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A BIOMECHANICAL ANALYSIS OF THE RELATIONSHIP BETWEEN TENNIS SERVICE MOTION AND BALL SPIN

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The purpose of this study was to investigate the relationship between the service motion and the ball spin. Ten male university tennis players were participated in this study. Three-dimensional coordinates data of the players performing flat, kick and slice services were collected using an 10-camera Vicon MX system. In a similar way, the three-dimensional coordinates data of the reflective markers on the ball were collected. The ball spin is controlled by swing direction of the racquet without changing swing speed. When players put a spin on the ball, they changed swing direction rightward to avoid a head-on collision of the ball and racquet. Moreover, the swing direction was mainly controlled by not change of arm swing motion but change of upper body posture.

KEY WORDS: posture, swing direction, rotation axis.

INTRODUCTION: The service is a key shot in a tennis match, because the service is the only closed skill, and service starts every point. Adachi (1999) reported that the first service speed of players who moved on the next round stayed fast and consistent throughout the tornament. It is generally considered that the speed of the first service is one of the important elements for developing a more competitive tennis match. Most previous research of the tennis service have focused on the mechanism to generate the racquet or ball speed in flat service (e.g. Sprigings, Marshall, Elliott, & Jennings, 1994；Tanabe & Ito, 2007). On the other hand, Sato, Eguchi, Iwashima, Kubota, Iwamoto, & Umebayashi (2003) investigated the strategy of service game in men's singles at the first round and second round in Australia Open 2001. They reported that it is more effectual to use a change-up first service and to make a show of the combination with various service speeds in order to keep the service game for the players who can hit even high speed first services over 200km/h. Sheets, Abrams, Corazza, Safran, & Andriacchi (2011) investigated differences in upper body movement patterns that distinguish the difference among flat service (**FLAT**), kick service (**KICK**), and slice service (**SLICE**) techniques in the same subject. However, the literature concerning the investigate biomechanical difference among **FLAT**, **KICK** and **SLICE** in the same subject is limited. Furthermore, most of previous research about **KICK** and **SLICE** do not measure the ball spin. Therefore, it is important to analyze the relations of characteristic of the ball (speed and spin) and the player's movement for biomechanics. The purpose of this study was to investigate the relationship between the service motion and the characteristic of the ball.

METHODS: Ten right-handed male university tennis players (Height: 1.72±0.03m，Body mass: 66.2±5.4kg) were participated in this study. We constructed the makeshift tennis court that based on the International Tennis Federation's regulation on the experiment floor, and set the target area of 1m in width from the center service line on the service box (Figure 7-a). Three-dimensional coordinates data of the players performing **FLAT**, **KICK** and **SLICE** were collected using a 10-camera Vicon MX system (Oxford Metrics Inc., UK) at 250Hz. At the same time, three-dimensional coordinates data of the reflective markers on the ball (stuck with double-stick tape) were collected at 500Hz. The marker was constructed with the reflective seal on foamed styrol hemisphere. The influence to the ball spin by the reflective markers appear vanishingly small, because markers are small and soft enough. Note that, we gave the following instructions. 1) **FLAT**: serve a ball as fast as possible. 2）**KICK**: serve a ball which bound as much as possible. 3） **SLICE**: serve a ball which does not bound as much as possible. The coordinate data were smoothed using a Butterworth low-pass filter with optimal cut-off frequencies, which were determined by the residual error method (Winter, 1980). Take back was defined as a instant when the CG of the body reached its lowest point. Analysis phase was from take back to ball impact. We divided the upper body into four segments (right hand, right upper arm, right forearm, upper trunk). Then, we calculated each kinematic parameters from coordinates data. The velocity (speed, horizontal angle: the angle between X-axis and the velocity vector that was projected on an X-Y plane, elevation angle: the angle between X-Y plane and the velocity vector) of the racquet face center (face velocity) in impact was calculated from the coordinate data of the racquet face center. The ball center was estimated from reflective markers of the ball by the least-square method. The ball speed was calculated from the coordinate value of the ball center. The angular velocity vector of the ball was calculated from the time changes of the movement coordinate system that set on the ball. The number of rotations of the ball was calculated from the angular velocity vector. The lean angle of the rotation axis of the ball was defined as the angle between Z-axis and the angular velocity vector that was projected on an X-Z plane (Figure 7-b). Note that, the X-axis was defined as a parallel unit vector of the baseline (a direction toward the deuce side is a plus). The Z-axis was defined as a vertical unit vector (an upper direction is a plus). The velocity difference between **FLAT** and **KICK** or **SLICE** were divided into the following terms. 1) $\Delta \boldsymbol{V}_{posture}$: A velocity difference due to the changes of the upper trunk posture. 2) $\Delta \boldsymbol{V}_{swing}$: A velocity difference due to the changes of the arm swing (kinematics of the upper limb). 3) $\Delta \boldsymbol{V}_{utrk}$: A velocity difference due to the changes of the CG velocity and angular velocity of the upper trunk. Specifically, each term of the face velocity difference between **FLAT** and **KICK** is given by the equation

