THREE-DIMENSIONAL KINEMATICS OF THE BATTED BALL IN BASEBALL: THE EFFECT OF SPIN ON THE BALL TRAJECTORY AND FLIGHT DISTANCE

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The purpose of this study was to describe the three-dimensional kinematics of batted baseballs toward the same-field, center-field, and opposite-field, and estimate the effect of ball spin on trajectory and flight distance. Two collegiate baseball players performed free-batting, and they were instructed to hit a ball as far as possible in each direction. Twenty-seven trials were analyzed, and compared the ball kinematics among three hitting directions. The mean flight distance for the center-field was greater than that of the other fields. For the same-field and opposite-field, the amount of side spin components was larger than that of the center-field. Thus, it was indicated that the batted ball trajectories for the same-field and opposite-field were curved due to the Magnus force works horizontally, and flight distance tended to be shorter than that of the center-field.

KEYWORDS: Magnus force, angular velocity, side spin, opposite-field, same-field.

INTRODUCTION: For baseball batters, acquiring the ability to make a long hit, including a home run, is one of the most important tasks. There has been considerable discussion concerning about the flight distance of the batted baseball, and several researchers have investigated the effect of ball spin on flight distance (Sawicki et al., 2003; Nathan, 2008). However, these studies assumed hitting a ball toward center-field and analyzed only the effect of back spin and top spin.

In baseball games, it is also important to hit a ball toward the same-field and opposite-field, along with the center-field, due to a variety of situations during the game or courses of the pitched ball. Kidokoro and Yanai (2015) reported that balls batted toward the opposite-field had a possibility of slicing to the direction of foul territory. This result implied that balls batted toward the opposite-field had side spin component and were given Magnus force in the horizontal direction. However, no studies have attempted to quantify the three-dimensional ball spin inclusive of side spin and spiral spin. Three-dimensional kinematic data of the batted balls toward the same-field, center-field, and opposite-field might help players and coaches to consider how to make a long hit to each direction.

Therefore, the purpose of this study was to describe the three-dimensional ball kinematics batted toward the same-field, center-field, and opposite-field in baseball, and estimate the effect of ball spin on trajectory and flight distance.

METHODS: Two collegiate male baseball players (age: 21 years [both], 1.67 m, 1.79 m; 68.6 kg, 91.2 kg, respectively) participated in this study. Both participants were right-handed batters. After sufficient warm-up, each player hit fastballs launched by a two-wheel ball pitching machine at outdoor baseball field (left and right field: 91.4 m, center field: 120 m). The pitching machine was placed about 1.5 m front of the pitcher's rubber, and the mean velocity of pitched balls was 23.4±1.3 m/s. A wooden bat (length: 0.84 m, mass: 0.90 kg) and official Japan amateur league baseballs with approximately 100 small marks on the surface to calculate the angular kinematics, were used. The players were instructed to hit the balls as far as possible. Successful trials were fulfilled with two requirements (1) the batted ball landed in fair territory and (2) the flight distance was more than 60 m. The experiment was continued until at least five successful trials were recorded in all three directions of the fair territories divided into three (same-field, center-field, and opposite-field for 30 degrees each).

The movements of the balls were recorded with three high-speed video cameras (Phantom Miro, Vision Research, USA). To calculate linear kinematics such as initial velocities and launch angle, Camera 1 and Camera 2 were used with a frame rate of 500 Hz and exposure time of 1/20,000 sec (Figure 1). Three dimensional coordinates of the center of the balls were acquired by using the direct linear transformation (DLT) methods. In addition, to quantify the ball trajectory in horizontal plane, the slice angle, which was defined as the angle between the initial velocity vector in horizontal plane and the vector from the home plate to the landing points, was calculated. To calculate angular kinematics such as spin rates and spin components, Camera 3 was used with a frame rate of 1,000 Hz and an exposure time of 1/20,000 sec (Figure 1). Angular kinematics of the batted balls immediately after bat-ball impact were calculated by using the methods of Jinji and Sakurai (2006). These angular kinematic values were converted to local coordinate system. The local coordinate system was constructed with By as the initial velocity vector in the horizontal plane, Bz as the vertically upward direction, and Bx as the cross product of By and Bz. Flight distances were measured with a tape in each trial. There were two home runs in the trials, the flight distances of which were assumed to be 125 m and the slice angles were not calculated.

