KINEMATIC ANALYSIS OF TENNIS VOLLEY

Hsiao-Wen Chao, Chen-Fu Huang, Hsiao-Han Chao, Yu-Da Chen, and Gin-Chang Liu*

Department of Physical Education, National Taiwan Normal University, Taipei, Taiwan
***Department of Athletic Performance, National Taiwan Normal University, Taipei, Taiwan**

The purpose of this study was to examine selected kinematic variables of the tennis volley. Fifteen skilled tennis players performed volley strokes under five (right, right-middle, middle, left-middle, left) different lateral contact locations. A ball machine was modified so subjects could not predict the ball trajectory before it was released from the machine. Two high-speed cameras (250Hz) were genlocked to collect the data and the Kwon3D software was used to analyze the temporal and kinematic variables. The results indicated the middle location have the shortest pushing (0.249s) and stroke (0.466s) time than other locations. An ipsilateral side step occurred more often in Backhand (BH, 86%) than in Forehand (FH, 67%). In addition, more FH volley (55%) was used than BH (45%) when return the ball from middle location.

KEY WORDS: biomechanics, temporal, lateral movement.

INTRODUCTION: Tennis volley is an important offensive technique in men's singles and both men's and women's doubles play. The volley is divided into four phases – backswing, forward acceleration, impact and follows through. The volley is usually performed under a time stress due to the reducing distance between the players. The anticipation, fast reactions, and quick movement are critical for performing good volley stroke.

Elliott et al. (1988) studied the tennis volley by using average pre-impact ball velocity of 15.7 m/s and found that subjects performed a significant difference on backswing, moving the racquet behind the hitting shoulder for both FH and BH strokes. Elliott et al. (1988) also found that the upper limb and racket tended to move as a single unit, but movement occurred at the shoulder, elbow and wrist joints.

Chow et al. (1999) examined the temporal and ground reaction force of tennis volley. Seven skilled players performed volley strokes under different contact location, ball contact height, and ball speed. They found the average reaction times of backhand (BH) volley was significantly shorter than the forehand (FH) volley. The FH used more ipsilateral side step (45%) then the BH (34%) on volley stroke. However, their study did not report the kinematic data on volley stroke.

Chow et al. (1999) studied muscle activation during the tennis volley and find that the muscle activity increased with increasing ball speed, the extensor of carpi radials was more active compare to the flexor of carpi radialis during both FH and BH volleys. They also find that the forearm muscles activity increase shortly before the ball impact and it indicated that the players did not tighten their grip and wrist until the pre-impact to the ball.

The purpose of this study was to examine the characteristic of volley stroke movement on different lateral locations. Specifically, the present study focused on the temporal characteristics and the upper extremity joint angle and velocity during the tennis volley.

METHODS: Fifteen skilled male tennis players served as subjects (age 21.3 ± 1.5 yr, height 180.3 ± 5.5 cm, mass 73.1 ± 6.61 kg). Twelve subjects were right-handed and the three others were left-handed and had played competitive tennis for many years. All subjects were all-court players and have competed in both singles and doubles, in the meanwhile, subjects can execute volley extensively. Subjects all signed informed consent before the test.

The test was conducted at an outdoor tennis court. A tennis ball machine (Prince TE38-11) was placed behind the baseline on the opposite side of the count from the subject. The ball machine was mounted on an iron board which have four wheels and were 59 cm from the ground. The researcher can control the lateral location of the ball's trajectory by rotating the iron board. Marks were placed on the ground near the rear right corner of the board showing the lateral of machine which allowed the repeatable of ball placement. The ball machine was adjusted to the fastest speed which projected the ball at 21.3 m/s. To prevent the subject from anticipating the ball placement, a black paper board (170 cm high × 60 cm wide) with an opening (35 high × 50 cm wide) was placed in front of ball machine (Figure 1).

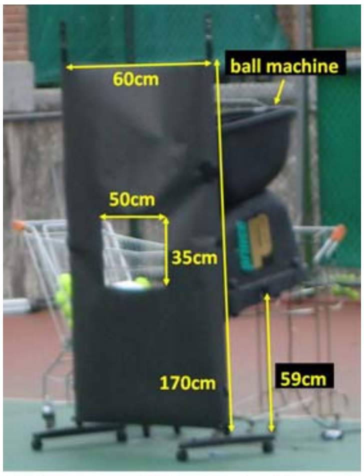

Figure 1 - Experiemental setup: ball machine and black paper board.

Due to the distinct noise from the pressure build up from the ball machine, the subject could anticipate the ball release. During the test subject adopted a ready position from 3 m behind the centre of the net. The ball machine projected three balls from the baseline into the count continuously with 2.26 sec interval. Five trials were collected for each subject with 15 volley strokes. The rest interval between trials was 1.5 minutes. The ball was projected into five lateral locations randomly with three balls on each trial. Five lateral locations were left (2 m from the centre line of court), left-middle (1 m), middle (0 m), right-middle (1 m), and right (2 m). For the left-handed subjects, however, the left location was on the forehand side of subjects.

