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INVESTIGATE THE MANIPULATION OF KINEMATICS ON TENNIS SERVE PERFORMANCE

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ABSTRACT

The study aimed to explore the effect of elite tennis player body kinematics during preparatory, force generation and follow through phase (between first serve and second serve) at three different time periods i.e. initial, mid and end of the match. Four Indian International male tennis players were selected as subjects for the study. The mean and standard deviation of players of age (year), height (cm) and weight (kg) were 27.00 ± 4.97, 186.50 ± 6.03, 81.25 ±7.41, respectively. The tennis service was modeled as segments of the kinematics chain composed of body segments. 2D kinematics data of the body were obtained for this study with the high speed canon camcorder operating at the shutter speed of 1/2000 with a frame rate of 50 Hz. Descriptive statistics and t-test were performed by SPSS version 17.0 for all the variables under this study were computed at Level of significance for 0.05 with 6 degree of freedom. Results revealed that selected kinematics variables of selected subjects does not play significant role in first and second serve at different phases during three different stages of the Tennis match.

KEYWORDS: Davis cup, Kinematics, first serve, second serve, motion analysis software and Tennis.

INTRODUCTION

All content The most important skill in game of tennis is serve which a player must get in order to have successful attack. It is also the power stroke that has gained attention to the most analytical interest as of biomechanists. The objective of the server's is to serve the ball directly into service area of challenger's court. For reducing the challenger's reaction time and their ability to return the ball accordingly, the ball must be smash with greater amount of ball velocity. According to Mark Kovacs, 2011, the serve has been studied in a similar manner to the throwing motion in baseball, although some significant differences do exist between the serving motion and the throwing motion. These differences include planes of motion, the non-dominant arm tossing the tennis ball, the tennis racket, the technical components of the serve, and the variety of placements and goals of the motion (spin, speed, angle, direction etc.).

Actually tennis serve is an overhead motion and characterized by a series of segmental rotations involving the entire kinematics of the player's body. It is the most complex stroke in tennis match. Effective server maximally utilizes their entire kinematic sequence via the synchronous use of selective joint angles, segmental rotations and coordinated lower and upper extremities. This lower extremity kinematics help into the upper body kinematics to produce momentum of the body through racket which is prerequisite for serve. If any kinematic series of the links in the lower and upper extremities sequence are not synchronized effectively, this results the ineffectiveness attack as the outcome of the serve.

Tennis coaches and trainers focus on the mechanical consistency in serve production. Traditionally tennis coaches and trainers decompose the service action and break down its component consistency in learning of the serve. In these circumstances, the serve practice is characterized by the preparation of ball toss into diagonally opponent service court directly without rally.

However, there is a limited scientific knowledge base for players and coaches to draw upon when seeking to improve serve technique in tennis game. Many of the kinematic variables analyses into tennis serves or strokes were conducted more than ten years ago, with different analysis methods during the match for enhancement the serve performance. It has only recently been possible to analyses the different types of the serve (flat, slice, kick serve,

etc.), and this has not been investigated in relation to the kinematics of a player. This study aimed to make an important contribution to the knowledge of tennis professionals by establishing which kinematic variables are related to variation in serves at three different stages of the match.

Many kinematic studies of tennis serving have focused on patterns of upper limb movements and the contributions of joint movements in the upper limb to racket speed. Elliott, Marsh, and Blanksby, (1986), have investigated the serving motion of four male and four female skilled tennis players. They reported that wrist flexion and forearm pronation were observed before ball impact in all players, and that maximum racket speed resulted from wrist flexion. Elliott, Reid, and Crespo, (2009), from a practical perspective, they represent the types of ball and racket characteristics routinely modified by coaches in their instruction of the serve. Matthew, Merrill, William, Ronald L & Hopkins, (2011), have studied twelve highly skilled male tennis players, and showed that all peak joint angles were significantly affected by post-impact ball speed, except external shoulder rotation and elbow extension. Martin, et al. ,(2013) examined correlation between segmental angular momentums and ball velocity in ten professional tennis players and found upper arm significant correlations between the angular momentum and ball velocity during the maximal elbow flexion-racket lowest point, racket lowest point - maximal shoulder external rotation, and maximal shoulder external rotation –ball impact phases, whereas the forearm did in all phases. Vaverka et al, (2013) computed the association between body height and serve speed in elite tennis players among the world's best tennis players and found that significant associations between body height and all three serve speed parameters in all of the Grand Slam tournaments for both men and women. Moreover, Reid et al., (2010) noted that consistency in select swing and toss kinematics characterize the performance of the first serve at a young age. This consistency decreases when the serve is decomposed, as is routinely done by coaches in practice while key characteristics of the serve. Reid et al., (2011), reviewed the research into the first serve, the lateral baseline position of the players as well as the lateral displacement of the ball at zenith and at impact were significantly different.

