DIRECTIONAL CONTROL IN TENNIS SERVES PERFORMED BY ELITE PLAYERS

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This study quantified the pre- and post-impact 3-D kinematics of the ball and racquet during the serves that landed at different locations performed by five male and four female professional tennis players. Data were collected during competition using two high-speed cameras (200 Hz). Two first serves -- one landed near the center line and the other near the side line -- were analyzed for each subject. A 2 x 2 ANOVA ($\alpha < .05$) was performed for each parameter. The results indicate that the males had significantly greater post-impact ball and racquet velocities than their female counterparts. Though not statistically significant, the ball tended to travel to the left less during the toss and have lower post-impact velocity for serves that landed near the side line. Altering the toss might be one of the strategies used by players to control ball direction in the serve.

KEY WORDS: kinematics, tennis serve, gender difference

INTRODUCTION: Although the mechanics of the serving motion have been examined [see the review by Elliott (1988)] and discussed in many tennis texts, the techniques or strategies used by tennis players in controlling ball placement in the tennis serve are rarely investigated or discussed. The purpose of this study was to determine the kinematic characteristics of the ball and racquet that are related to the control of direction in the tennis serve performed by elite players. Specifically, it was the intent of this study to examine how elite tennis players control the ball placement in their serves.

METHODS: Data were collected during the 1996 Atlanta Olympic Games. Two synchronized high-speed video systems (JC Labs, Inc., Mountain View, CA 94043, field rate 200 Hz) were used to record the serving motions of the subjects performed on the deuce side (right side of the baseline). To determine the landing locations of the balls delivered by the servers, a Panasonic AG-450 S-VHS (60 Hz) camcorder was used to record the overview of the whole court. All cameras were mounted on brackets that were fixed on permanent structures in the spectator area.
All matches completed in the stadium court were recorded. In addition, the speeds of the serves, as determined by radar devices displayed at court sides, were manually recorded. Although more than 300 legal serves performed by 16 females and 14 males were available, the trials from only nine of these players were usable for the purpose of this study (left-handers were excluded). The subjects in this study included four females (world singles ranking ranged from 2 – 28, age 24 ± 3 yrs, height 1.73 ± 0.11 m, mass 61.3 ± 8.8 kg) and five males (ranking 3 – 137, 24 ± 2 yrs, 1.83 ± 0.5 m, 76.8 ± 6.1 kg). Two first serves performed by each subject, one which landing near the center line and the other which landing near the sideline were selected for subsequent analysis. When there was more than one trial available for each landing location, the one with the highest speed (determined by a radar device) was used.
Data Reduction: A Peak Motion Measurement System was used to obtain 2-dimensional (2D) coordinate data from the video recordings. For the selected trials, the ball and four points defining the orientation of the racquet (top, bottom, left, and right of the racquet head) were digitized starting approximately10 fields before to 6 fields after the impact. In addition, the left toe and ball were also digitized from the field showing the instant of ball release from hand. The multi-phase calibration procedure (Challis, 1995) for the DLT method (Abdel-Aziz & Karara, 1971) was used for 3-dimensional (3D) space reconstruction from the 2D images. The calibration errors for the combined calibration space for different sessions ranged from

8.86 to 9.99 mm. The 3D coordinates were transformed to a trial specific coordinate system – principal axes parallel to the sideline (x-direction, pointing away from the server toward the net), baseline (z-direction, pointing from left to right when viewing from behind the server), and the vertical (y-direction, pointing upward), respectively, and the origin located at the vertical projection of the left toe (LT) on the court at the instant of ball release from hand. In other words, the antero-posterior (A-P) and medio-lateral (M-L) locations of the ball reported are locations relative to the LT.

Dependent variables were selected based on a model proposed by Chow et al. (2003). The velocity of the ball at hand release was determined using the locations of the ball at release and at impact, the known elapse time, and the equations for uniformly accelerated motion. The pre-impact velocity of the racquet head (intersection of the line joining the left and right and the line joining the top and bottom of the racquet head) and post-impact ball and racquet velocities were determined from location data in the first and second video fields before the impact and the first and second video fields after the impact, respectively. The orientation of the racquet head was represented by a unit vector perpendicular to the racquet face and pointing away from the side making contact with the ball. Details of the experimental setup and data reduction procedures can be found in Chow et al. (2003).

Data Analysis: Group means standard deviations were computed for each of the parameters measured for each gender/landing location combination. For each parameter, a 2 x 2 (gender x landing location) analysis of variance (ANOVA) with repeated measures in the second factor was used to test for significant differences between males and females and between the two landing locations.

