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Kinematic Characteristics of Two Different Service at Three Varied Stages during the Match

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Abstract: The purpose of the study was designed to determine the variation between first and second serve at different time frame, i.e.: start of the match (initial period), mid of the match (mid period) and at the end flag of the match (end period) for Indian players during Davis cup. Four Indian international tennis players of mean age, height and weight were 27.00 ± 4.97 years, 186.50 ± 6.03 cm, 81.25 ±7.41 kg, respectively were recorded in Davis Cup held in Indore, India. The study focused on the mechanical source of service by comparing the body, racket and ball kinematics of first and second service. The recorded service motion was analyzed by motion analysis software and was used to calculate the selected parameters for this study and statistical analysis was accepted using SPSSv.17, mean, standard deviations and t-test was used to find out the difference between the kinematic parameters of this second service for Indian elite players except the ball velocity in the end period of the match in follow through.
Keywords: Kinematics, first serve, second serve, time frame.

I. INTRODUCTION TO TENNIS SERVE

A good serve in tennis is essential. Every point in a tennis match begins with a serve. Probably the most analyzed shot in tennis, an effective serve requires precise timing and arm coordination. Success in tennis is greatly affected by the technique a player uses and biomechanics plays an integral role in stroke production. Player development based on scientific evidence allows an individualized approach to be structured, with due consideration to the key mechanical features of each skill, while also fostering fair and permitting the physical characteristics of a player to be considered (Elliot, 2006).

The serve is one of the most important skills a tennis player must acquire in order to have an effective attack. The primary objective of the serve is to direct the ball into the service area on the opponent's side of the court. The serve is an effective offensive weapon because the ball can be hit with a tremendous amount of velocity, thus reducing the opposition’s reaction time and consequently their ability to return the ball. The tennis serve is a more complex sequence that uses a combination of horizontal and vertical movements. Variations of the service action can also cause the ball to spin. A slice serve is used in order to gain an advantage via the unpredictability of a spinning ball bounce. Biomechanical analysis of the skill enables us to give effective instruction and appropriate technical cues to improve the performance of students and athletes (Hooper, 2001). One of the elements that all high level tennis players, college tennis players and world class tennis professionals share are efficient and biomechanical sound tennis strokes.

The serve, a closed skill which players have total control over is also a difficult stroke to master. Not only do the arms prescribe different movement patterns and rhythms, but they must coordinate with the movement of the lower limbs and the trunk. Because of its importance and complexity, the tennis serve becomes a closely watched issue; especially the flat serve which is the fastest of all the service types and is also probably the most intimidating and fearsome weapon a player can have (Yuliang Sun, Yu Liu and Xinglong Zhou, 2012)

Powerful serve in tennis requires balancing the generation of forces and motions necessary to move the body, especially the shoulder and elbow, and propel the racquet and the control of these forces and motions for precision of performance and protection of the joints from excessive loading. The body achieves this balance by integrating the physiological muscle activations and the resulting biomechanical forces and motions throughout all the segments or links of the kinetic chain (Kibler, 2009).

Kinematics of the tennis serve have been described quite extensively, focusing on the upper-limb movements (Elliott, Marsh, & Blanksby, 1986; Elliott, Fleisig, Nicholls, & Escamilia, 2003; Reid, Elliott, & Alderson, 2007), or the patterns of the lower-limb

(Elliott & Wood, 1983; Girard, Micallef, & Millet, 2005), or the function of trunk (Chow, Shim, & Lim, 2003; Chow, Park, & Tillman, 2009). According to Tanabe, 2007 the joint movement that produces the difference in horizontal racket head velocity between fast and slow servers is shoulder internal rotation, and angular velocity of shoulder internal rotation must be developed to produce a high racket speed.

The tennis serve is commonly associated with musculoskeletal injury. Different types of serves, e.g. the flat and the kick types, may involve different kinematics and different musculoskeletal demands at the joints that play an important role in the development of long term injuries (Reid, 2007).

The spin serves produces more lateral flexion moments than flat serve; this moment comes mainly from the lateral flexion of the trunk. The spin serve has a significant difference from the flat serve: the former produces more knee bend than the latter during acceleration, and more backward pelvis tilting. This will help to increase the momentum during the serve and its transfer (Kuo-Cheng Lo, 2004). The tennis serve is a commonly performed athletic skill and has received some attention in the scientific biomechanical literature. During the tennis serve the greatest forces and moments are applied at the shoulder joint. Also, the lower extremities are important to the successful performance of the tennis serve (Seeley, n.d.).

The study has been designed to determine the variation between first and second serve at different time frame i.e.: start of the match (initial period), mid of the match (mid period) and at the end flag of the match (end period) for Indian players during Davis cup. The study focused on the mechanical source of service by comparing the body, racket and ball kinematics of first and second service.

II. METHODOLOGY

A. Participants

A total of four elite male International tennis players were selected as subjects for the study, who participants in Davis Cup, held at Indore, India in November, 2013. The mean and standard deviation (SD) of players of age (year), height (cm) and weight (kg) were 27.00 ± 4.97, 186.50 ± 6.03, 81.25 ±7.41, respectively.

B. Model of Tennis Serve

The tennis service was modeled as segments of the kinetic 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.

C. Equipment's and Set-up

To obtain the kinematic data for this study the equipment used 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.

D. Parameters

The kinematic parameters considered for this study during preparation phase, force generation phase and follow through phase were toss angle (ToA), toss height (TH), reach height (RH), ball velocity (Bv), racket velocity at impact (RIv), racket velocity post impact (RPv), wrist velocity (Wv), elbow velocity (Ev), shoulder velocity (Sv), pelvic/ hip velocity (Hv), knee velocity (Kv), ankle velocity (Av), toe velocity (Tv), wrist angular velocity (WAv), elbow angular velocity (EAv), shoulder angular velocity (SAv), pelvic angular velocity (HAv), knee angular velocity (KAv), ankle angular velocity (AAv), toe angular velocity (TAv)

E. Subject and Trail Identification

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

F. Data Reduction

The identified valid first and second serve of each player's selected video footages were downloaded, slashed, edited and trimmed by using the Xilisoft Video Converter. The trimmed video data were digitized in motion analysis software with the process of

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markless digitization and a database of each player's serves was developed.

G. Statistical Procedure

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.

III. RESULT

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

Ball velocity and velocity of a racket at the time of impact and post impact were also studied during first and second serve.

Table No.: 1 Kinematics parameters of first and second serve during preparation Phase at Initial, mid & End Period of Match.

