THE FUNCTIONS OF SPIN ON SHOT TRAJECTORY IN TABLE TENNIS

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The purpose of this study was to examine the function of spin on shot trajectory during flight in table tennis. Using film images of an actual match, we computed the 3D coordinates of a ball to analyze the shot trajectories. The theoretical spin-free (TSF) ball trajectories, obtained using a similar approach to Jinji and Sakurai (2006), were compared with the observed shot trajectories. For drive shots, the shot length in the TSF ball was significantly longer than in the observed shots. However, for push shots, among the 30 shots analyzed, 17 of the TSF balls traveled a shorter distance than the observed shots, though difference between them was found not to be significant. The work done by Magnus effect on the ball was estimated by the amount of deflection in vertical direction during flight.

KEY WORDS: shot trajectory, table tennis, spin, Magnus effect.

INTRODUCTION: Table tennis players employ various kinds of shots to play games to their advantage, reacting flexibly in response to their opponent's tactics. As a table tennis ball is light and it is easy to vary its flight, shot trajectories employed by players in a match reveal great diversity. It is generally well known that ball spin is closely associated with its trajectory during flight. As the spin direction between drive and push shot is different for example, opponents have to read each shot cautiously (Seemiller & Holowchak, 1997). Thus ball spin seems to be very important not only to control shots, but also to play the game strategically. However the influence of spin direction on shot trajectory is not clear.

Previous studies have examined ball spin in baseball (Bahill & Baldwin, 2007) and tennis service (Sakurai et al., 2007). However, it is uncertain how players use ball spin during a table tennis match. Jinji and Sakurai (2006) examined the trajectories of pitched baseball and described the difference between the observed and the theoretical spin-free (TSF) trajectories by taking the aerodynamic force acting on baseball into consideration. If it is possible to determine the spin-free ball trajectory, it enables scientists to compare observed and spin-free ball trajectories and to better understand the functions of spin on shot trajectory. The purpose of this study was to examine the functions of spin on shot trajectory in table tennis by comparing the differences between the observed and the TSF ball trajectories.

METHODS: Videoing procedures and data analysis: Both left-handed men's singles finalists at the 2010 Japan Open (ITTF pro tour event) were videotaped by two electrically synchronized high speed cameras (HSV-500C^3, nac) operating at 250Hz, with 1/1000-1/1500 sec exposure time. To compute 3D coordinates of the ball, 52 markers of known coordinates were videotaped using a reference frame that encompassed the space around the table (*X* 4.525m × *Y* 6.74m × *Z* 2.5 m). A right-hand orthogonal global reference system was set on the floor such that the *Y*-axis was parallel to the long side of the table, and *Z*-axis vertical to the floor.

The film images were imported into a personal computer where the calibration landmarks and the ball were digitized using computer software (Frame-DIAS Ⅳ, DKH Inc.). Thirty successful drives and 30 push shots were analyzed with the direct linear transformation procedure. Average standard errors of *X*, *Y* and *Z* values were 9mm, 10mm, 9mm, respectively. Digitizing reliability was ensured by the *Z* values of ball bounce points on the table (table height 0.76 m + ball radius 0.02 m = 0.78 m), whose mean was 0.7 8m (SE = 7.60×10^{-4}).

Theoretical spin-free ball trajectory: Pitched baseball trajectory can be approximated by the least-square method with second-order regression equations with respect to time (Jinji & Sakurai, 2006). In this study, we computed the coordinate values of the TSF ball trajectories using an approach similar to Jinji and Sakurai (2006). Based on the assumption that the forces acting on the ball would be the sum of gravity and the drag, we computed the TSF ball trajectories, taking only the component in *Y* direction of the ball acceleration into account. The observed trajectories were examined to determine whether they could be approximated by the least-square method with second-order regression equations with respect to time. By differentiating the obtained second-order regression equations twice, the mean acceleration values of the balls were obtained. Then the product of the mean acceleration values of the balls in the *Y* direction and the orthogonal projection of the approximated balls displacement vector on each axis of the global reference system were computed. Thus the motion equations of a ball during flight are as follows:

$$\frac{d^2\mathbf{x}}{dt^2} = A_Y \cdot \mathbf{x}_{\mathbf{BOP}}; \qquad \frac{d^2\mathbf{y}}{dt^2} = A_Y \cdot \mathbf{y}_{\mathbf{BOP}}; \qquad \frac{d^2\mathbf{z}}{dt^2} = A_Y \cdot \mathbf{z}_{\mathbf{BOP}} - \mathbf{g},$$