$$\boldsymbol{V}_{FACE,KC} - \boldsymbol{V}_{FACE,FL} = \Delta \boldsymbol{V}_{posture} + \Delta \boldsymbol{V}_{swing} + \Delta \boldsymbol{V}_{utrk}.$$

where,

$$\Delta \boldsymbol{V}_{posture} = (\boldsymbol{R}_{UTRK,KC} - \boldsymbol{R}_{UTRK,FL})\boldsymbol{V}_{FACE/UTRK,FL}.$$

$$\Delta \boldsymbol{V}_{swing} = \boldsymbol{R}_{UTRK,KC}(\boldsymbol{V}_{FACE/UTRK,KC} - \boldsymbol{V}_{FACE/UTRK,FL}).$$

$$\Delta \boldsymbol{V}_{utrk} = (\boldsymbol{V}_{UTRK,KC} - \boldsymbol{V}_{UTRK,FL}) + (\boldsymbol{\omega}_{UTRK,KC} \times \boldsymbol{r}_{UTRK \to FACE,KC} - \boldsymbol{\omega}_{UTRK,FL} \times \boldsymbol{r}_{UTRK \to FACE,FL}).$$

Note that, $\boldsymbol{r}_{i \to j}$is displacement vector form point $\boldsymbol{i}$ to point $\boldsymbol{j}$, $\boldsymbol{V}_{i}$ is a velocity of the point $\boldsymbol{i}$, $\boldsymbol{\omega}_{i}$ is an angular velocity of the segment $\boldsymbol{i}$, $\boldsymbol{V}_{i/j}$ is a relative velocity of point $\boldsymbol{i}$ from the segment $\boldsymbol{j}$, $\boldsymbol{R}_{i}$ is a moving coordinate system of the segment $\boldsymbol{i}$. Furthermore, $\boldsymbol{FL}$ means **FLAT** and $\boldsymbol{KC}$ means **KICK**. The face velocity difference between **FLAT** and **SLICE** was calcurated in the same way. Repeated measures ANOVA with Bonferroni multiple comparison procedure was used to evaluate the effects of form changes (with spin difference) on each kinematics parameter.

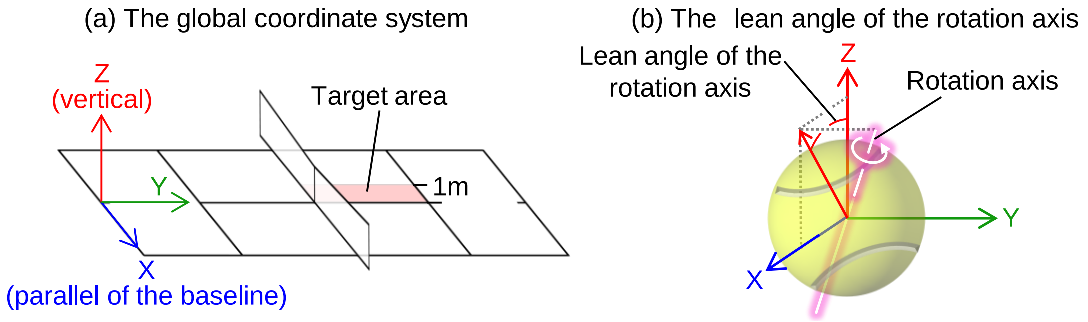

Figure 7: Definition of the global coordinate system and the lean angle of the ball.

