error between actual value (0.450 m) and calculated value (mean ± SD = 0.453 ± 0.0004) was less than 2%. For the test-retest reliability of the distance, r was = 0.953.

To clarify the spatial relationship between the bat's sweet spot and the ball at the point of impact, the "impact Z deviation" is calculated (Figure 2). First, the bat vector is defined as lying on the long axis of the bat and as being oriented from the bat grip to the top. Then, the impact Z deviation can be computed as

$$\text{Impact } Z \text{ deviation} = \mathbf{b}_Z \cdot (\mathbf{r}_{Imp} - \mathbf{r}_{SS}) \tag{1}$$

where $\mathbf{b}_Z$ = unit vector that is perpendicular to the bat vector directed upward in the vertical plane, $\mathbf{r}_{Imp}$ = position of the ball center at impact, and $\mathbf{r}_{SS}$ = position of the sweet spot at impact. The impact Z deviation provides a measure of hitting accuracy in the direction perpendicular to the bat.

Statistical Analysis

The Pearson product-moment correlation between ball backspin rate and the impact Z deviation was calculated. The alpha level for significance was set at $P < .05$. To examine the variability of launched balls, the range, mean, and standard deviation of ball backspin rate and launched

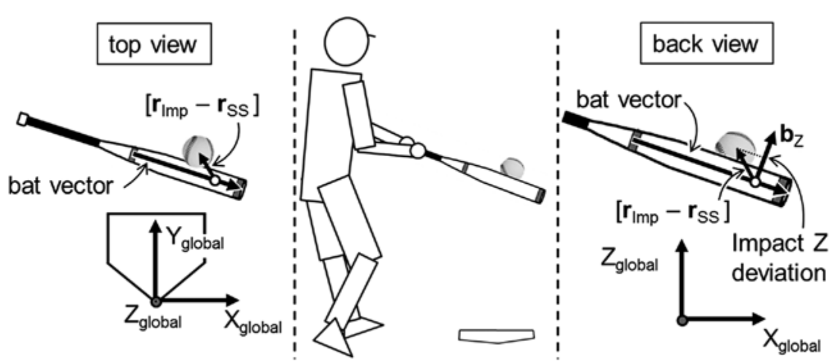

Figure 2 — Top view (left) and back view (right) at the moment of ball bat impact by a batter (middle). Impact Z deviation is the distance between the ball center ($\mathbf{r}_{Imp}$) and the sweet spot of the bat (white circle; $\mathbf{r}_{SS}$) in the direction of $\mathbf{b}_Z$.

ball velocity were calculated. The Pearson product-moment correlation coefficient (r) was calculated and used to analyze (1) the relationship between ball backspin rate and launched ball velocity, (2) the relationship between ball backspin rate and launched ball height, and (3) the relationship between launched ball velocity and the impact Z deviation. The alpha level for significance was set at $P < .05$.

Results

An increase in the launched four-seam fastball backspin rate led to an increase in the impact Z deviation. There was a significant positive correlation between ball backspin rate and the impact Z deviation ($r = .38$, $P < .001$) (Figure 3). The linear regression equation for the scatterplot is as follows: Impact Z deviation = 1.42 × (ball backspin rate – 35.83). This equation indicates that a 10 rps increase in the ball backspin rate of a launched fastball would augment the impact Z deviation by 14.2 mm.

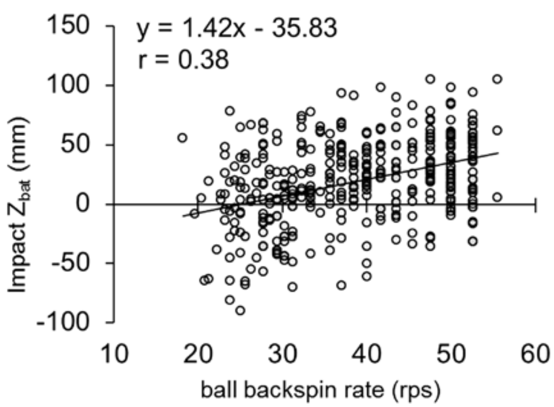

Figure 3 — Scatterplot with the linear regression equation coefficient for impact Z_{bat} at the moment of ball-bat impact against the ball backspin rate of the projected ball.

The variability of launched balls and the lack of a significant influence of launched ball velocity and ball height on the impact Z deviation were confirmed. The mean and standard deviation of launched ball velocity was 36.5 ± 0.8 $m \cdot s^{-1}$. The range of ball backspin rate for all trials was from 18.2 rps to 55.6 rps. The mean and standard deviation of ball backspin rates were 38.3 ± 9.6 rps. No correlation was observed between ball backspin rate and launched ball speed ($r = .02$, $P = .632$), between spin rate and ball height at the moment of ball-bat impact ($r = .002$, $P = .976$), between ball backspin rates and ball location at the moment of ball-bat impact in X_{global}-axis ($r = .09$, $P = 0.941$), or between launched ball linear velocity and the impact Z deviation ($r = .02$, $P = .771$).