where **g** is gravitational acceleration (9.80665m · s^{-2}), A_Y is the mean acceleration value of the ball in the *Y* direction. $\mathbf{x}_{\mathbf{BOP}}$, $\mathbf{y}_{\mathbf{BOP}}$, $\mathbf{z}_{\mathbf{BOP}}$ are the orthogonal projections of the approximated ball displacement vector on the *X*, *Y*, and *Z*-axes of the global reference system, respectively. Therefore the trajectory of the TSF ball $\boldsymbol{T_{SF}}$ is expressed as follow:

$$\boldsymbol{T_{SF}} = \left(X_0 + V_{X_0}t + \frac{1}{2}(A_Y \cdot \mathbf{x}_{\mathbf{BOP}})t^2,\ Y_0 + V_{Y_0}t + \frac{1}{2}(A_Y \cdot \mathbf{y}_{\mathbf{BOP}})t^2,\ Z_0 + V_{Z_0}t + \frac{1}{2}(A_Y \cdot \mathbf{z}_{\mathbf{BOP}} - \mathbf{g})t^2 \right),$$

where (X_0, Y_0, Z_0) and (V_{X0}, V_{Y0}, V_{Z0}) are the coordinate values of a ball at impact, the initial velocity values of a ball immediately after impact, respectively.

RESULTS AND DISCUSSION: All the shot trajectories could be approximated to a significant degree by the least-square method with second-order regression equations, irrespective of the kind of shot (R^2 = .703 ~ .999). Figure 1 provides an example of a backhand drive shot, and Figure 2 a forehand

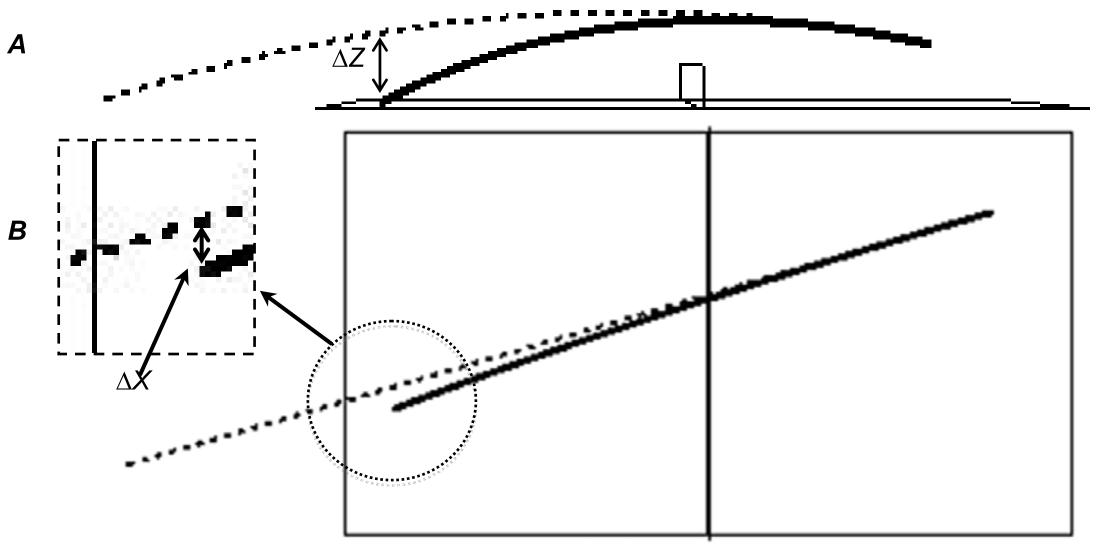

Figure 1: An example of ball trajectory in a backhand drive shot. Solid line and dashed line are approximations of the observed and the theoretical spin-free ball trajectories, respectively (*A* = side view; *B* = top view). End point of dashed line indicates the landing point on virtual table (height of the ball = 0.78m).

push shot. For drive shots, all the TSF balls traveled farther than the observed shots, and all the TSF balls continued beyond the end of the table. In contrast, for push shots, the 17 TSF balls traveled a shorter distance than the observed ones. For drive shots, TSF balls traveled significantly farther than the observed balls, however, no significant difference was found in the case of push shots (Table 1).