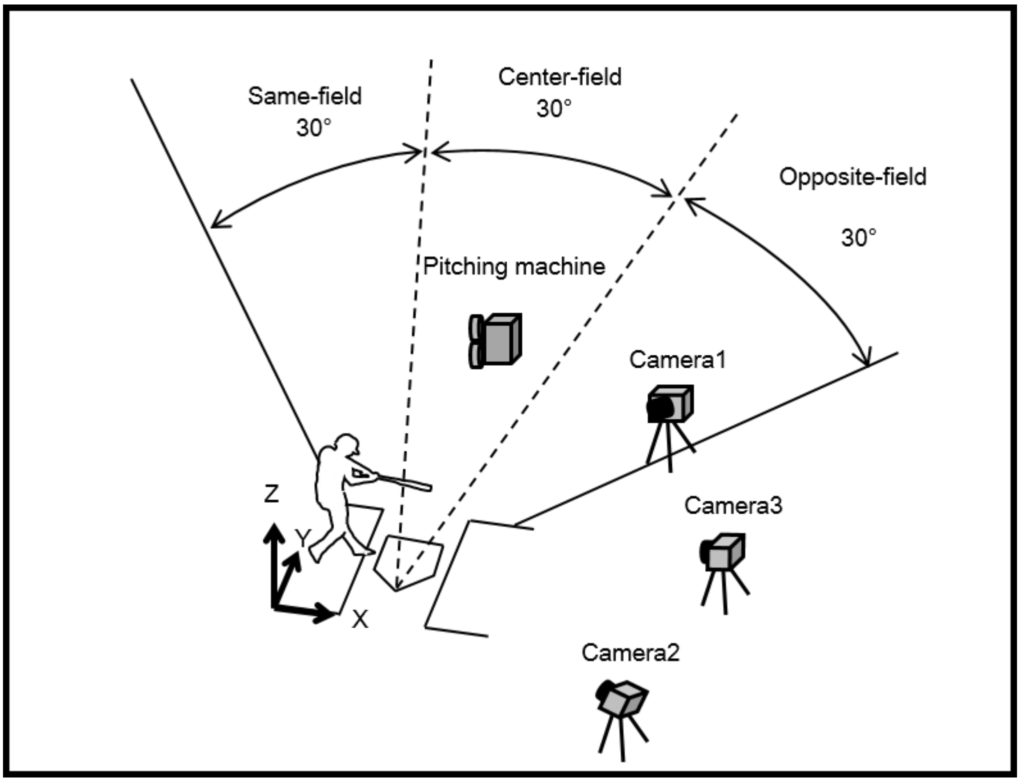

Figure 1: Experimental setup and the definition of the global coordinate system.

A one-way analysis of variance (ANOVA) and Bonferroni post-hoc test was used to examine the kinematic differences of the batted balls among each direction. The significance level was set at p <0.05.

RESULTS: The trials, in which the digitized points on the balls were difficult to be identify, were eliminated from the study, and twenty-seven trials were analyzed. Table 1 shows the mean flight distance, initial velocity, launching angle in vertical, and slice angle of batted balls for each direction. Flight distance and initial velocity for the center-field were significantly greater than those for the opposite-field. Slice angle for the center-field were significantly less than those for the other-fields. Table 2 shows the mean spin rate and spin components (back, spiral, and side). For the opposite-field, spin rates were significantly greater, and side spin components were significantly different compared to the other fields. No statistically significant differences were found in any other variables and conditions.

Table 1: Comparison of the kinematic parameters of the batted ball.