Variable	Serve	Initial Period		Mid Period		End Period	
		Mean±SD	t-value	Mean±SD	t-value	Mean±SD	t-value
TA^{O}	FS	9.25 ± 5.56	0.00	9.00 ± 3.83	0.09	9.00 ± 4.69	0.15
	SS	9.25 ± 4.35		9.25 ± 4.03		9.50 ± 4.80	
WR_{vel}	FS	147.31±16.30	0.18	143.49±33.88	0.26	125.15±33.36	0.34
	SS	144.71±23.67		137.83±27.25		133.18±33.42	
ER_{vel}	FS	106.77±18.57	0.86	98.66±25.36	0.01	84.83±24.28	0.74
	SS	94.89±20.31		98.48±13.54		94.89±12.49	
SR_{vel}	FS	98.86±9.70	0.77	86.48±18.92	0.11	77.41±19.05	0.51
	SS	86.29±11.73		85.35±9.15		82.99±10.55	
PR_{vel}	FS	84.95±14.20	0.91	77.40±21.99	0.30	65.72±17.65	0.15
	SS	70.11±12.53		73.74±12.61		67.43±14.81	
KR_{vel}	FS	74.25±19.85	0.11	65.23±22.38	0.38	54.53±12.80	0.12
	SS	55.77±8.80		60.65±9.16		55.43±8.24	
AR_{vel}	FS	44.76±17.29	0.15	33.64±10.38	0.50	35.59±15.66	0.17
	SS	36.83±6.18		37.33±10.74		33.95±12.27	
TR_{vel}	FS	44.67±22.83	0.13	31.14±15.36	0.53	35.84±15.43	0.31
	SS	31.85±8.38		36.51±13.00		32.52±15.08	
WA_{acc}	FS	539.02±27.53	0.17	598.79±166.62	0.98	525.67±161.01	0.20
	SS	528.56±117.85		515.39±36.11		506.66±111.35	
EA_{acc}	FS	1083.78±231.56	1.54	970.39±307.93	0.58	687.14±221.46	0.44
	SS	853.65±189.45		877.55±94.61		749.07±172.68	
WA^{O}	FS	145.99±6.20	0.57	153.88±21.72	0.08	154.76±17.31	0.89
	SS	150.07±12.97		152.86±14.64		146.11±8.67	
EA^{O}	FS	108.15±9.90	1.09	115.79±24.65	0.27	123.68±21.95	0.41
	SS	118.67±16.57		120.03±18.69		118.25±14.79	
SA^{O}	FS	39.01±11.23	0.27	36.58±10.64	0.03	36.42±10.75	0.07
	SS	37.11±8.76		36.78±13.72		36.95±10.78	
$WA^{O/S}$	FS	509.73±193.84	0.86	354.45±143.34	0.42	403.92±197.39	0.65
	SS	401.21±160.51		397.68±150.56		470.04±53.60	
$EA^{O/S}$	FS	392.41±190.12	0.40	358.16±203.68	0.94	427.60±207.06	0.15
	SS	445.64±188.84		494.86±209.97		449.58±197.50	
$SA^{O/S}$	FS	97.33±27.36	0.39	93.89±22.50	0.21	83.29±26.22	0.34
	SS	90.31±23.72		96.77±15.93		89.13±22.14	

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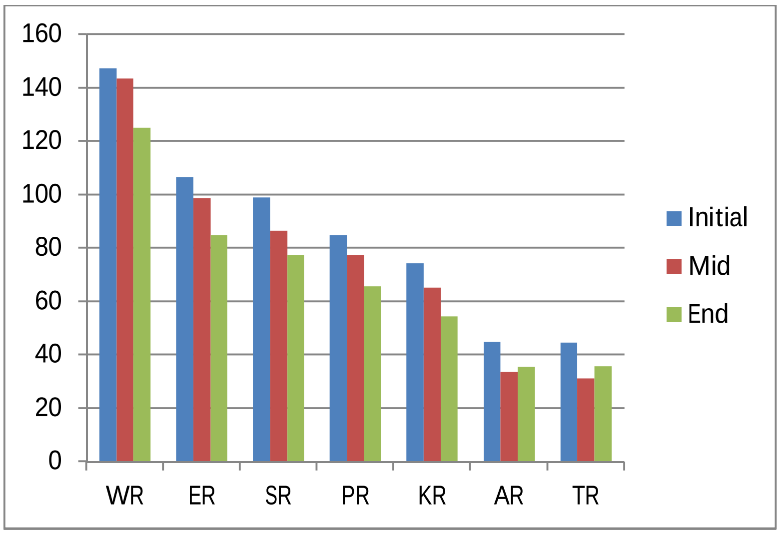
Tab $t_{0.05}$ (6) =2.45 *Significance at 0.05 levels.

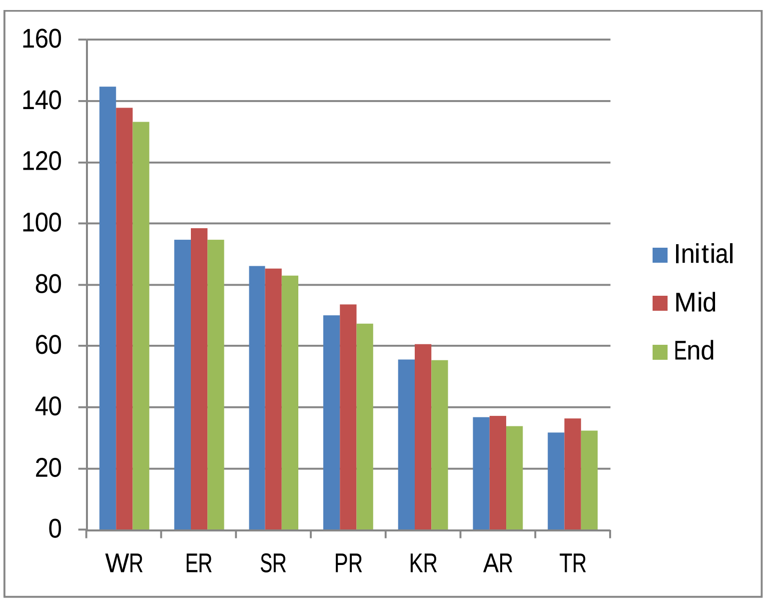
The analysis of data table -1 shows that there is no significant differences found between first and second serve of body kinematics. The linear kinematic of toss angle (TA), the velocity of wrist angle (WR), elbow angle (ER), shoulder angle (SR), pelvic angle (PR), knee right (KR) and ankle right (AR). The acceleration of wrist angle (WA_{acc}), elbow angle (EA_{acc}), angles and angular velocity of wrist angle ($WA^{O/S}$), elbow angle ($EA^{O/S}$), shoulder angle ($SA^{O/S}$) have shown $|t|_{cal.}$ values are less than the $t_{0.05,\,6}$ value at 0.05 level of significance.

This statistical finding exhibits that all the linear and angular kinematics of right side of wrist, elbow, shoulder, pelvic, Knee and ankle during first and second serve does not differ significantly and hence does not influence on the performance of tennis serve at preparation phase during initial, mid and end phases under the match condition.

Graph no. 1: Graphical representation of the linear velocity (meter/s) of the parameters in first serve during preparation phase of tennis serve.



Graph no. 2: Graphical representation of the linear velocity (meter/s) of the parameters in second serve during preparation phase of tennis serve.