Two high-speed cameras (Fastec Imaging) operated at 250 Hz were genlocked to capture the volley stroke (Figure 2). Twenty-one body landmarks (head, ears, shoulders, elbows, wrists, fingers, hip, knees, ankles, heels, and toes) were digitized and analyzed with the Kwon3d motion measurement system. The Butterworth 4th order zero lag digital filter with the 6 Hz cut-off frequency was used to filter the body landmarks data. The second central different differentiation method was then used to determine velocities.

A 25-points calibration frame (Peak Performance Technologies, Inc., Centennial, CO, USA.) was used at the beginning and the end of the data collection session. The collected motion data was calibrated with Direct Linear Transformation (DLT) and analyzed in Kwon 3D motion analysis system (Visol Inc., Seoul, Korea).

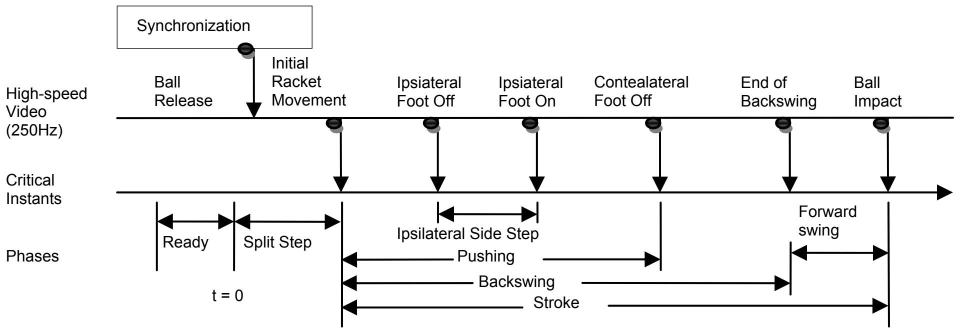

Figure 2 - Phases of a tennis volley defined by criticed instants identified from the video images.

For the purpose of this study, phases of a volley were defined as follow (Figure 2):

- Split-step phase — which is the time of the small jump step before volley action, and it defined as the time of the toes off ground until the toes contact the ground.
- Ipsilateral side step phase — which is defined as a step of the foot on the same side of oncoming ball before the crossover step of other foot.
- Pushing phase — from initial racket movement to contra lateral foot off.
- Backswing phase — from the ball release to initial racket movement.
- Forward swing phase — from the end of backswing to ball impact.
- Stroke phase — from the initial racket movement to ball impact.

- All time phase — which is defined as the time from split step to ball impact and follow through (until the racket move backward).

The means and standard deviation were used to compute for all phase times. The temporal parameters were obtained by counting the numbers of video field on the file. One-way analysis of variance (ANOVA) was used to examine the effect of the volley in five lateral locations on selected temporal and kinematic variables. α=.05 was used to indicate the statistical significance. Furthermore, a LSD post hoc comparison was used if the result achieved the significant level.

RESULTS AND DISCUSSION:

TABLE 1. Durations of different phases of a tennis volley.(s)

Lateral Location	Phase Time (s)						
	Split-Step	Ipsilateral Side Step	Pushing *(α=.002)	Backswing	Forward Swing	Stroke *(α=.006)	All Time
Right	0.314 (0.095) [15]	0.150 (0.095) [14]	0.324*4 (0.083) [15]	0.391 (0.064) [15]	0.135 (0.071) [15]	0.526*1 (0.057) [15]	1.092 (0.209) [15]
Right-middle	0.363 (0.088) [14]	0.156 (0.081) [9]	0.365*1 (0.125) [15]	0.396 (0.131) [15]	0.131 (0.027) [15]	0.527*2 (0.147) [15]	1.108 (0.164) [14]
Middle	0.330 (0.103) [14]	0.120 (0.077) [3]	0.249*123 (0.089) [15]	0.345 (0.062) [15]	0.121 (0.23) [15]	0.466*3 (0.062) [15]	1.035 (0.257) [15]
Left-middle	0.320 (0.085) [15]	0.145 (0.090) [10]	0.389*2 (0.133) [15]	0.403 (0.099) [15]	0.131 (0.020) [15]	0.534*4 (0.104) [15]	1.036 (0.165) [15]
Left	0.332 (0.067) [14]	0.271 (0.191) [12]	0.418*34 (0.135) [13]	0.451 (0.123) [13]	0.165 (0.36) [12]	0.624*1234 (0.112) [12]	1.150 (0.240) [13]

*Same number indicated significant post hoc comparison between two groups.

There were significant differences on pushing and stroke phase among five of the volley locations (Table 1). The middle locations have the shortest pushing (0.249s) and stroke (0.466s) time on tennis volley, however, there were longest tennis volley times on the left locations, pushing (0.418s) and stroke (0.624s).