Above mention biomechanical researches on the tennis serve have focused on the flat serve, with some data on the kick serve, and very little published data elucidating the biomechanics of the slice serve. However, no study has quantified serve kinematics of the top-level players. The purpose of this study was to quantify high velocity serve kinematics of top-level tennis players and identify the motions and timing related to maximum ball velocity through the comparison of serve at different stages of match and to clarify kinematics and mechanisms during tennis serving. Results of this study can help competitive players and their coaches to understand the mechanics needed to generate high serve velocity, provided a good foundation for understanding serve biomechanics used by skilled players and may help to better inform coaching instruction, help coaches to better understand the player's kinematics required to produce better outcomes. This study also provides a more in-depth analysis that should be utilized in all tennis players to help better understand areas of weakness, possible areas to use body kinematics, as well as service sections that can be improved for greater performance.

MATERIALS AND METHODS

Participants

Four Indian International male tennis players were selected as subjects for the study, they were participants in Davis Cup, held at Indore, India in November, 2013. The mean and standard deviation of players of age, height and weight were 27.00 ± 4.97, 186.50 ± 6.03, 81.25 ±7.41, respectively.

Table 1. Demographic profile of the Participants of the study.

	Mean	SD
Age (Years)	**27.00**	**4.97**
Height (cm)	**186.50**	**6.02**
Weight (kg)	**81.25**	**7.41**

Model of Tennis Serve

The tennis service was modeled as segments of the kinematics chain composed together of (a) foot (b) lower leg segment (c) upper leg segment (d) trunk segment (e) upper arm segment (f) forearm and (g) hand with tennis racket. The ankle, knee and upper body significantly flexed to make use of ground reaction force (GRF) to start the

execution while extending ankle, knee and upper body in a sequential manner for summation of force. The body makes an arc extending the shoulder with internal rotation of the upper arm and pronation of the forearm.

Equipments and Set-up:

To obtain the kinematic data, the equipment used for this study were camera, tripod, computer, two-dimensional calibration frame, motion analysis software and measuring tape. Two-dimensional kinematics data of the body were obtained with the high speed canon camcorder operating at the shutter speed of 1/2000 with a frame rate of 50 Hz. The camera was placed perpendicular to sagittal plane on the right side at a distance of seventeen meters from the mid of base line of the tennis court to capture the service motion.

Parameters:

The kinematic parameters considered were toss angle (TA), toss height (TH), reach height (RH), contact distance (CD), ball velocity (Bv), racket velocity(Rv), wrist velocity (Wv), elbow velocity (Ev), shoulder velocity (Sv), pelvic/ hip velocity (Hv), knee velocity (Kv), ankle velocity (Av), toe velocity (Tv), wrist angle (WA), elbow angle (EA), shoulder angle (SA), pelvic angle (PA), knee angle (KA), ankle angle (AA), wrist angular velocity (WAv), elbow angular velocity (EAv), shoulder angular velocity (SAv), pelvic angular velocity (PAv), knee angular velocity (KAv) and ankle angular velocity (AAv). The velocity, angular velocity, joint angle, ball and racket velocity and height of the selected kinematics parameters during preparatory, force generation and follow through phase. The height and distance were measured in meter (m), angles in degrees (°), velocity in meter per second (m/s), angular velocity in degree per second (°/s) respectively.