Obviously the players hit the ball with topspin in a drive shot, and with backspin or negligible spin in a push shot. Magnus effect acting downward is essential to enable attacking shot to land on the table. Furthermore, the deflections on *X*-*Y* plane at the landing point between the TSF and the observed balls (Δ*X*, Figure 1) are similar (Table 1). Especially in the drive shot, spin seems to be used as an essential factor, primarily to avoid a ball crossing over the line—the end of the table. The mean amount of lateral deflection in a pitched baseball is 0.2m in 18.44-m distance (Jinji & Sakurai, 2006). The values of Δ*X* in this study were not so large compared with the trajectory length during flight for the smaller mass of a table tennis ball. These results appear to indicate that the sidespin rate may be low in both the drive and the push shot. However, in an actual match, large lateral deflection is commonly seen before opponent makes racket-ball contact. Unfortunately, the effect of spin on ball rebound was beyond the scope of this study. Groppel (1984) has pointed out that spin should exert an influence on ball rebound in tennis and has described this effect in detail. Therefore it is also necessary in future study to examine the changes in trajectory after bounce in table tennis.
In this study, we found the maximum trajectory height of TSF balls to be significantly higher than those in the observed drive shots. However, in the push shot, the opposite result was obtained (Table 1). These results seem to reflect well the influence of Magnus effect. In push shot, backspin provides enough height to clear the net, which can reduce the risk of shot error.

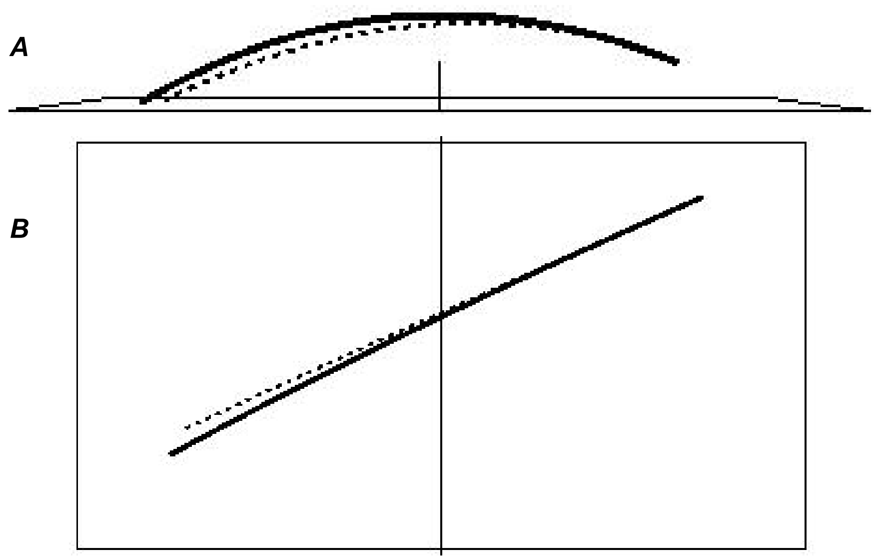

Figure 2: An example of the ball trajectories in a forehand push shot in return. Solid line and dashed line are approximations of the observed and the theoretical spin-free ball trajectories, respectively (*A* = side view; *B* = top view). End point of dashed line indicates the landing point on virtual table (height of the ball = 0.78m).

The deflection in *Z* direction at the ball bounce in the observed shots (Δ*Z*, Figure 1) is the outcome of the work done by the Magnus effect during flight (Table 1). This was significantly larger in the drive shot than in the push shot. Even though the amount of the work is very little, in the drive shot spin can also be considered essential to make the shot successful.
In this study, the approach to calculate the TSF ball trajectories is based on a somewhat simplistic assumption, yet it seems to have a certain amount of adequacy. That is, this calculated TSF ball trajectories, when compared with the observed ball trajectories, helped to highlight the generally expected spin effect (Magnus effect) on actual game shots well.

CONCLUSION: In this study, the theoretical spin-free ball trajectories in table tennis were calculated, and compared with the observed ball trajectories. The spin function on a ball was clearly confirmed especially in vertical and anterior (shot) direction. Topspin is an essential factor in drive shots to prevent balls from going beyond the line at the opponent's end of the table. By contrast, backspin is necessary in push shots to reduce the risk of shot error.

Table 1 Means (*SD*) for drive and push shot. Δ*X* is the deflections on *X*-*Y* plane at the landing point between the TSF and the observed balls.

*Significant difference between the TSF and the observed ball ($p < 0.0001$).
†Significant difference between drive and push shot ($p < 0.0001$).

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	Drive shot (n = 30)	Push shot (n = 30)
ΔX (m)	0.10 (0.08)	0.07 (0.07)
Trajectory length (m)		
Observed ball	2.91 (0.60)	1.80 (0.28)
TSF ball	6.16 (2.40)*	1.81 (0.29)
Maximum trajectory height during flight (m)		
Observed ball	1.08 (0.05)	1.03 (0.03)*
TSF ball	1.18 (0.09)*	1.02 (0.03)
The estimated work done by Magnus effect on a ball during flight (J)	0.01 (0.01)†	4.29×10^{-4} (3.06×10^{-4})

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