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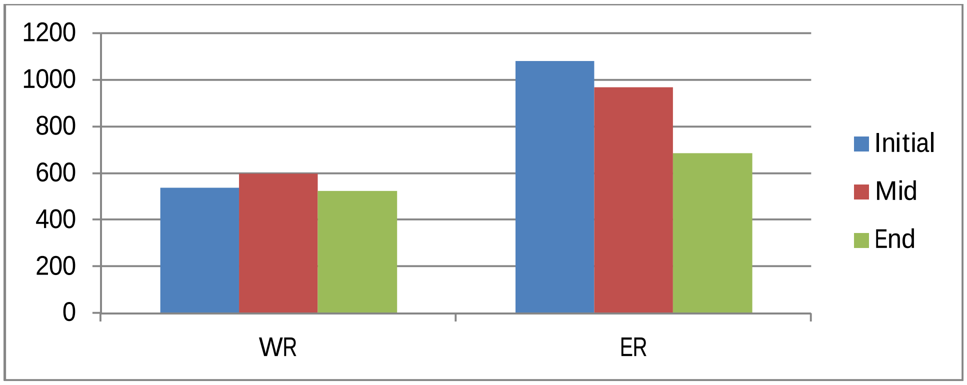
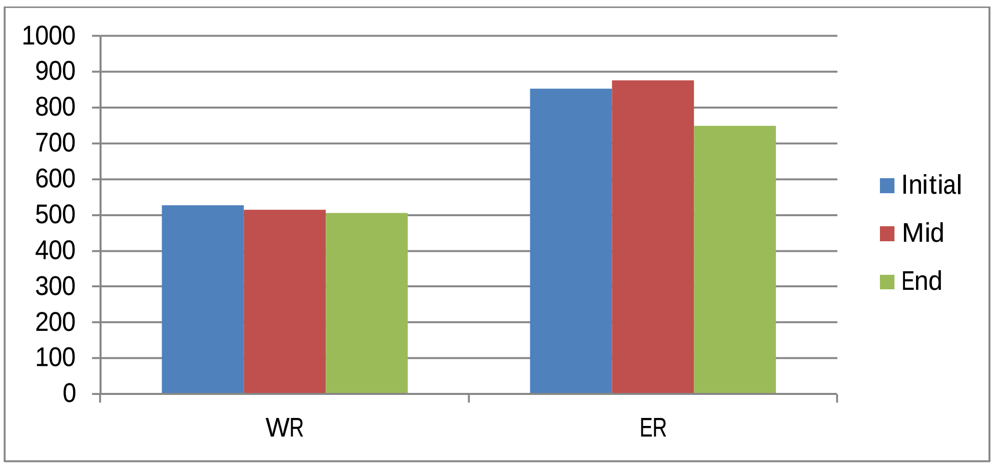
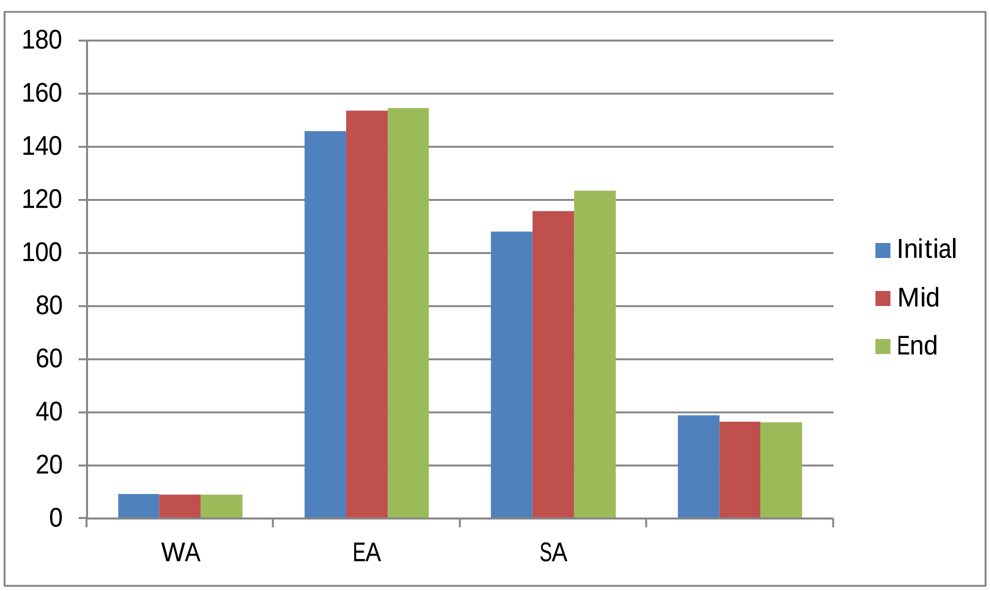
Graph no. 3: Graphical representation of the linear acceleration (meter/s^2) of the parameters in first serve during preparation phase of tennis serve.



Graph no. 4: Graphical representation of the linear acceleration (meter/s^2) of the parameters in second serve during preparation phase of tennis serve.



Graph no. 5: Graphical representation of the angle (degree) of the parameters in first serve during preparation phase of tennis serve.



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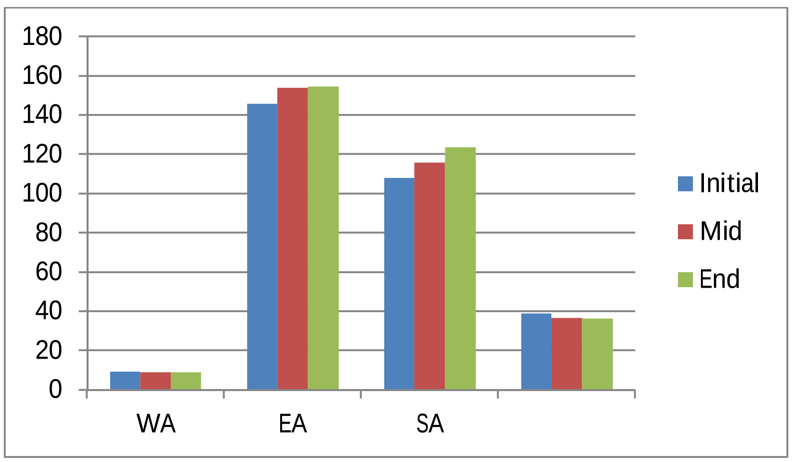
Graph no. 7: Graphical representation of the angular velocity (degree/second) of the parameters in first serve during preparation phase of tennis serve.

Graph no. 6: Graphical representation of the angle (degree) of the parameters in second serve during preparation phase of tennis serve.



Graph no. 8: Graphical representation of the angular velocity (degree/second) of the parameters in second serve during preparation phase of tennis serve.

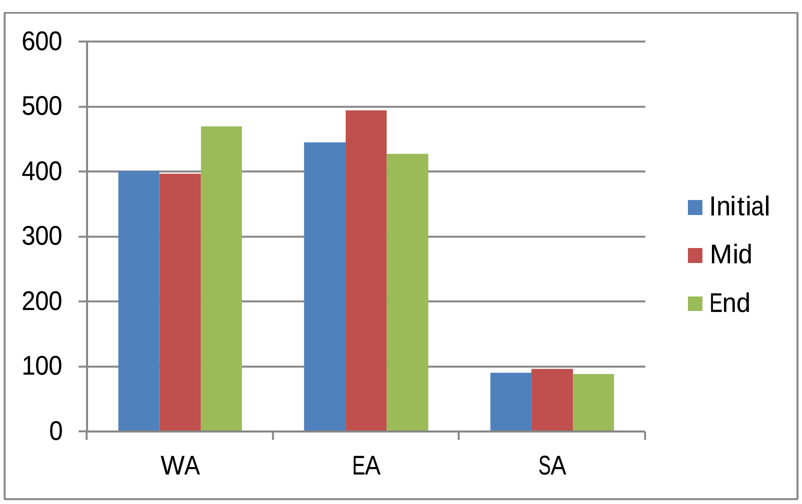


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Table No.: 2 Kinematics parameters of first and second serve during Force Generation Phase at Initial, mid & End Period of Match.