Subject and Trail Identification

The subjects identification code in the video recording were given for distinguishing them in the recorded data. The recorded videos were viewed carefully in the playback system and extracted the best performance of the subjects for analysis.

Data Reduction

The identified valid first and second serve of each player's selected video footages were downloaded, slashed, edited and trimmed by using video editing software. The trimmed video data were digitized in motion analysis software with the process of markerless digitization and a database of each player's serves was developed.

Statistical Procedure

Descriptive statistics and F-test were performed by SPSS version 17.0 for all the variables under this study were computed at Level of significance for 0.05 with 6 degree of freedom.

RESULTS AND DISCUSSION

The main purpose of this study was to determine the kinematical differences at the time of the preparation phase, force generation phase and follow through phase of first and second serve during three time periods of the match i.e.: initial period, mid period and end period.

Table 2. Kinematics parameters of first and second serve during preparation Phase at Initial, Mid & End Period of the Match.

Variable	Serve	Initial Period	Mid Period	End Period	F- value
		Mean±SD	Mean±SD	Mean±SD	
TA	FS	9.25 ± 5.56	9.00 ± 3.83	9.00 ± 4.69	0.00
	SS	9.25 ± 4.35	9.25 ± 4.03	9.50 ± 4.80	0.00
Wv	FS	147.31±16.30	143.49±33.88	125.15±33.36	0.67
	SS	144.71±23.67	137.83±27.25	133.18±33.42	0.17
Ev	FS	106.77±18.57	98.66±25.36	84.83±24.28	0.93
	SS	94.89±20.31	98.48±13.54	94.89±12.49	0.07
Sv	FS	98.86±9.70	86.48±18.92	77.41±19.05	1.71
	SS	86.29±11.73	85.35±9.15	82.99±10.55	0.10
Pv	FS	84.95±14.20	77.40±21.99	65.72±17.65	1.13
	SS	70.11±12.53	73.74±12.61	67.43±14.81	0.23
Kv	FS	74.25±19.85	65.23±22.38	54.53±12.80	1.11
	SS	55.77±8.80	60.65±9.16	55.43±8.24	0.45

Av	FS	44.76±17.29	33.64±10.38	35.59±15.66	0.65
	SS	36.83±6.18	37.33±10.74	33.95±12.27	0.13
Tv	FS	44.67±22.83	31.14±15.36	35.84±15.43	0.57
	SS	31.85±8.38	36.51±13.00	32.52±15.08	0.16
Rv	FS	439.93±33.48	391.71±72.50	371.84±82.20	1.44
	SS	336.31±142.99	417.18±52.01	393.71±71.16	0.24
Bv	FS	232.63±50.55	255.32±48.62	276.73±30.61	0.22
	SS	216.19±90.19	297.88±33.50	281.55±27.41	0.66
WA	FS	145.99±6.20	153.88±21.72	154.76±17.31	0.35
	SS	150.07±12.97	152.86±14.64	146.11±8.67	0.30
EA	FS	108.15±9.90	115.79±24.65	123.68±21.95	0.61
	SS	118.67±16.57	120.03±18.69	118.25±14.79	0.01
SA	FS	39.01±11.23	36.58±10.64	36.42±10.75	0.31
	SS	37.11±8.76	36.78±13.72	36.95±10.78	0.52
PA	FS	171.43±17.41	171.65±15.26	168.65±11.15	0.10
	SS	141.19±61.97	166.83±15.16	163.03±10.03	0.14
KA	FS	176.51±13.08	173.75±10.70	170.10±0.77	0.19
	SS	140.19±66.28	173.56±9.66	167.47±2.44	1.78
AA	FS	178.26±48.96	181.49±52.18	168.55±52.59	0.20
	SS	160.90±62.99	142.78±60.69	130.66±9.19	0.38
WAv	FS	489.28±212.20	354.45±143.34	403.92±197.39	0.78
	SS	383.73±181.82	397.68±150.56	470.04±53.60	0.39
EAv	FS	326.14±187.07	358.16±203.68	427.60±207.06	0.12
	SS	338.16±170.06	494.86±209.97	449.58±197.50	0.08
SAv	FS	101.07±27.26	93.89±22.50	83.29±26.22	0.33
	SS	80.71±32.36	96.77±15.93	89.13±22.14	0.16
PAv	FS	59.59±38.97	175.36±167.86	223.87±233.71	0.19
	SS	122.87±94.83	133.87±154.69	322.96±190.97	1.86
KAv	FS	511.14±506.53	698.63±679.06	906.00±616.57	0.12
	SS	651.93±473.17	826.58±562.29	653.41±436.05	0.21
AAv	FS	367.62±188.99	170.06±81.53	229.35±113.66	1.40
	SS	200.50±154.86	285.15±294.04	343.17±316.46	1.04

