# BIOMECHANICAL CASE STUDY ON TOSS UP MOTION IN TENNIS SERVE

**Erina OTSUKA[1] and Norihisa FUJII[2]**

**Graduate School of Comprehensive Human Sciences Master's Program in Health and Sport Sciences, University of Tsukuba, Tsukuba, Japan[1]**
**Faculty of Health and Sport Sciences, University of Tsukuba, Tsukuba, Japan [2]**

The purpose of this case study was to suggest some coachings through the analysis of relationship between the ball toss and the whole body motion variability observed during the tennis serve. Comparing the standard deviation (SD) of impact location for each serve (flat serve, slice serve, and kick serve), in Y-axis direction (forward/backward), SD of flat serve was larger than slice and kick serve. To correspond such variability, subjects i) moved along the direction of variability, ii) did NOT adjust the trunk joint motion. The small angular motion of proximal segments, such as the trunk and upper arm, significantly affect the impact location. Therefore we encouraged players to use the translational motion of upper trunk to adjust the variability.

**KEY WORDS:** tennis serve, toss, kinematics, standard deviation, variability

**INTRODUCTION:** There are many kinds of shots such as serve, smash, groundstrokes, and volley in tennis. Among those, a serve is the only shot able to approach for an attack, as well as for controlling the match. The final aim for the serve is to lower an opponent's ability of the ball return and to take an advantage on the point. Accordingly, serves require a high ball speed for decreasing opponent's preparing time, variety of ball spins, ball speed adjustment, and precise ball placement for preventing opponent's prediction and familiarity to the shot.
Serve has two phases, toss up and swing. However, many previous studies focused on swing phase. Mendes (2013) found that the players tended to stabilize the zenith height of the toss in all the practice conditions (with and without crosswind). Reid, Whiteside, and Elliott (2011) studied the effect of three common serve locations on the toss kinematics of both the first serve (FS) and the second serve (SS). They found that toss zenith and ball impact location were significantly different in the FS, while kinematics across all SS were consistent. Some coaching texts encourage servers to use the same toss for every serve (Yandell, 1999). However, according to the previous research (Abe, 2013), we receive some noise due to the nervous system even in a simple ploblem. There is a need for better understanding the correspond to the variability of toss kinematics. The purpose of this case study was to suggest some coachings through the analysis of relationship between the ball toss and the whole body motion variability observed during the tennis serve.

**METHODS:** Four male Japanese tennis players (age: 20-22 [yr], height: 1.68-1.73 [m], weight: 55-75 [kg], and experience: 7-12 [yr]) participated in this study with informed consents. Subjects performed warm-up before experimental trials, and performed three kinds of serve (FL: Flat serve, SL: Slice serve, and KC: Kick serve) to 1m-wide target area bordering the T of the deuce service box with maximal effort. Subjects hit 20 trials per one kind of serve (total of 60 trials). The global coordinate system was defined; X-axis was right and parallel with the baseline (right/left), Y-axis was forward and parallel with the singles sideline (forward/backward), and Z-axis was vertically axis (vertical). The 3D coordinates of the reflective markers on body segments (47point), racket (7point), and ball (6point) were captured by a motion capture system (Vicon MX+, 500Hz), and filtered the captured data with a Butterworth digital filter. Toss up (TUP) was defined as the instant of ball release, and impact (IMP) as the instant time of contact with racket and ball. The body, racket, and ball kinematics data were calculated from TUP to IMP. The motion from TUP to IMP was normalized as shown in Figure 1. In addition, data was separated for the torso into the upper and lower torsos, and named the "virtual trunk joint'' that connected the upper and lower torsos.