Variable	Serve	Initial Period		Mid Period		End Period	
		Mean±SD	t-value	Mean±SD	t-value	Mean±SD	t-value
HA^o	FS	11.75±2.63	1.60	10.50±1.29	1.70	10.00±3.74	0.72
	SS	8.50±3.12		7.75±2.99		8.50±1.92	
Rh	FS	4.03±0.47	1.19	3.99±0.23	0.73	3.55±0.43	0.82
	SS	3.04±1.60		3.32±1.83		2.89±1.53	
Dh	FS	1.12±0.54	0.59	0.81±0.10	1.13	0.76±0.10	1.10
	SS	1.65±1.68		1.73±1.64		1.64±1.60	
Th	FS	4.80±0.56	0.05	4.81±0.59	0.57	4.71±0.48	0.66
	SS	4.78±0.62		5.10±0.82		4.52±0.31	
WR_{vel}	FS	860.95±133.46	1.49	836.91±74.44	0.08	795.23±188.90	0.10
	SS	754.12±53.37		842.36±107.08		805.59±65.60	
ER_{vel}	FS	720.08±30.06	2.28	711.19±38.45	0.48	637.10±63.82	0.59
	SS	641.11±62.55		696.23±49.20		666.43±76.05	
SR_{vel}	FS	409.13±18.85	2.35	386.14±24.41	0.79	367.72±46.29	0.35
	SS	379.48±16.79		403.04±35.12		378.10±38.35	
PR_{vel}	FS	186.83±57.30	0.12	197.92±55.08	0.40	170.90±45.91	0.13
	SS	191.70±62.18		197.92±55.09		175.66±54.28	
KR_{vel}	FS	162.32±50.56	0.49	187.57±11.45	2.99	153.10±41.38	0.17
	SS	178.10±40.75		164.63±10.21		157.54±13.51	
AR_{vel}	FS	151.20±55.47	0.17	171.80±29.77	1.41	123.42±24.65	2.43
	SS	156.70±34.11		145.12±23.28		157.54±13.51	
TR_{vel}	FS	247.93±86.18	0.31	261.18±37.93	1.38	190.84±103.81	0.45
	SS	228.14±92.64		210.97±62.42		216.50±48.74	
WA_{acc}	FS	5857.27±1513.51	0.99	4756.04±1295.25	1.50	6411.59±1434.44	0.79
	SS	4982.01±913.52		5936.92±902.56		5625.94±1374.06	
EA_{acc}	FS	3728.68±348.03	0.51	3484.43±324.07	0.17	3554.24±247.60	1.02
	SS	3525.55±724.83		3434.62±484.22		3176.67±695.79	
WA^O	FS	138.87±7.43	0.21	161.61±20.52	0.82	154.64±25.54	1.43
	SS	136.30±23.11		151.50±13.81		120.03±41.24	
EA^O	FS	113.53±26.47	1.43	139.05±54.69	1.39	121.62±33.85	1.10
	SS	88.31±23.20		100.81±6.03		101.40±14.85	
SA^O	FS	160.46±46.37	0.33	174.41±45.88	0.61	158.06±46.78	1.24
	SS	148.74±52.57		154.55±45.99		128.56±8.20	
$WA^{O/S}$	FS	1783.28±89.47	0.32	2049.09±579.17	1.04	1974.30±496.14	0.41
	SS	1683.18±621.21		2519.40±695.23		2171.79±831.95	
$EA^{O/S}$	FS	1683.18±438.70	1.29	1644.66±339.47	0.00	1798.28±298.28	0.41
	SS	1308.69±380.67		1645.09±398.26		1670.64±552.80	
$SA^{O/S}$	FS	499.80±74.35	1.26	477.54±185.27	0.78	408.01±74.53	0.62
	SS	413.20±116.14		404.53±31.86		437.75±61.35	

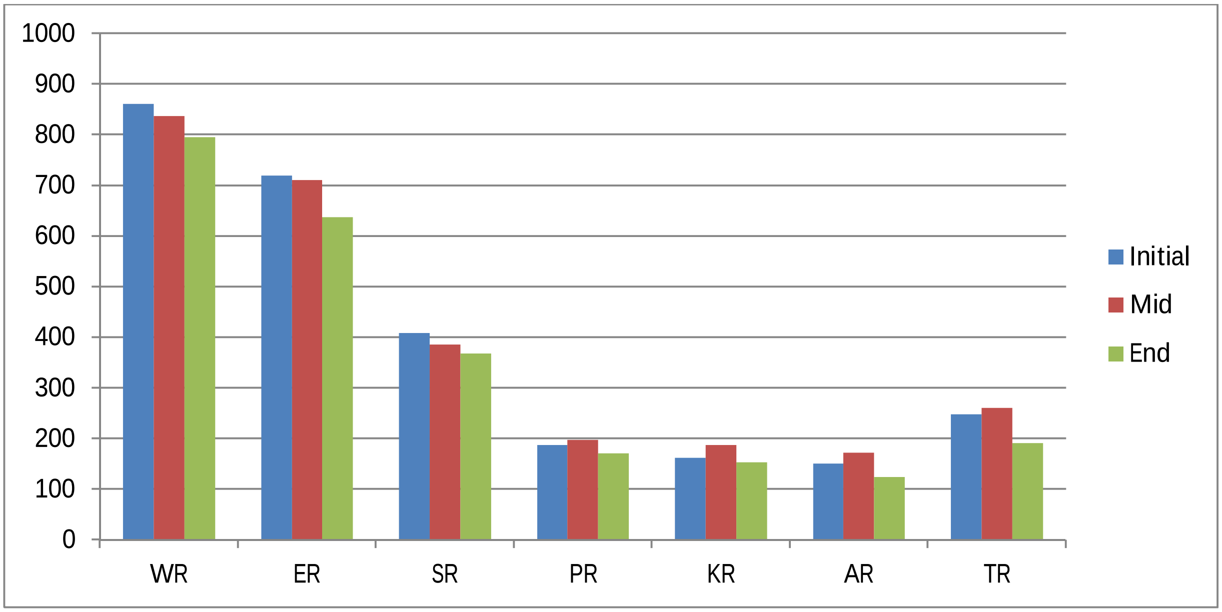
Tab $t_{0.05}$ (6) =2.447 *Significance at 0.05 levels.

The analysis of data table -2 shows that there is no significant differences found between first and second serve of body kinematics. The linear kinematics of hit angle (HA), reach height (Rh) and distance of hit (Dh), toss height (Th), velocity of wrist angle (WA), elbow angle (EA), shoulder angle (SA), pelvic angle (PR), knee right (KR) and ankle right (AR). The acceleration of racket

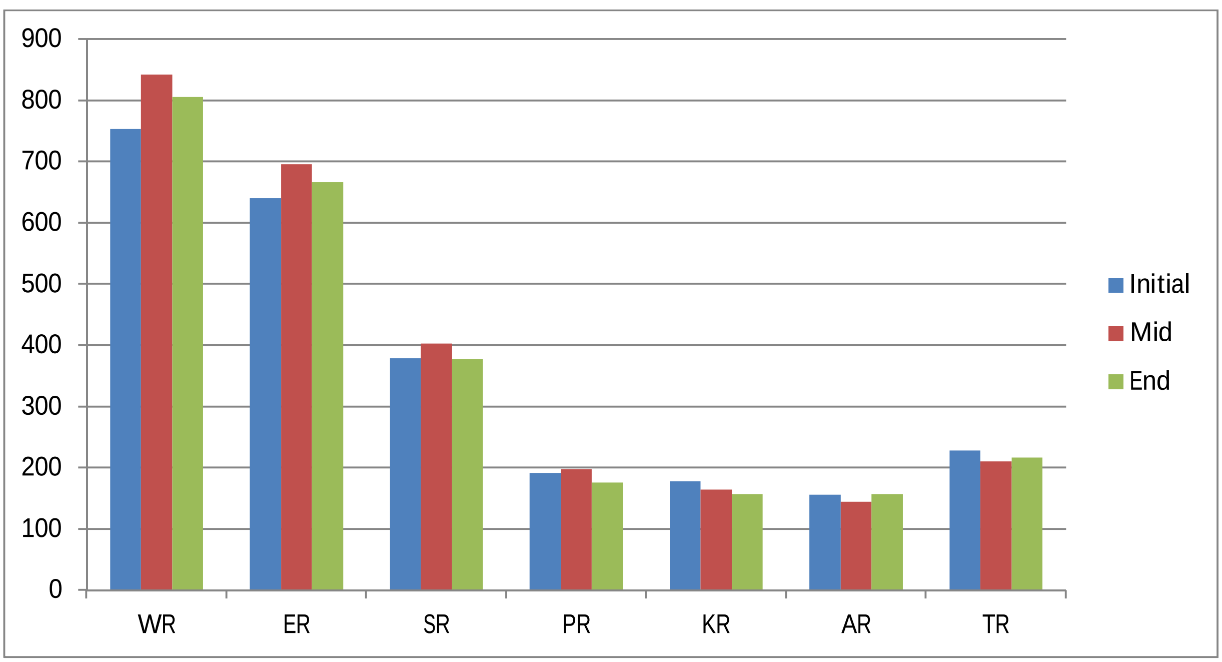
(RaC_{acc}), wrist angle (WA_{acc}), elbow angle (EA_{acc}), angles and angular velocity of wrist angle ($WA^{O/S}$), elbow angle ($EA^{O/S}$), shoulder angle ($SA^{O/S}$) have shown $|t|_{cal.}$ values are less than the $t_{0.05,\,6}$ value at 0.05 level of significance.