Tab $F_{0.05}(2,9) = 4.26$ *Significance at 0.05 levels.

Table-2 reveals that calculated F-value of selected kinematical variables of tennis players in first and second serve at preparatory phase in different three time periods of the match of tennis match is less than tabulated F-value. Hence there are selected kinematics variables of selected subjects does not play significant role in first and second serve at preparatory phase during three different stages of the Tennis match.

Table 3. Kinematics parameters of first and second serve during Force Generation Phase at Initial, Mid & End Period of the Match.

Variable	Serve	Initial Period	Mid Period	End Period	F- value
		Mean±SD	Mean±SD	Mean±SD	
TA	FS	11.75±2.63	10.50±1.29	10.00±3.74	0.43
	SS	8.50±3.11	7.75±2.99	8.50±1.91	0.10
RH	FS	4.03±0.47	3.99±0.23	3.55±0.43	1.88
	SS	3.04±1.60	3.32±1.83	2.89±1.53	0.07
CD	FS	1.12±0.54	0.81±0.10	0.76±0.10	0.27

	SS	1.65±1.60	1.73±1.64	1.64±1.60	0.00
TH	FS	4.80±0.56	4.81±0.59	4.71±0.48	0.04
	SS	4.78±0.62	5.10±0.82	4.52±0.31	0.88
Wv	FS	860.95±133.46	836.91±74.44	795.23±188.90	0.23
	SS	754.12±53.37	842.36±107.08	805.59±65.60	1.27
Ev	FS	720.08±30.06	711.19±38.45	637.10±63.82	3.86
	SS	641.11±62.55	696.23±49.20	666.43±76.05	0.75
Sv	FS	409.13±18.85	386.14±24.41	367.72±46.29	1.67
	SS	379.48±16.79	403.04±35.12	378.10±38.35	0.79
Pv	FS	186.83±57.30	197.92±55.08	170.90±45.91	0.27
	SS	191.70±62.18	197.92±55.09	175.66±54.28	0.12
Kv	FS	162.32±50.56	187.57±11.45	153.10±41.38	0.87
	SS	178.10±40.75	164.63±10.21	157.54±13.51	0.37
Av	FS	151.20±55.47	171.80±29.77	123.42±24.65	1.55
	SS	156.70±34.11	145.12±23.28	157.54±13.51	0.31
Tv	FS	247.93±86.18	261.18±37.93	190.84±103.81	0.85
	SS	228.14±92.64	210.97±62.42	216.50±48.74	0.06
Rv	FS	1530.47±289.32	1498.55±187.30	1484.24±303.23	0.03
	SS	1336.96±193.32	1491.90±168.47	1401.35±107.88	0.92
Bv	FS	731.25±323.30	860.08±261.82	812.16±192.98	0.24
	SS	675.55±236.32	730.54±184.13	683.12±146.86	0.10
WA	FS	138.87±7.43	161.61±20.52	154.64±25.54	1.44
	SS	136.30±23.11	151.50±13.81	120.03±41.24	1.23
EA	FS	113.53±26.47	139.05±54.69	121.62±33.85	0.42
	SS	88.31±23.20	100.81±6.03	101.40±14.85	0.82
SA	FS	160.46±46.37	174.41±45.88	158.06±46.78	0.15
	SS	148.74±52.57	154.55±45.99	128.56±8.20	0.45
PA	FS	170.94±4.29	165.63±4.43	177.89±3.77	1.41
	SS	165.70±6.51	163.91±4.72	165.51±4.28	0.14
KA	FS	177.89±3.77	178.73±4.15	175.08±3.45	1.01
	SS	179.67±6.02	165.18±26.67	175.98±1.99	0.91
AA	FS	139.36±9.62	141.56±16.31	143.45±8.03	0.12
	SS	149.11±7.51	136.26±18.47	155.57±7.63	2.55
WAv	FS	1783.28±89.47	2049.09±579.17	1974.30±496.14	0.38
	SS	1683.18±621.21	2519.40±695.23	2171.79±831.95	0.78
EAv	FS	1683.18±438.70	1644.66±339.47	1798.28±298.28	0.19
	SS	1308.69±380.67	1645.09±398.26	1670.64±552.80	0.80
SAv	FS	499.80±74.35	477.54±185.27	408.01±74.53	1.47
	SS	413.20±116.14	404.53±31.86	437.75±61.35	2.10
PAv	FS	1982.33±453.79	1748.72±538.31	1520.34±460.40	0.91
	SS	1091.78±650.74	1664.78±543.07	1901.32±524.14	1.42
KAv	FS	1423.30±533.08	1432.29±546.39	1939.79±1039.79	0.63
	SS	1745.57±701.90	1134.95±20.36	1430.80±545.33	0.57
AAv	FS	821.59±519.56	1094.16±1447.99	1039.25±593.92	0.39