TABLE 2. Lateral Location ball velocity at impact.(m/s)

	Right	Right-middle	Middle	Left-middle	Left
Ball Velocity	16.52 (6.04) [14]	18.95 (3.98) [15]	18.93 (3.32) [14]	17.54 (2.81) [15]	14.63 (4.78) [12]

TABLE 3. Lateral Location Ball height at impact.(cm)

	Right	Right-middle	Middle	Left-middle	Left
Ball Height	109.7 (42.5) [14]	106.8 (32.1) [15]	116.8 (39.1) [13]	122.1 (18.6) [13]	122.5 (34.7) [13]

The ball velocity at volley impact on five locations were listed on was from 14.63 m/s to 18.95 m/s (Table 2). No significant difference was found on ball velocity and contact height on five locations (Table 3).
The peak wrist linear velocity of backswing and forward swing at the ball pre-impact were showed at Table 4. No significant difference among five locations and peak wrist linear velocity on forward swing; however, there was a significant difference on backswing. The further locations (both forehand and backhand) have a higher wrist velocity than the shorter location, furthermore, the left wrist velocity was greater than right wrist indicated that the

players performed a fast backswing on backhand than forehand volley stoke.

TABLE 4. Peak wrist linear velocity at backswing and forward swing at the ball pre-impact.(m/s)

Lateral Location	Backswing *(α=.000)	Forward Swing
Right	4.64*1235 (0.77) [13]	4.81 (0.57) [13]
Right-middle	3.73*1 (1.17) [15]	4.29 (0.75) [15]
Middle	3.22*4 (0.73) [14]	4.45 (0.76) [14]
Left-middle	4.94*2 (1.08) [15]	4.58 (1.00) [15]
Left	5.45*345 (1.12) [14]	5.07 (1.12) [14]

The joint and racket angle of the upper extremity during the volley stroke at ball impact were showed at Table 5. There was no significant difference on wrist and racket angle at ball impact, which is in agreement with coaching instruction for the volley ball impact, the player should tighten the grip for push the ball forward, however, the shoulder and elbow angle have significant differences among different lateral location at volley ball impact. As expected, the middle location (0 m) have the smallest shoulder and elbow angle at ball impact, and on the other hand, the present investigator doubted the players have to extend their elbow and shoulder during the volley stroke, it may have resulted the greater shoulder and elbow angle on the right and left location.

TABLE 5. Upper extremity joint and racket angle at the ball impact.

Lateral Location	Shoulder angle *(α=.000)	Elbow angle *(α=.004)	Wrist angle	Racket angle
Right	100.7^{*124} (27.2) [14]	152.1^{*12} (25.8) [14]	163.5 (11.1) [14]	134.9 (23.3) [14]
Right-middle	72.1^{*13} (31.7) [15]	142.5 (20.0) [15]	158.48 (13.8) [15]	120.9 (17.4) [15]
Middle	52.3^{*3456} (21.2) [14]	132.4^{*23} (16.7) [14]	156.9 (15.4) [14]	115.7 (14.8) [14]
Left-middle	82.9^{*5} (22.6) [15]	145.9^{*4} (16.2) [15]	159.9 (13.2) [15]	124.0 (20.7) [15]
Left	97.4^{*26} (17.0) [13]	160.5^{*134} (11.9) [13]	161.7 (10.7) [13]	124.9 (19.3) [13]

The left location (43%) had the lowest percentage of ball return than the right (59%), right-middle (53%), middle (63%) and left-middle (67%) location. The researchers suggested that those results (lower sucessful rate on left location volley) may due to the longer distance for player to return the ball with backhand.
When the ball was projected to the middle location (to the player directly), subjects prefered to perform the FH volley (55%) than BH volley(45%), hence, this result may suggested that players can master the FH under the similar situation.

CONCLUSION: The purpose of this study was to examine the selected kinematic variables under five tennis volley locations. The present study concluded that there are lower sucessful rate when player perform a deep volley return with backhand. In addition, players prefer to perform the FH volley than the BH volley when the ball is projected to them directly.

REFERENCES:

Chow, J. W., Carton, L.G., Lim, Y. T., Shim, J. H., Chae, W. S. & Kuenster, A. F. (1999). Muscle activation during the tennis volley. *Medicine & Science in Sports & Exercise*,*31*(6), 846-854.
Chow, J. W., Carlton, L. G., Chae, W. S., Shim, J. H., Lim, Y. T., & Kuenster, A. F. (1999). Movement characteristics of the tennis volley. *Medicine & Science in Sports & Exercise*, *31*(6), 855-863.
Elliott, B., Overheu, P., & Marsh, A. (1988). The service line and net volley in tennis: a cinematographic analysis. *Australian Journal of Science and Medicine in Sport*, *20*, 10-18.