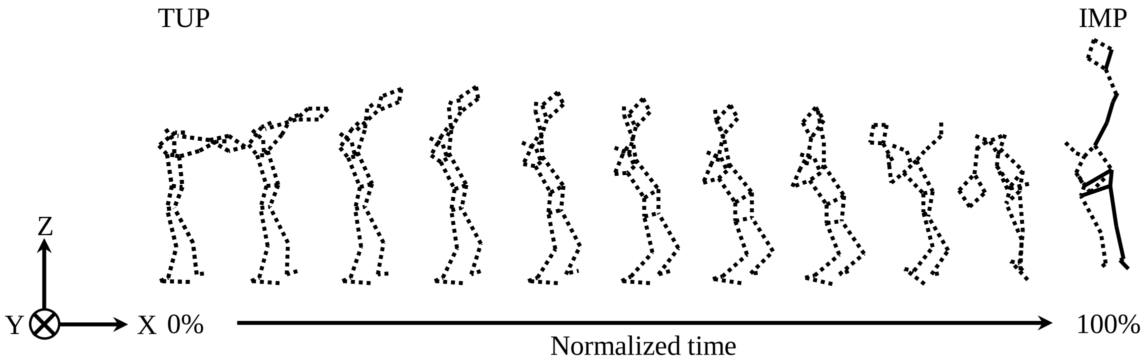


**Figure 1: Global coordinate system and analysis phase of serve motion.**

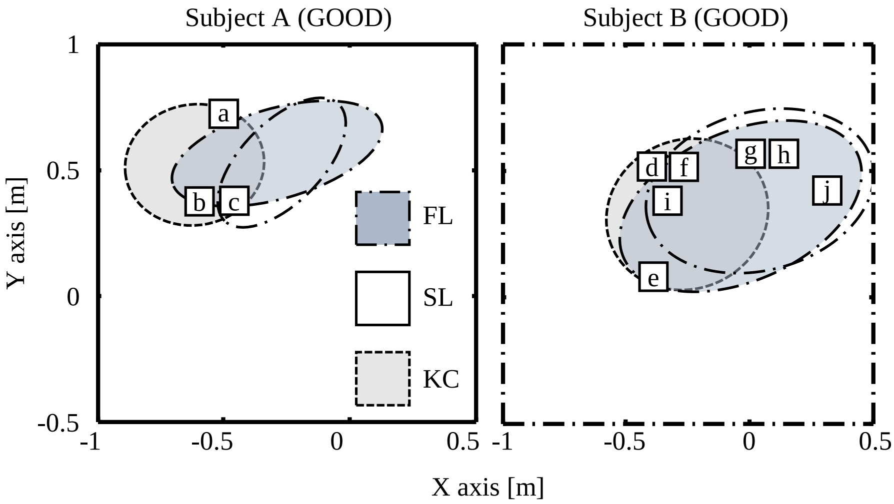


**Figure 2: Variability of IMP location (XY-axis) and analyzed trials.**

**Table1: Trial data of ball impact.**

| Subject | Trial | Variability Axis / Side | | Impact location [m] X | Y | Z | Kinds of serve | Success (○) or fault (×) |
|---|---|---|---|---|---|---|---|---|
| Subject A | a | Y | Forward | -0.52 | **0.72** | 2.47 | KC | ○ |
| | b | Y | Back | -0.51 | **0.36** | 2.58 | KC | ○ |
| | c | Y | Back | -0.47 | **0.36** | 2.50 | KC | × |
| Subject B | d | Y | Forward | -0.44 | **0.51** | 2.37 | KC | ○ |
| | e | Y | Back | -0.37 | **0.07** | 2.49 | KC | ○ |
| | f | X | Left | **-0.32** | 0.52 | 2.46 | FL | ○ |
| | g | X | Right | **0.09** | 0.57 | 2.40 | FL | ○ |
| | h | X | Right | **0.09** | 0.57 | 2.46 | FL | × |
| | i | X | Left | **-0.37** | 0.41 | 2.45 | SL | ○ |
| | j | X | Right | **0.33** | 0.45 | 2.35 | SL | ○ |

**Table2: Contribution to the displacement of the impact location.**

| Compared trial | | Variability direction (Success (○) or fault (×)) | Displacement of IMP [m] | Trunk displacement [%] | Trunk joint [%] | Shoulder joint [%] | Elbow joint [%] | Wrist joint [%] | Hand joint [%] |
|---|---|---|---|---|---|---|---|---|---|
| a | b | Y (○) | 0.565 | **51.9** | 26.6 | -5.75 | 20.3 | 6.92 | 0.11 |
| | c | Y (×) | 0.838 | **40.7** | **-0.14** | 12.2 | 41.1 | 4.34 | 1.78 |
| d — | e | Y (○) | 0.461 | **63.6** | 21.6 | 27.0 | -14.6 | 1.26 | 1.21 |
| f | g | X (○) | 0.336 | **62.9** | 26.2 | 19.9 | **111.4** | **-93.0** | -27.4 |
| | h | X (×) | 0.345 | **57.6** | **86.5** | -57.8 | **130.8** | **-86.6** | -30.5 |
| i — | j | X (○) | 0.648 | **57.7** | 12.6 | 7.03 | 9.24 | 9.41 | 4.03 |