Discussion

There was a significant positive correlation between the rate of ball backspin and the impact Z deviation between ball center and sweet spot at the moment of ball-bat impact. The pitching machine successfully maintained a constant launched ball velocity about 36 $m \cdot s^{-1}$ (81 mph) over the three settings of the pitching machine. This speed is not normally difficult for elite batters to hit. However, the distance between the sweet spot and ball center in the Z_{bat} direction became greater as ball backspin rate increased. One explanation for this result is based on the positive correlation between launched velocity and ball backspin rate that exists for real pitchers.[23,24] This correlation may allow batters to estimate spin rate from their judgment of a launched ball's velocity. Since the typical spin rate is around 30 rps for the 36 $m \cdot s^{-1}$ fastball that was used in the current study, this is likely the spin rate that the batters assumed for the pitches and the spin rate that would be most effectively hit. However, this expectation would cause a mis-estimation of the trajectory of this experiment's 36 $m \cdot s^{-1}$ fastballs that had ball backspin rates other than 30 rps.

According to a numerical simulation study, for a pitch with a velocity of 39 $m \cdot s^{-1}$ (87 mph), a pitch with a backspin rate of 40 rps will arrive 70 mm higher than a ball with a backspin rate of 30 rps.[22] The linear regression equation established by this study indicates that the increase in backspin rate referred to above would lead to an increase in the impact Z deviation of only 14.2 mm. This smaller deviation is likely explained by (1) batters' attempts to adjust the difference between their predicted ball location and the visually obtained ball location, (2) underestimation of ball spin effect due to the utilization of the bat coordinate system and tilted bat angle at impact, and/or (3) changes in perceived ball shape due to the repeated projections observed from the machine and the subsequent impacts with the bat.

McBeath[18] suggested that underestimation of the initial speed of a fastball could cause batters to have the illusion that the pitch was rising. Over the years, batters have often used the term *hop* to describe such a phenomenon. The subjects in the current study may have had this same illusion due to underestimating the backspin rate. As noted, a higher backspin rate produces less drop due to a greater Magnus force, which opposes gravitational attraction.[20] Interestingly, it was not just an increase in ball backspin rate that made a particular pitch harder to hit. When the ball backspin rates were less than 30 rps, there were trials in which subjects mis-hit pitches by swinging over the ball (Figure 3). The batters likely overestimated spin rate and thus expected a higher trajectory than the actual one.

At the high end, for actual pitchers, a ball backspin rate of 40 rps is about the maximum that has been observed for pitch velocity of 36 $m \cdot s^{-1}$ (81mph).[22] The trajectory of a pitch with this back spin rate, therefore, should be relatively unfamiliar to most batters. Since there is no record of a pitcher with a ball backspin rate of 50 rps,[23,24] the trajectory of this pitch is completely unaccustomed. In the current study, this extreme ball backspin rate was used to ensure the acquisition of a complete function relating backspin to hitting success. Once players and coaches acknowledge the importance of this relationship, they could well profit from an effort to develop better control over backspin and, possibly, find a way to vary it independently from pitch speed.

Some variation in ball backspin rate occurred due to the characteristics of the two-wheel pitching machine. The experimental settings in this study reflected an attempt to eliminate as many variables as possible. Even though all subjects used a wooden bat for their official games, an aluminum bat was used for the experiment to standardize the specification and sweet spot of the bat. In the future, it would be valuable to evaluate hit quality in an open field and to allow the batters to use the type of bat they use in league games. While the standard error for the video analysis was less than 2%, in future studies there will be an effort to achieve still-better camera resolution and a more accurate calibration to increase the precision of the measurements.

The findings in this study can benefit both batters and pitchers because ball backspin rate had a significant influence on batter's performance. What makes a four-seam fastball hard to hit is not only its speed but also the degree to which it is difficult for the batter to predict its trajectory. An increased ball backspin decreases the drop of a fastball, and a pitched ball with backspin that deviates from the norm produces an unexpected trajectory which decreases the batter's hitting accuracy. Based on this study's finding, the mean change in the impact Z deviation following a 10 rps increase in ball backspin rate was 14.2 mm. This is sufficient to change a clean hit into a ground out or fly out. Players and coaches should pay attention to not only the speed of a fastball but also to its spin and trajectory.

Batters could gain an advantage by developing an increased awareness of the fact that pitch velocity is not the only determinant for pitch trajectory and thus be better prepared to adjust to each pitcher's fastball trajectory. Because of a fastball's speed, batters must rely on their predictive ability to make a clean hit. Improved hitting success should accrue if hitters were able to augment their ability to adjust their swing in relation to different trajectories for fastballs of the same speed.

In this study, the impact of fastball backspin rate on hitting accuracy was investigated. When swinging at a machine launched ball, at higher rates of backspin, batters swung under the ball more than usual. Batters were most successful when the ball backspin rate was around 30 rps, which is the most common ball backspin rate for elite pitchers throwing fastballs at the velocity used in this experiment (36 $m \cdot s^{-1}$ [81 mph]). In the final analysis, an increased awareness of the importance of the ball backspin rate of a fastball could have significant impact on the battle between pitcher and batter.

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