This statistical finding exhibits that all the linear and angular kinematics of right side of wrist, elbow, shoulder, pelvic, knee and ankle during first and second serve does not differ significantly and hence does not influence on the performance of tennis serve at force generation phase during initial, mid and end phases under the match condition.

Graph no. 9: Graphical representation of the linear velocity (meter/s) of the parameters in first serve during force generation phase of tennis serve.



Graph no. 10: Graphical representation of the linear velocity (meter/s) of the parameters in second serve during force generation phase of tennis serve.



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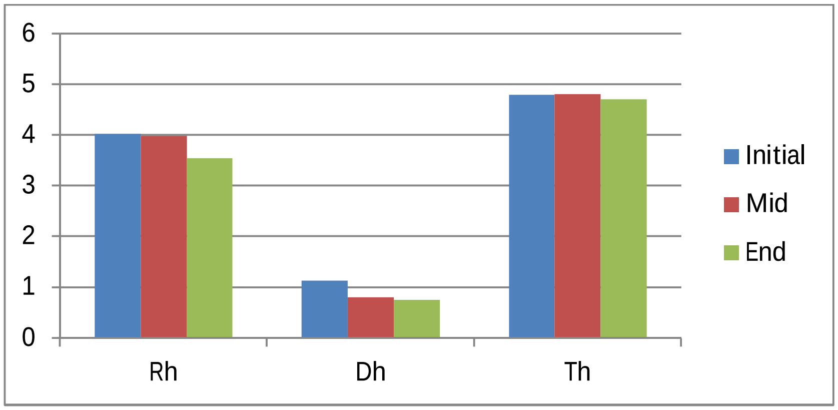
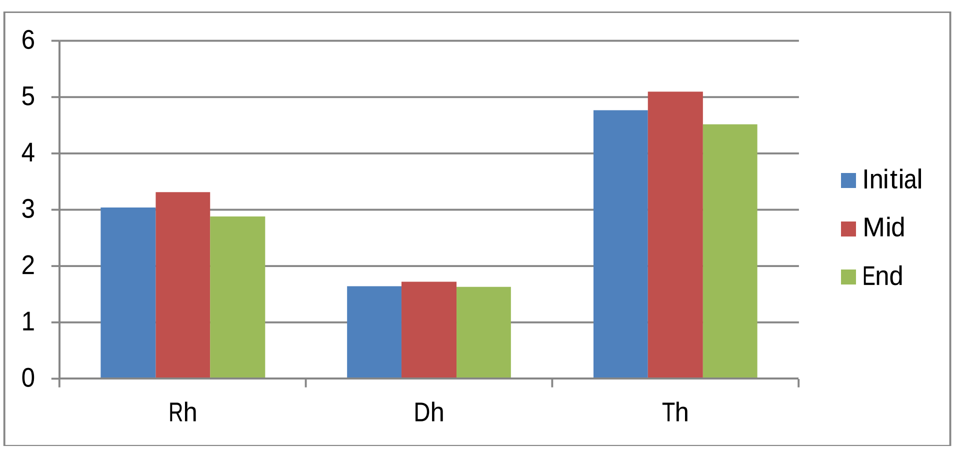
Graph no. 11: Graphical representation of the linear distance (meter) of the parameters in first serve during force generation phase of tennis serve.



Graph no. 13: Graphical representation of the linear acceleration (meter/s^2) of the parameters in first serve during force generation phase of tennis serve.

Graph no. 12: Graphical representation of the linear distance (meter) of the parameters in second serve during force generation phase of tennis serve.



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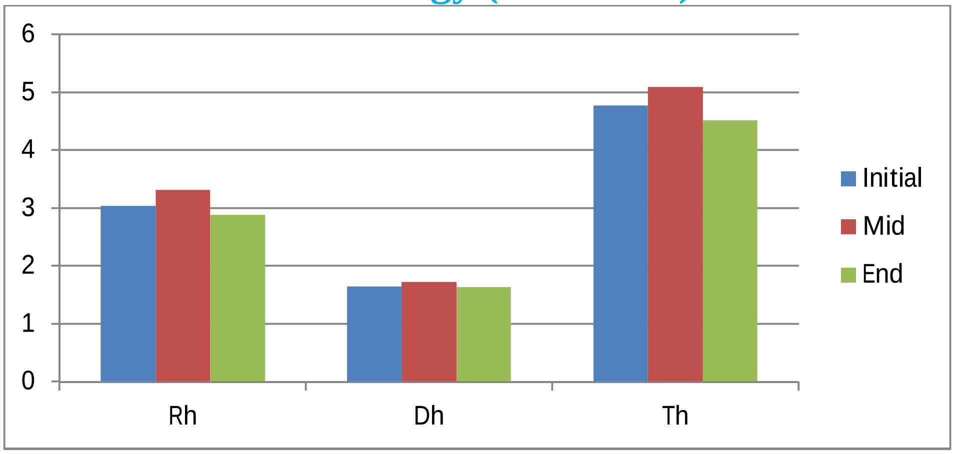

Graph no. 14: Graphical representation of the linear acceleration (meter/s^2) of the parameters in second serve during force generation phase of tennis serve.

Graph no. 15: Graphical representation of the angle (degree) of the parameters in first serve during force generation phase of tennis serve.

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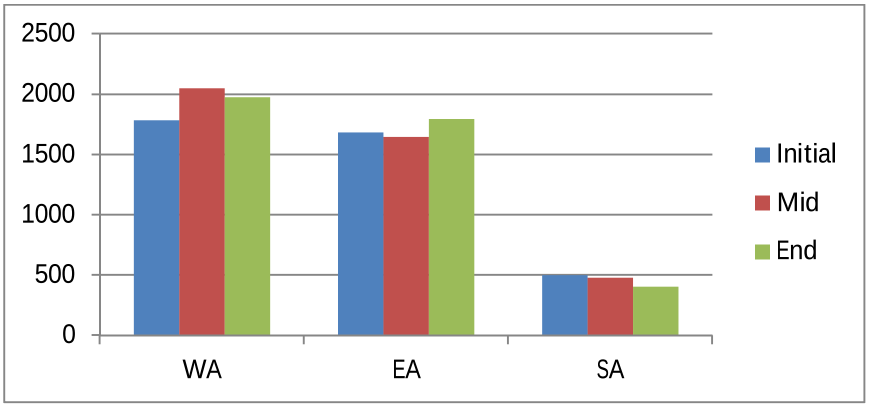
Graph no. 17: Graphical representation of the angular velocity (degree/second) of the parameters in first serve during force generation phase of tennis serve.



Graph no. 16: Graphical representation of the angle (degree) of the parameters in first serve during force generation phase of second serve.

Graph no. 18: Graphical representation of the angular velocity (degree/second) of the parameters in second serve during force generation phase of tennis serve.