RESULTS AND DISCUSSION: The speeds of the serves, as recorded by a radar device, were 180.9 ± 12.4 and 140.7 ± 9.6 km/h for the males and females, respectively. Descriptive statistics are presented in Table 1.

Kinematics of the Ball During the Flight Phase Before Impact: Trends were found in the medio-lateral pre-impact ball location (p = 0.067), medio-lateral ball displacement during the toss (p = 0.076), and medio-lateral ball velocity at ball release/pre-impact (p=0.075) (Table 1). These trends suggest that, when compared to center line serves, the ball tended to travel to the left (-z direction) less during the toss for serves that landed near the side line. No significant main effects or interactions were found in any ball characteristics associated with the toss (the first 5 variables in Table 1). Even though there may be differences in lateral location of the ball at impact between side line and center line serves, the differences (e.g, 10 cm) are probably too small to be meaningful to a receiver. Jones and Miles (1978) found that expert tennis players were, on average, only 40% accurate in

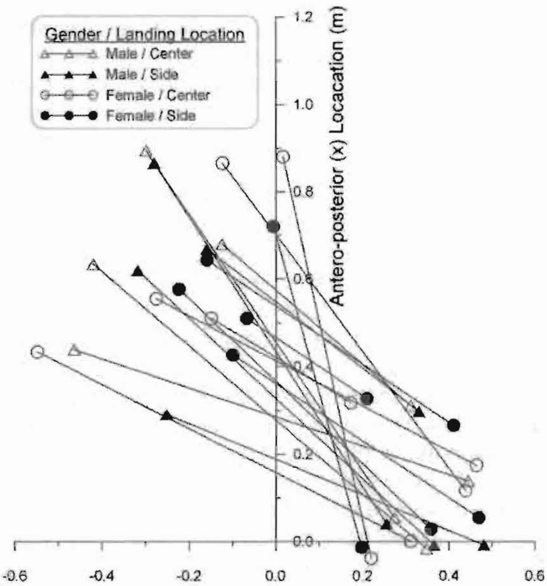

Figure 1 An overhead view of the horizontal displacement of the ball from the instant of release from the hand (data points at lower right) to the instant of ball/racquet impact. Data from the same trial are connected by a straight line. The origin is the location of the left toe at ball release.

estimating whether the ball was served to the left, right, or directly toward the experts. Goulet, Bard, and Fleury (1989) found that observers could tell the type of serve, flat or twist, but were not able to determine the direction that the ball was hit.
Post-impact Ball Velocity: Significant differences between males and females were found in the A-P, vertical, and resultant velocities of the ball at post-impact. This is not surprising because of the differences in strength between the two genders in general. Significant landing location main effects were found in the A-P and M-L post-impact ball velocities. The difference in M-L post-impact ball velocity is expected because of the difference in landing location. The serves toward the side line tended to have lower post-impact resultant velocity than serves that landed near the center line ($p = 0.076$). Such tendency may be explained by two reasons. First, players may to be more aggressive when serving toward the center line because the net near the center is lower and providing a greater margin of error. Second, players may use a slice serve when they try to place the ball near the side line.
Racquet Kinematics: Significant gender main effects were found in the M-L pre-impact racquet velocity, A-P post-impact racquet velocity, and A-P component of the unit vector that represents the pre-impact racquet orientation. It is obvious that the male subjects were able to generate much greater racquet speed than their female counterparts in this study. The A-P racquet face component represents the degree of forward facing of the racquet. For example, the A-P component will be 1 (i.e., both the M-L and vertical components are zero) when the racquet is directly facing forward toward the x direction. The smaller A-P racquet face component (greater deviation from the forward facing orientation) for males may suggested that male subjects in this study applied more spin to the ball in their serves. No landing location main effects or interactions were found in any of the kinematic parameters of the racquet.

CONCLUSION: Although altering the toss might be one of the strategies used by players to control ball direction in the serve, the practical significance of different tosses appears to be minimum because the change in ball trajectory is too small to be detected by a receiver. The lack of significant differences between the two serve locations seems to suggest that players use different combinations of adjustments in the toss, racquet swing, and racquet orientation at impact to control ball placement.

Table 1 Mean (SD) of ball and racquet kinematics.