**RESULTS:** Data were divided for four subjects into two groups (good and poor) by ranking. And data of two subjects (Subject A and B) in the good group were treated as a typical example.
Figure 2 showed the relative locations of ball impact to the toe of front foot (origin). Impact location of trials in the each of FL, SL, and KC ranged within the ellipse. Comparing the standard deviation of the impact location (SD) for each serve (FL, SL, and KC), SD in X-axis direction (right/left) was the largest of all kinds of serves. In Y-axis direction (forward/backward), SD of FL was larger than SL and KC. In Z-axis direction (vertical), SD of all serves were not large as shown in the previous research (Mendes, 2013). Similarly, the center of variability for KC was located in the most left side and backward, while there was no clear difference between FL and SL.
The number of success trials was almost the same between the subjects and kinds of serve. Among the trials, data extracted ten analysis trials (Figure 2). Trial a, b, c of Subject A, trial d and e of Subject B had large variability in Y-axis (forward/backward). Trial f, g, h, i, and j of Subject B had large variability in X-axis (right/left). Trial a to e were KC, trial f to h were FL, and trial i and j were SL. Furthermore, trial c and h were fault trials.
Table 2 shows the contribution of change in joint angles to the displacement of the impact location in XY-plane. The variability in each axis was set as 100%, and represented as a contribution to affect the direction of variability. The displacement of impact location showed the distance between two trials. In any case, the movement of trunk segment was the largest about 40-65%. Comparing between the success and fault trials (trial b and c, trial g and h), the fault trials had too large or small contribution of trunk joint movement. Moreover, the fault trials were adjusted by the trunk rotation and lean in particular. Comparing in direction of variability, trials f to g and trial h had the large positive contribution of elbow joint movement (111-130%), and had the large negative contribution of wrist joint movement (-85-95%).

**DISCUSSION:** It is considered that the toss up motion affects the swing motion. In this study, the subjects were instructed to hit three kinds of serve. Therefore, the subjects changed the direction of toss up, and controlled the postures. Since it is important to tilt the upper trunk backward to hit KC serve, the subjects performed the toss up toward the direction of left and backward to hit with those posture.
It is considered that the subjects want to repeat the same motion as much as possible to increase stability. However, the data contained some noise due to the nervous system even in a simple ploblem (Abe, 2013). It is impossible for the subject to eliminate the variability of ball toss completely. To correspond such variability, subjects i) moved along the direction of variability, ii) did NOT adjust the trunk joint motion. The small angular motion of proximal segments, such as the trunk and upper arm, significantly affect the IMP location. Therefore, the players were encouraged to use the translational motion of trunk to adjust the variability. But unfortunately, if the direction of variability is X-axis, there is a constraint to the distance that subjects move in the direction of variability. It is likely because that the directioins of hitted ball and the variability. In such a case, speculation is to combine the other motions, for

example, the translational motion of trunk and the flexion and extension of elbow joint to adjust the variability for X-axis. At the same time, it is recommended to adjust the wrist joint angle to adjust the racket posture. There were two reasons why subjects keep the racket posture. One of the reasons is to keep the impact height, the other reason is to get the ball speed. In tennis serve, hitted balls have to exceed the net. Therefore, players obtained the height of the impact. In addition, the subjects were instructed to perform the maximal effort. In order to get ball spped, it is important to use the internal rotation of shoulder (Elliott, B. Marshall, N. and Noffal, J., 1995). So the subjects changed the wrist joint angle to keep the impact height, and to make it easy to use internal rotation of upper arm.

**CONCLUSION:** Because the toss up motion affects the swing motion, it is important to do proper coaching of the toss up motion. This study showed analysis of relationship between the ball toss and the whole body motion kinematics in tennis serve. Comparing to standard deviation of impact location (SD) for each serve (Flat serve, Slice serve, and Kick serve), SD in X-axis direction (left/right) was the largest. In Y-axis direction (forward/backward), SD of FL was larger than SL and KC. In Z-axis direction (vertical), SD of all serves were small. To correspond such variability, subjects i) moved along the direction of variability, ii) did NOT adjust the trunk joint motion.

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