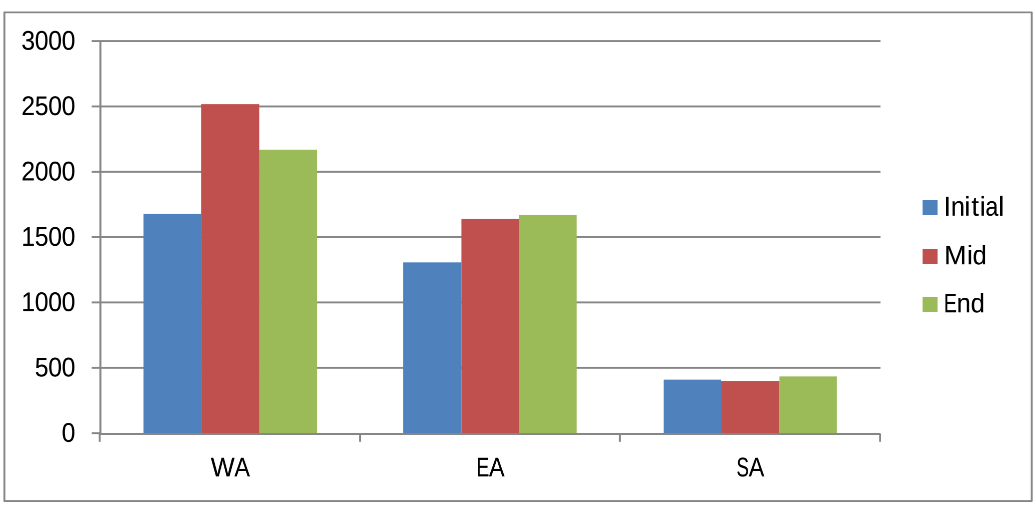


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Table No.: 3 Kinematics parameters of first and second serve during Follow through Phase at Initial, mid & End Period of Match.

Variable	Serve	Initial Period		Mid Period		End Period	
		Mean±SD	t-value	Mean±SD	t-value	Mean±SD	t-value
RI_{vel}	FS	1530.47±289.32	1.11	1498.56±187.30	0.05	1484.24±303.23	0.52
	SS	1336.96±193.32		1491.90±168.47		1401.35±107.89	
RPI_{vel}	FS	1786.71±316.22	2.47*	1663.00±395.82	0.80	1311.45±249.88	0.46
	SS	1371.55±115.23		1480.74±224.44		1376.80±137.32	
$Ball_{vel}$	FS	4735.37±873.40	2.06	4236.07±447.93	1.14	4020.27±759.62	0.80
	SS	3763.12±360.27		3856.12±490.26		3713.00±82.72	
WR_{vel}	FS	837.91±113.48	1.45	756.20±83.98	0.17	713.42±102.95	0.05
	SS	729.71±96.30		770.59±151.02		716.35±55.24	
ER_{vel}	FS	420.72±27.52	2.70	396.40±25.85	0.77	368.71±35.35	2.08
	SS	382.02±7.96		416.80±45.57		411.57±21.15	
SR_{vel}	FS	216.34±35.25	0.87	211.46±37.42	0.75	205.78±35.18	0.49
	SS	235.85±27.55		227.43±20.53		215.64±19.10	
PR_{vel}	FS	168.48±47.49	0.41	194.01±22.39	0.70	176.27±39.94	0.31
	SS	181.23±41.43		179.42±35.40		168.96±26.31	
KR_{vel}	FS	75.83±17.02	0.02	76.56±36.15	0.19	88.35±23.12	0.81
	SS	75.64±15.53		80.96±28.14		75.80±20.86	
AR_{vel}	FS	328.25±56.22	0.10	342.70±43.45	0.04	334.78±84.87	0.37
	SS	323.24±78.22		344.19±51.38		317.52±36.77	
TR_{vel}	FS	399.18±63.19	0.00	428.49±47.34	0.18	407.88±80.65	0.64
	SS	398.99±101.71		420.60±76.40		379.96±32.39	
WA_{acc}	FS	2191.65±380.80	0.17	2254.27±530.74	1.29	3267.26±1121.65	0.39
	SS	2274.98±892.58		3198.78±1367.00		3597.08±1290.19	
EA_{acc}	FS	1497.49±607.10	0.93	1278.36±547.82	0.02	1118.60±775.77	1.48
	SS	1140.61±476.10		1287.12±604.38		1850.05±615.07	
WA^{O}	FS	146.86±18.94	1.70	143.73±7.24	0.56	140.90±5.91	0.02
	SS	129.60±7.18		140.22±10.34		140.78±13.86	
EA^{O}	FS	159.17±10.60	1.82	138.03±39.28	0.30	140.95±24.82	0.43
	SS	125.97±34.84		144.52±17.56		146.45±6.62	
SA^{O}	FS	134.74±8.10	0.56	118.08±18.98	2.26	150.12±19.55	1.14
	SS	125.41±32.30		142.78±10.89		135.92±15.35	
$WA^{O/S}$	FS	1219.91±523.83	0.06	1104.02±825.79	0.34	900.28±214.34	0.82
	SS	1242.19±461.93		953.57±343.55		1107.08±458.05	
$EA^{O/S}$	FS	1911.67±1033.24	0.39	1723.01±856.58	0.00	1725.99±542.85	0.25
	SS	1659.29±780.01		1725.45±1089.08		1599.41±870.47	
$SA^{O/S}$	FS	1540.91±710.73	1.01	1094.08±949.85	0.61	1665.34±823.28	0.22
	SS	1085.24±555.21		1443.88±657.58		1763.04±370.14	

Tab $t_{0.05}$ (6) =2.447 *Significance at 0.05 levels.

The analysis of data table - 3 shows that there are no significant differences found between first and second serve of body kinematics. The linear velocity of racket velocity at impact (RI_{vel}), racket velocity at post impact (RPI_{vel}), ball ($Ball_{vel}$) wrist angle (WA), elbow angle (EA), shoulder angle (SA), pelvic angle (PR), knee right (KR) and ankle right (AR). The acceleration of wrist angle (WA_{acc}), elbow angle (EA_{acc}), angles and angular velocity of wrist angle ($WA^{O/S}$), elbow angle ($EA^{O/S}$), shoulder angle ($SA^{O/S}$) have shown $|t|_{cal}$. values are less than the $t_{0.05,\,6}$ value at 0.05 level of significance. Except the racket velocity at post impact (RPI_{vel})