RESULTS: Table 2 shows the face velocity and the kinematic parameter of the ball in impact. There was almost no difference about racquet face speed in impact among each other. The horizontal angle of the face velocity vector of **FLAT** was largest, it was almost swung forward (90 deg). On the other hand, the racquet was swung laterally in **KICK** and **SLICE**. The elevation angle of the face velocity vector of **FLAT** was smallest, it was almost swung horizontally (0 deg). The racquet was swung upward in **KICK** and **SLICE**. In particular, **KICK** had the largest vertical velocity. The ball speed of **FLAT** was largest and that of **KICK** was smallest. On the other hand, the number of ball rotations of **KICK** was largest and that of **FLAT** was smallest. Compared the lean angle of the rotation axis of the ball, that axis in **KICK** was more horizontally than that of **SLICE**. Figure 1 shows the ratio of $\Delta\boldsymbol{V}_{utrk}$, $\Delta\boldsymbol{V}_{swing}$ and $\Delta\boldsymbol{V}_{posture}$ of the face velocity difference of **FLAT**-**KICK** and **FLAT**-**SLICE**. The most contributed term to the face velocity difference of **FLAT**-**KICK** was $\Delta\boldsymbol{V}_{posture}$ (Figure 8-a, $\Delta\boldsymbol{V}_{posture}$**:** 63.3%, $\Delta\boldsymbol{V}_{swing}$**:** 15.0%, $\Delta\boldsymbol{V}_{utrk}$**:** 21.7%). $\Delta\boldsymbol{V}_{posture}$ was most contributed to the face velocity difference of **FLAT**-**SLICE** (Figure 8-b, $\Delta\boldsymbol{V}_{posture}$**:** 63.7%, $\Delta\boldsymbol{V}_{swing}$**:** 18.3%, $\Delta\boldsymbol{V}_{utrk}$**:** 18.0%). Figure 9 shows the superimposed stick picture of **FLAT**, **KICK** and **SLICE** during service motion (top: *view from the* global coordinate system, bottom: *view from the* moving coordinate system of the upper trunk). The racquet coordinates in the global coordinate system were different from each other (particularly at the impact). On the other hand, The racquet coordinate in the moving coordinate system were highly compatible with each other during service motion.

Table 2
Face velocity and ball parameter in impact.

	Racquet velocity in impact			Ball parameter		
	Speed [m/s]	Horizontal angle [deg]	Elevation angle [deg]	Speed [km/h]	Lean angle of rotation axis [deg]	Number of rotations [rps]
FLAT	36.2±2.0	86.2±3.4	4.4±4.2	179.6±17.1	13.2±15.8	20.1±9.2
KICK	33.9±3.2	69.4±5.1	20.5±3.5	126.3±12.1	35.6±6.7	63.9±7.7
SLICE	35.7±2.8	74.6±4.4	10.8±3.7	157.3±15.7	15.4±7.2	41.4±10.4

$*$: p<0.05 $**$: p<0.01 $***$: p<0.001

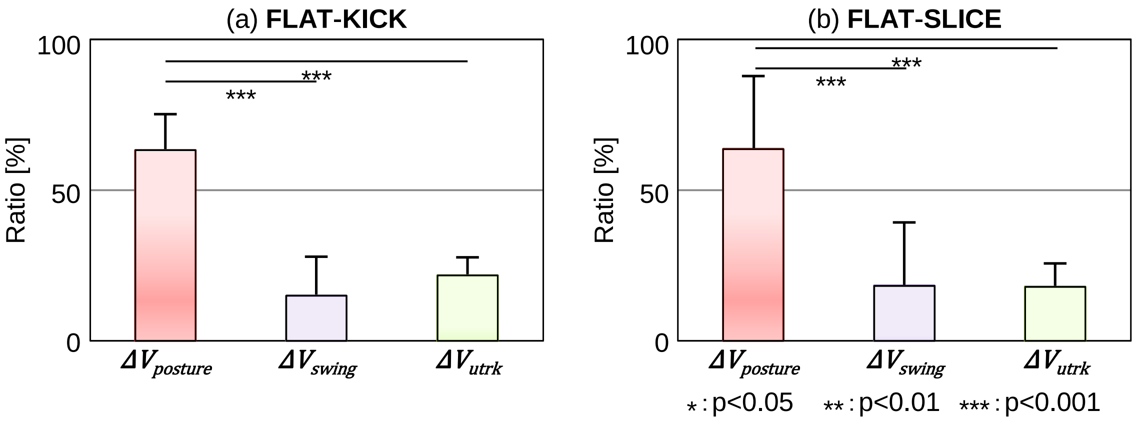

Figure 8: Each term of racquet velocity differential (between FLAT and KICK or SLICE) in impact.

DISCUSSION: FLAT had a smallest number of rotations of the ball and highest ball speed. The rotation axis of KICK was more horizontal than SLICE. From the results, players of this study were able to control the spin characteristics of the ball. There was no significant difference in face speed in impact. On the other hand, there was a significant difference in the direction of racquet face vector; KICK and SLICE were swung more laterally than FLAT. This results is in agreement with previous result by Sheets et al. (2011). It follows from this that, the characteristic of the ball is controlled by the swing direction of the face velocity vector. It is necessary to avoid the head-on collision of a ball and the racquet (the ball hit against the racquet face vertically) to generate a ball spin, and the impact point is near the vertex of the trajectory of racquet. Therefore, players changed the direction of racquet face vector not upward but rightward to avoid a direct collision of a ball and the racquet.