	Flight distance [m]	Initial Velocity [m/s]	Launching Angle [m/s]	Slice Angle [deg.]
Same-field	95.9 ± 14.2	39.8 ± 3.7	28.7 ± 9.5	7.4 ± 2.2
Center-field	101.9 ± 16.5	40.7 ± 3.7	29.0 ± 8.6	4.2 ± 2.4 *
Opposite-field	81.7 ± 4.1 *	36.6 ± 2.0 *	27.2 ± 6.9	9.7 ± 1.9 *

$p < 0.05$

Table 2: Comparison of the spin parameters of the batted ball.

	Spin Rate [rps]	Back Spin [rps]	Spiral Spin [rps]	Side Spin [rps]
Same-field	26.7 ± 8.2	18.6 ± 11.3	5.3 ± 11.2	10.7 ± 8.4
Center-field	27.7 ± 10.4 *	24.7 ± 9.8	4.9 ± 4.7	-6.9 ± 9.2 *
Opposite-field	41.5 ± 10.6 *	23.4 ± 10.6	-2.0 ± 7.1	-32.6 ± 8.7 *

$p < 0.05$

DISCUSSION: This study was conducted to investigate the three-dimensional ball kinematics batted toward the same-field, center-field, and opposite-field in baseball, and discuss the effect of ball spin on trajectory and flight distance.

For the center-field, the flight distances were the longest among all three directions. The initial velocity and back spin component for the center-field were greater than those for the other fields. Long flight distance was thought to be caused by high initial velocity and upward Magnus force produced from a large amount of back spin components.

For both kinematics and flight distance in the same-field trials, there were no statistically significant difference with center-field trials. However, mean flight distance for the same-field was approximately 6 m shorter than that for the center-field. Taking into account the result that initial velocity and launching angle for the same-field were almost the same as those for the center-field, it was considered that the difference between angular kinematics made the difference between flight distances. Back spin component for same-field battings was comparatively small compared with the center-field battings, and it indicated that the upward Magnus force was also small. In addition, the amount of side spin components for the same-field were larger than that for the center-field. It was indicated that ball trajectories toward the same-field were curved more than those toward the center-field. The slice angle for the same-field were greater than that for the center-field, and it was confirmed that ball trajectories for the same-field were curved more than those for the center-field. Thus, it was considered that the straight line from the home plate to the point where the ball landed in the same-field tended to be short.

For the opposite-field, flight distance and initial velocity were significantly less than those for the center-field, and spin rate were significantly greater than that for the other fields. It had been understood that opposite-field hitting was conducted by directing the bat toward the opposite-field in horizontal plane (McIntyre & Pfautsch, 1982). However, Kidokoro and Yanai (2015) found that facing the surface of the bat in the horizontal plane toward the opposite-field was not necessary, and opposite-field hitting could be accomplished by inclining the bat in the vertical plane and impacting the lower half of balls. According to the report by Bahill and Baldwin (2008), the farther the ball impact points were from the center of the bat's cross-section, the greater the spin rates and lower-velocity batted balls. The ball characteristics for the opposite-field were different from those for the other fields, the reason of which was that impacting was conducted through the mechanism that Kidokoro and Yanai (2015) reported in case of the same bat head velocity with the other fields. Focusing on spin components for the opposite-field, although the back spin component was almost the same as that for the center-field, the amount of side spin components was significantly larger than that for the other field. The slice angle was larger than that for the center-field. These results indicated that a large slice of ball trajectories in addition to less initial velocity resulted in less flight distance.

This study indicated that spin characteristic, especially side spin component, affected to the ball trajectory and flight distance.

CONCLUSION: The purpose of this study was to investigate the three-dimensional kinematics, including ball spin, of batted baseballs toward the same-field, center-field, and opposite-field, and the batted ball kinematics among three hitting directions were compared. As a result, it was revealed that the batted ball had different spin characteristics depend on hitting directions. The results in this study might help coaches and players to consider how to swing to make a long ball flight in several directions. In addition, this study revealed that the ball trajectory batted toward the same-field and opposite-field was curved. These results might assist outfielders to anticipate the location of landing points of fly balls.

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