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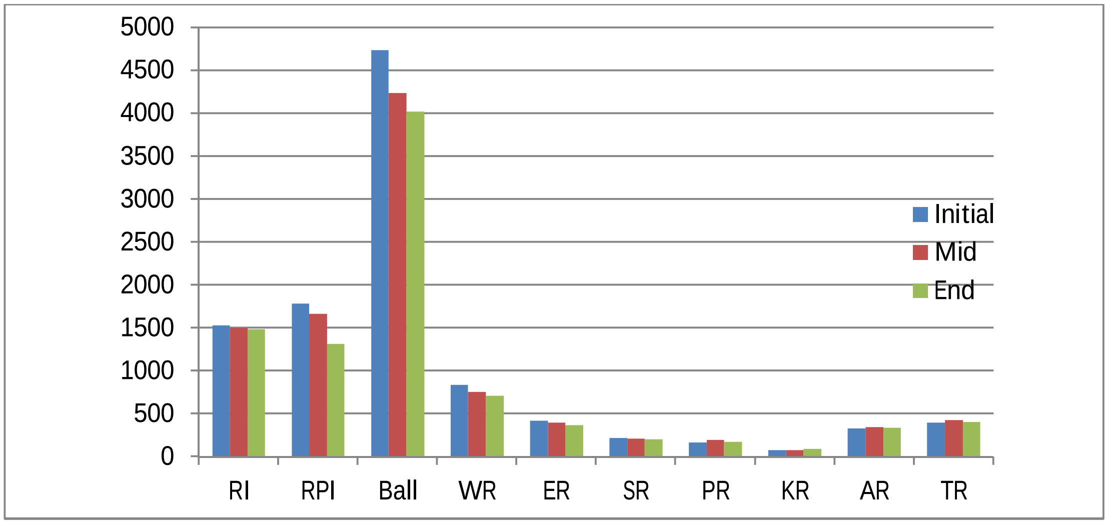
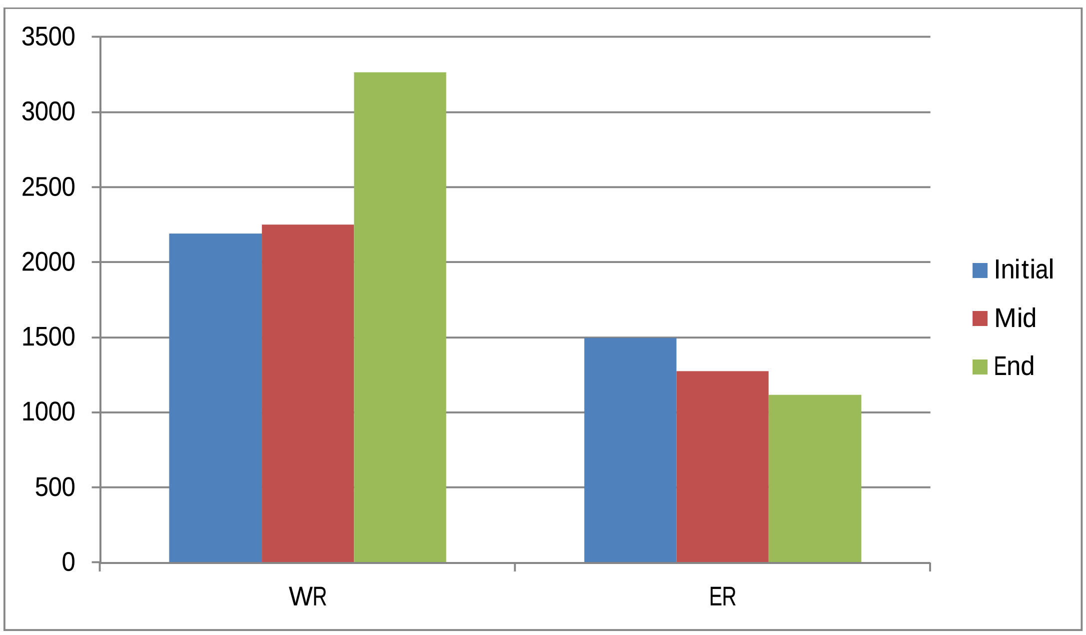
during initial period of the match. Which shows a significant difference where $|t|_{cal}$. values is more than the $t_{0.05,\,6}$ value at 0.05 level of significance.

Graph no. 19: Graphical representation of the linear velocity (meter/s) of the parameters in first serve during follow through phase of tennis serve.



Graph no. 21: Graphical representation of the linear acceleration (meter/s^2) of the parameters in first serve during follow through phase of tennis serve.



Graph no. 20: Graphical representation of the linear velocity (meter/s) of the parameters in second serve during follow through phase of tennis serve.

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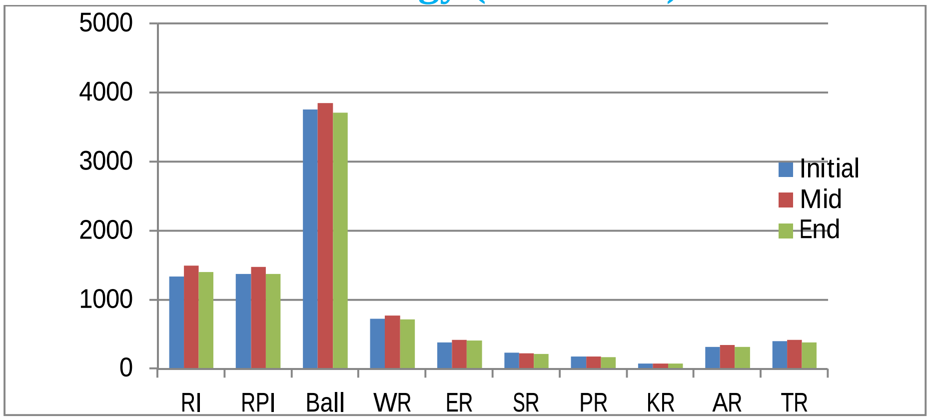
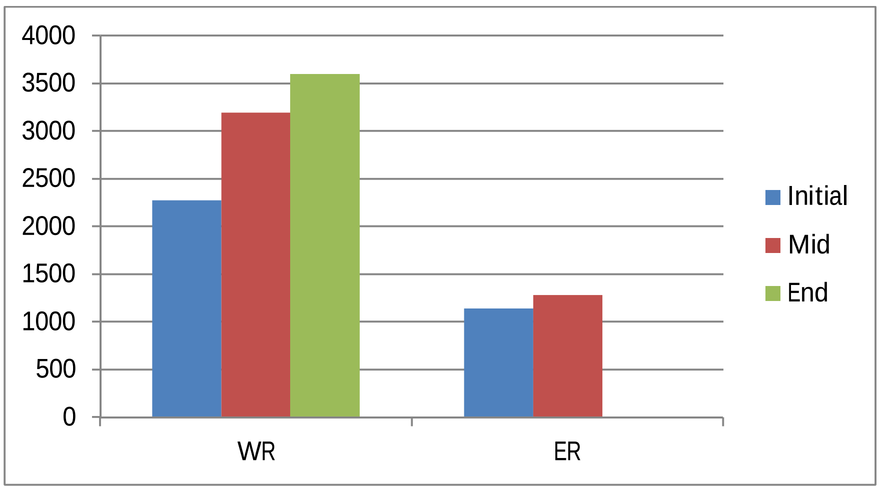
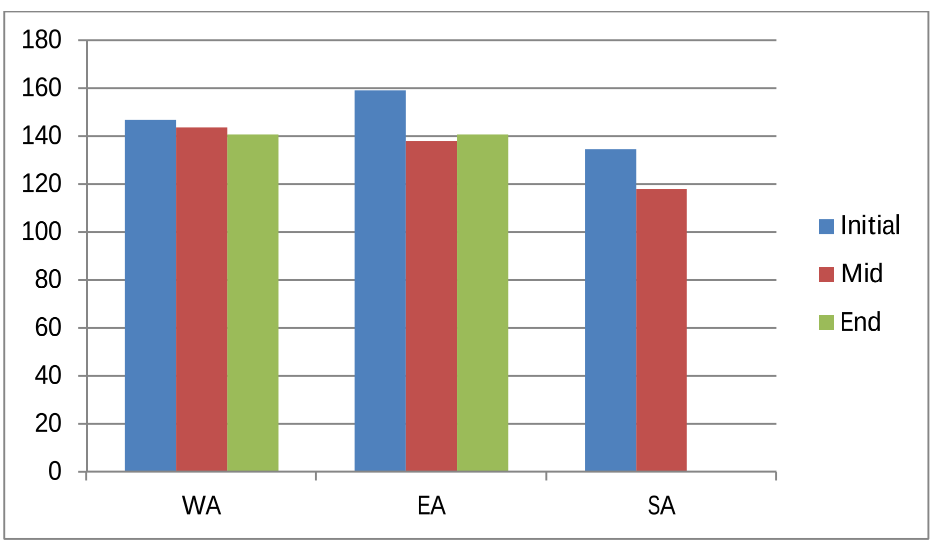


Graph no. 22: Graphical representation of the linear acceleration (meter/s^2) of the parameters in second serve during follow through phase of tennis serve.



Graph no. 23: Graphical representation of the angle (degree) of the parameters in first serve during follow through phase of tennis serve.