	Male/Center	Male/Side	Female/Center	Female/Side
Ball Location at Ball Release (m)				
Antero-posterior	0.12 (0.14)	0.08 (0.15)	0.11 (0.14)	0.13 (0.15)
Vertical	1.67 (0.19)	1.62 (0.19)	1.53 (0.28)	1.55 (0.26)
Medio-lateral	0.34 (0.07)	0.36 (0.09)	0.32 (0.13)	0.33 (0.12)
Pre-impact Ball Location (m)				
Antero-posterior	0.66 (0.19)	0.61 (0.24)	0.65 (0.21)	0.57 (0.11)
Vertical	2.58 (0.31)	2.58 (0.30)	2.44 (0.25)	2.45 (0.28)
Medio-lateral^	-0.33 (0.15)	-0.25 (0.07)	-0.22 (0.21)	-0.11 (0.08)
Ball Displacement before Impact (m)				
Antero-posterior	0.54 (0.25)	0.53 (0.24)	0.53 (0.29)	0.44 (0.21)
Vertical	0.91 (0.18)	0.96 (0.16)	0.91 (0.06)	0.90 (0.08)
Medio-lateral^	-0.67 (0.21)	-0.61 (0.12)	-0.54 (0.28)	-0.44 (0.18)
Ball Velocity at Ball Release (m)				
Antero-posterior	0.56 (0.28)	0.56 (0.28)	0.59 (0.26)	0.52 (0.23)
Vertical	5.74 (0.14)	5.73 (0.24)	5.58 (0.90)	5.49 (0.98)
Medio-lateral^	-0.69 (0.21)	-0.64 (0.14)	-0.68 (0.52)	-0.57 (0.39)
Resultant	5.82 (0.13)	5.80 (0.21)	5.69 (0.81)	5.57 (0.91)

Pre-impact Ball Velocity (m/s)				
Antero-posterior	0.56 (0.28)	0.56 (0.28)	0.59 (0.26)	0.52 (0.23)
Vertical	-3.86 (0.55)	-3.71 (0.65)	-3.36 (1.80)	-3.29 (1.73)
Medio-lateral	-0.69 (0.21)	-0.64 (0.14)	-0.68 (0.52)	-0.57 (0.39)
Resultant	3.97 (0.51)	3.82 (0.60)	3.67 (1.35)	3.53 (1.37)
Post-impact Ball Velocity (m/s)				
Antero-posterior#*	55.75 (11.99)	48.51 (9.26)	41.41 (5.82)	38.99 (2.63)
Vertical*	-7.19 (2.63)	-5.27 (0.81)	-3.85 (1.12)	-3.86 (0.47)
Medio-lateral#	-8.00 (4.02)	-17.0 (4.55)	-6.12 (1.76)	-12.12 (4.52)
Resultant*^	56.85 (12.50)	51.75 (9.82)	42.06 (6.04)	41.16 (3.55)
Pre-impact Racquet Velocity (m/s)				
Antero-posterior	32.65 (6.17)	30.87 (7.93)	26.96 (3.27)	28.13 (3.29)
Vertical	18.41(4.28)	20.22 (2.51)	16.82 (3.88)	15.26 (5.69)
Medio-lateral*	-6.53 (3.76)	-8.99 (3.75)	-3.19 (3.98)	-2.65 (1.90)
Resultant	38.55 (4.41)	38.42 (6.19)	32.27 (3.87)	32.41 (4.80)
Post-impact Racquet Velocity (m/s)				
Antero-posterior*	33.38 (2.65)	33.98 (4.00)	25.33 (4.65)	24.09 (4.14)
Vertical	-9.82 (4.10)	-5.35 (8.42)	-10.61 (5.13)	-10.40 (1.51)
Medio-lateral	5.19 (4.93)	0.60 (3.47)	4.08 (9.72)	4.47 (5.27)
Resultant#	35.65 (1.91)	35.32 (3.70)	29.52 (4.13)	27.03 (4.42)
Pre-impact Racquet Orientation				
Antero-posterior*	0.90 (0.07)	0.83 (0.12)	0.93 (0.04)	0.93 (0.05)
Vertical	-0.32 (0.11)	-0.28 (0.21)	-0.22 (0.12)	-0.15 (0.06)
Medio-lateral	-0.23 (0.17)	-0.40 (0.17)	-0.23 (0.17)	-0.28 (0.16)

#Significantly different between center and side landing locations ($p < .05$)
*Significantly different between males and females for ($p < .05$)
^A trend of a difference between center and side landing locations ($p \leqslant .076$)

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