	SS	1604.21±876.42	1164.37±766.46	1686.18±540.92	0.58

Tab $F_{0.05}$ (2,9) =4.26 *Significance at 0.05 levels.

Table-3 reveals that calculated F-value of selected kinematical variables of tennis players in first and second serve at force generation phase in different three time periods of the match of tennis match is less than tabulated F-value. Hence there are selected kinematics variables of selected subjects does not play significant role in first and second serve at preparatory phase during three different stages of the Tennis match.

Table 4. Kinematics parameters of first and second serve during Follow through Phase at Initial, Mid & End Period of the Match.

Variable	Serve	Initial Period	Mid Period	End Period	F- value
		Mean±SD	Mean±SD	Mean±SD	
Wv	FS	837.91±113.48	756.20±83.98	713.42±102.95	1.56
	SS	729.71±96.30	770.59±151.02	716.35±55.24	0.27
Ev	FS	420.72±27.52	396.40±25.85	368.71±35.35	3.04
	SS	382.02±7.96	416.80±45.57	411.57±21.15	1.58
Sv	FS	216.34±35.25	211.46±37.42	205.78±35.18	0.09
	SS	235.85±27.55	227.43±20.53	215.64±19.10	0.80
Pv	FS	168.48±47.49	194.01±22.39	176.27±39.94	0.47
	SS	181.23±41.43	179.42±35.40	168.96±26.31	0.15
Kv	FS	75.83±17.02	76.56±36.15	88.35±23.12	0.28
	SS	75.64±15.53	80.96±28.14	75.80±20.86	0.08
Av	FS	328.25±56.22	342.70±43.45	334.78±84.87	0.05
	SS	323.24±78.22	344.19±51.38	317.52±36.77	0.23
Tv	FS	399.18±63.19	428.49±47.34	407.88±80.65	0.21
	SS	398.99±101.71	420.60±76.40	379.96±32.39	0.29
Rv	FS	1786.71±316.22	1663.00±395.82	1311.45±249.87	2.29
	SS	1371.55±115.23	1480.74±224.44	1376.80±137.32	0.55
Bv	FS	4735.37±873.40	4236.08±447.94	5020.27±692.05	1.31
	SS	3763.12±360.27	3856.11±490.26	3713.00±82.72	0.17
WA	FS	146.86±18.94	143.73±7.24	140.90±5.91	0.24
	SS	129.60±7.18	140.22±10.34	140.78±13.86	1.36
EA	FS	159.17±10.60	138.03±39.28	140.95±24.82	0.69
	SS	125.97±34.84	144.52±17.56	146.45±6.62	0.98
SA	FS	134.74±8.10	118.08±18.98	150.12±19.55	3.81
	SS	125.41±32.30	142.78±10.89	135.92±15.35	0.66
PA	FS	157.54±4.87	160.08±10.14	161.35±6.97	0.26
	SS	162.03±4.10	159.36±4.02	163.43±6.42	0.69
KA	FS	172.97±16.68	184.32±16.01	168.95±16.79	0.93
	SS	177.75±11.59	161.85±37.81	166.24±8.80	0.49
AA	FS	119.76±11.67	128.77±12.02	123.39±11.71	0.59
	SS	127.89±13.97	118.08±20.33	131.34±17.08	0.63
Wav	FS	1219.91±523.83	1104.02±825.79	900.28±214.34	0.31
	SS	1242.19±461.93	953.57±343.55	1107.08±458.05	0.46
EAv	FS	1911.67±1033.24	1723.01±856.58	1725.99±542.85	0.53
	SS	1659.29±780.01	1725.45±1089.08	1599.41±870.47	0.01
SAv	FS	1540.91±710.73	1094.08±949.85	1665.34±823.28	0.52