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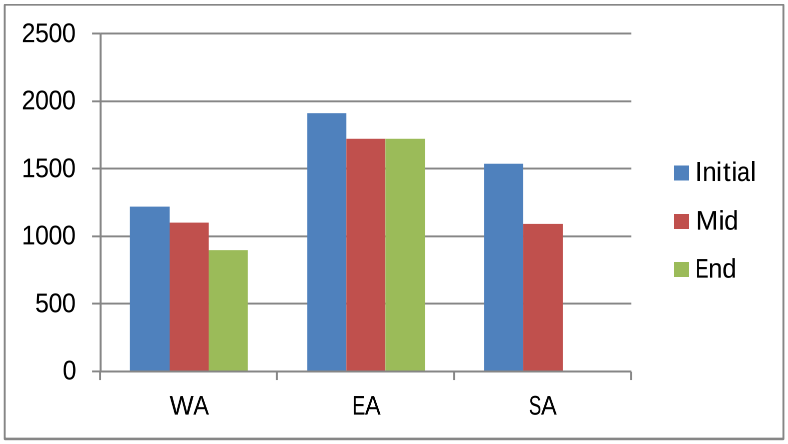
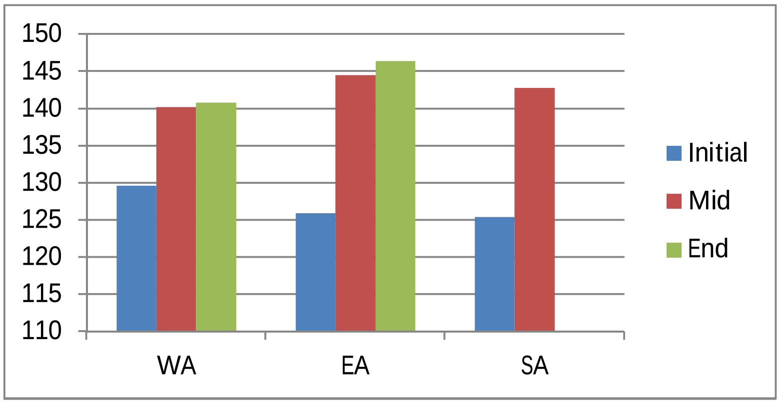
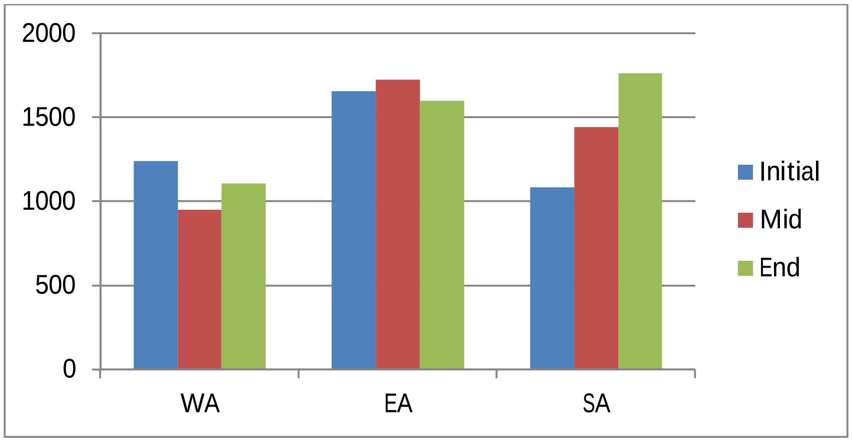
Graph no. 25: Graphical representation of the angular velocity (degree/second) of the parameters in first serve during follow through phase of tennis serve.



Graph no. 24: Graphical representation of the angle (degree) of the parameters in second serve during follow through phase of tennis serve.



Graph no. 26: Graphical representation of the angular velocity (degree/second) of the parameters in second serve during follow through phase of tennis serve.



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This statistical finding exhibits that all the linear and angular kinematics of right side of wrist, elbow, shoulder, pelvic, Knee and ankle during first and second serve does not differ significantly and hence does not influence on the performance of tennis serve at follow through phase during initial, mid and end phases under the match condition.

IV. DISCUSSION

Service is a key element in the game of tennis. Advanced players can hit the serve in many different ways and often use it as an offensive weapon to gain an advantage in the point or to win. Professional players are expected to win most of their games in service, may be the first serve or second serve. The flexion & extension of body joints are the keys to generate maximum momentum and also contribute in performance of tennis serves. When executing a tennis serve, vigorous movement of the trunk help to generate as much angular momentum as possible to transfer it to the racquet (Bahamonde, 2000). The statistical analysis of data for different body segment kinematics revealed no significance difference between first and second service for Indian elite players.

The linear and angular kinematics of body joints point and body joint angle of right wrist, elbow, shoulder, pelvis, knee and ankle. And other kinematics as, toss angle, hit angle, reach, height, distance of the hit, toss height, racket velocity at impact, racket velocity at post impact, ball shows no significant differences between the both first and second tennis serve. The knees and hips extend and the back moves from extension to flexion and rotates toward the non-dominant side (Abrams, 2011).

Chew et. al. (2003) reported absolute racket velocities were comparable between first serve and second serve, and were developed to similar magnitudes, independent of serve location. The comparison of studies has reached to the conclusion that the shoulder plays an important role in generating power, as well as transfers the power to the distal segments to contribute to the performance (Putnam, 1993; Elliott et al., 1995). However, there are some disagreements between different investigations. For example, Elliott et al. (1995) concluded that forearm extension at the elbow actually has a negative effect on racquet speed which may reduce the ball speed. This contradicts another study that showed elbow extension to be the second greatest contributor to racquet speed at impact (Gordon & Dapena, 2006).

Elliott et al. (2003) studied the tennis serve's biomechanical properties using a two-camera system and compared male and female results during competition at the 2000 Sydney Olympic Games. They chose to analyze serves with the highest velocity and concluded that males created higher forces from their shoulder and elbow while also serving at higher speed. They also founded that an increased knee flexion during the backswing leads to generate low forces of upper extremity and recommended that players be encouraged to perform knee flexion. Reid et al. (2008) have investigated the factors which were most critical to the different serving techniques were the range of extension of front and rear knee, peak angular velocity of rear knee drive extension. The shoulder joint and foot kinematics influence higher in higher racquet linear velocity.

The tennis serve and throwing motion have a great relationship within each other. The movement uses whole body kinematics to impact the direction and velocity on the ball. There are ten segments in a position to be activated during these movements of tennis serve and throw. They are the ankles, feet, knees, pelvis, trunk, shoulder girdle, arm, forearm, and hand working in synchronicity. Each has its own movements relative to its own proximal articulation. These articulations can perform more than one movement; each movement depends upon the skill to be performed. Therefore, the link system tends to go faster as the movements proceed to its distal end to gain maximum ball velocity (Wigley, n.d). Finally, the follow-through phase begins just after the ball contact and ending with completion of the stroke (Pradhan, 2001). A number of investigations have been conducted to further delineate the specific biomechanics of serve in tennis (Elliott, 1986; Bahamonde, 1989; Dillman, 1995; Elliott, 1995; Noffal, 1999; Elliott, 2003; Gordon & Dapena, 2006).

V. CONCLUSION

From the data of the 2-D kinematics of the body moment of tennis serve of elite Indian players, we can see that the velocity of the ball produces more by the combination of the body kinematics moment, and this moment comes mainly from the extension of the knee, trunk, shoulder, elbow and wrist. This point can be verified by the 2-D kinematics results of the study. Elite tennis players maintain their body kinematics in both first and second serve, and also manipulate their body kinematics to control the maximum ball velocity till the end period of the match, which is executed through the racket velocity generated by the sequential movement of the body segments involve in the serve motion of the tennis. From this study, we can further understand the role of body joint kinematics in the on the maintenance of the performance of the tennis serve throughout the match. This will provide a reference to the serve motions and the execution of the serve techniques for training and teaching, with a view to improve serving efficiency.

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