The impact points in the global coordinate system were different from each other at the impact. On the other hand, The impact points in the moving coordinate system were highly compatible with each other at the impact. Furthermore, the difference of face velocity vector direction was mainly coused by posture changes of the upper turnk. This means that, the impact point and swing direction were mainly controlled by not the change of arm swing motion but the change of upper body posture.

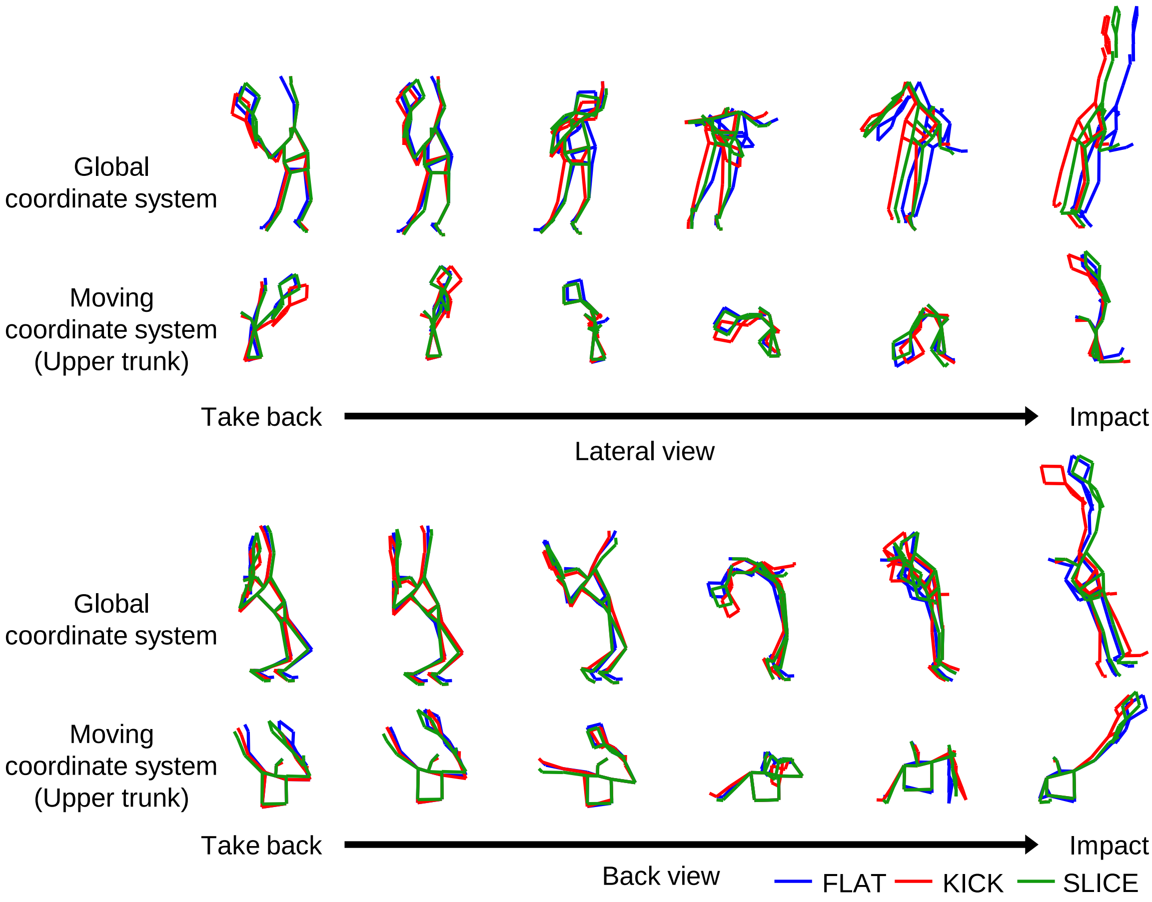

Figure 9: Superimposed stick picture of FLAT, KICK and SLICE.

CONCLUSION: The impact point and swing direction were mainly controlled by not arm swing motion but the change of upper body posture in tennis service. Players swing more laterally (rightward in back view) to generate a ball spin. Furthermore, players swing the racquet more vertically (upward in back view) in **KICK** than **SLICE** to lean the rotation axis of the ball.

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