	SS	1085.24±555.21	1443.88±657.58	1763.04±370.14	1.57
PAv	FS	1324.92±315.77	1099.24±721.75	1145.30±868.73	0.12
	SS	1170.28±23.42	1055.20±662.85	1201.26±768.32	0.07
KAv	FS	1001.70±580.15	1466.09±545.44	1163.09±58.70	0.24
	SS	1114.88±76.66	1415.84±559.06	1413.85±443.27	0.70
AAv	FS	236.16±67.365	212.94±113.77	170.28±52.35	0.66
	SS	317.07±270.03	135.19±73.08	322.95±66.05	1.66

Tab $F_{0.05}$ (2,9) =4.26 *Significance at 0.05 levels.

Table-4 reveals that calculated F-value of selected kinematical variables of tennis players in first and second serve at force generation phase in different three stages of Tennis match is less than tabulated F-value. Hence there are selected kinematics variables of selected subjects does not play significant role in first and second serve at preparatory phase during three different stages of the Tennis match.

CONCLUSION

The result of the statistical analysis for tennis serve kinematics at initial, mid and end period as well as during preparatory, force generation phase and follow through phase showed no significant differences. However kinematics parameters tested have shown visible variation from initial to final as well as from preparatory to follow through phase. Elliott (1988) found in his research that the linear velocities of various joints during tennis serves progressively increased which is distinction of the present study. The results of Murray et al., 2001; Escamilla et al., 2007 suggested that the kinematics and kinetics parameters decreases from initial to end period during baseball pitching.

Angular velocities of the different kinematical parameters have mean variations in three phases (Preparatory, force generation and follow through) between FS and SS, at initial, mid and end period of served during the tennis match. In baseball, the trunk forward tilt angle and angular velocity at the instant of ball release are of higher magnitude for higher velocity throwers, Matsuo et al., (2001) and Elliott (2006) suggested that the anteroposterior rotation of the trunk enables internal rotation of the upper arm at the shoulder to play an important role in the Picher's action.

The joint angles of different parameters of the study have variation in FS &SS at initial, mid and end period of the match. Matthew K.et al (2011) research results showed that peak joint angle and joint angle at impact were significantly influenced by ball speed for all racket-side joints, except the elbow and shoulder. The horizontal abduction angle shows that the upper arm is marginally in front of the shoulder alignment at this point in the service action. While the magnitude of external rotation may seem extreme, it is similar to the 175° to 185° mean values found for elite baseball pitchers (Dillman et al, 1993; Fleisig et al, 1999; Matsuo et al., 2001).

Result shows that the toss angle, reach height, reach distance and toss height have variations at three different stages of match in different phases of the first and second serve. Mendes et al., (2013), the location and height of the tennis ball toss becomes fundamental in the tennis serve, since these variables can help to identify tennis serve effectiveness and impact location on the tennis racket. It was investigated that the serve performance of the elite tennis players marks a partial difference in mean ball velocity on first serve rather than negligible difference was observed in second serve of tennis at different stages of the match. Through above the conduct study inspite of internal physiological changes of the elite tennis players, it is the kinematic manipulation cooperate to maintain the serve performance in tennis player.

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