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Influence of Body Kinematics on Tennis Serve

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Abstract:

Improving the serve speed is most important for competitive tennis players. The aim of this study was to examine the influence of body kinematics on ball velocity, thereby to propose possible suggestions to improve serving skill. Body kinematics of four Indian international players, who participated in Davis cup held at Indore, India having mean age (years), height (cm) and weight (kg) of 27.00±4.97, 186.50±6.03 and 81.25±7.41, respectively were investigated. The tennis serve was divided into three phases: (I) preparatory phase, (II) force-generation phase, and (III) follow-through phase. The recorded data of service motion was analyzed using appropriate motion analysis software and statistical analysis was done by using SPSSv 17. The mean, standard deviation (SD) and correlation coefficient (r) were determined to find out any relationship between the selected kinematic variables and ball velocity. It was shown that, during phase I, wrist angular velocity (r= 0.50), during phase II, wrist velocity (r= 0.52), shoulder velocity (r= 0.45), elbow angular velocity (r= 0.43), elbow angular acceleration (r= 0.45) and during phase III, racket velocity at impact (r= 0.53), elbow angular acceleration (r= 0.44) were significantly correlated with ball velocity. Players therefore should concentrate on increasing the extension velocities of these identified joints during training.

Key words: Body kinematics, Ball velocity, Tennis serve, Motion Analysis Software.

Introduction

In tennis, serve is one of the most important basic techniques of the sport, the efficacy of which is the key to success (Elliot, Marsh & Balankshy, 1986). The importance of serve in tennis is so paramount that it is the only one segment of the whole sport that determines the success of a player. The stroke has also a determining role in deciding the outcome of the match. So, all level players try to develop fast and powerful serve as most influential and fearsome weapon of their game (Sun, Lui & Zhon, 2012). Tennis serve is the only closed skill stroke in which a player has a full control on the trajectory (path) of the ball. But at the same time, it is difficult to master as it involves the complex coordination of the lower and upper body segments (Brody, 1987; Elliot & Kilderry, 1983). By understanding the role of different body segments in the effectiveness of tennis serve, it is also expected that it may help us to develop the training sessions for players and simultaneously will help them in reducing the chances of injuries due to false execution of serve. In order to improve the efficacy of the serve, there must be the integrated movement of the whole body. The kinematic chain involves the motion of the body produced by the body segments from proximal to distal end. In case of tennis serve it originates from the plantar-flexion of the feet and ends at racket. The most important performance outcome from this kinematic chain is the maximum speed (Kibler & Meer, 2001).

Various kinematic and kinetic studies have been proposed which helps in better understanding of tennis serves by skilled players. Most of them correlated the kinematic motion analysis with several performance outcomes like post impact ball speed, height of impact and time of execution (Sgro, Mango, Nicolosi, Schembri & Lipoma, 2013). Gordon & Dapena

(2006) studied that the speed of racket came sequentially from kinematic motions of different body segments like shoulder abduction, elbow extension, ulnar deviation, rotation at the wrist, axial rotation of upper trunk relative to lower trunk and wrist flexion. They also found that forearm pronation had a little negative effect on racket speed. Springer, Marshal, Elliott & Jennings (1994), also reported the reduction of racket head speed by elbow extension at contact. This was also supported by (Springer, 1994) who also noted a negative role played by elbow extension which reduced the forward velocity of centre of the racket impact. Contrary to the previous researches, Elliot (1988) found that during tennis serve execution, the linear velocities of various body joints increased progressively from knee, hip, shoulder, elbow and wrist and summation of the resultant linear velocities of these joints resulted in maximum angular velocity of the racket. Fleising, Nichollas, Elliot & Escamilla (2003) studied the serve motion of players in 2000 Olympics and quantified their kinematics of knees, pelvis, trunk, shoulder, elbows and wrists during high velocity serves and suggested that the players must be trained to develop kinematic profiles similar to 2000 Olympics, so as to produce high velocity serves. Also a significant association between body height and serve speed was reported by Vaverka & Cernosek (2013). For high speed tennis serves, it is believed that vertical drive from legs is one of the most determining factor, however researchers differs in views demands the kinematic analysis of whole body segments to be investigated for better understanding of serve kinematic chain. Therefore present study was structured to study the influence of whole body kinematic parameters on ball velocity, thereby proposing the possible training strategies for quality tennis serve to gain high ball velocity.

Methodology

Four male International players, participated in Davis Cup, held at Indore in November 2013 were recruited for the study. The mean and standard deviation (SD) of their age (yrs), body height (cm) and body weight (kg) were 27 ± 4.97, 186 ± 6.03 and 81.25 ± 7.41 respectively.

The kinematic chain of body segments (producing motion in the body) was taken as a model for tennis serve and composed of (a) foot (b) lower leg (c) thigh (d) Trunk (e) Upper arm (f) fore arm (g) hand and racket.

A cannon camcorder operating at shutter speed of 1/2000 and frame rate of 50 Hz was used for obtaining the two-dimensional kinematic data of whole body particularly focusing on right side of the players. The camera was positioned perpendicular to the sagittal plane on the right side at a distance of 17 meters from the mid of base line of tennis court to capture the serve motion.

The total number of four trials of each player were taken under consideration for the study and the selected parameters of various body segments i.e. Toe velocity (V_T), Ankle velocity (V_A), Knee velocity (V_K), Hip velocity (V_H), Shoulder velocity (V_S), Elbow velocity (V_E), Wrist velocity (V_w), Ankle angular velocity (AV_A), Knee angular velocity (AV_K), Hip angular velocity (AV_H), Shoulder angular velocity (AV_S), Elbow angular velocity (AV_E), Wrist angular velocity (AV_W), Elbow angular acceleration (AA_E) and also, Toss height (TH), Toss angle (TA), Reach height (RH), Racket velocity at impact (V_{RI}), Racket velocity post impact (V_{RPI}), and Ball velocity (V_B), were analyzed during three time periods of the serve i.e. at preparation phase, at force generation phase and finally at follow through phase. This procedure was applied for first and second serve only.

After obtaining the required data, the recorded videos were carefully viewed and best performance clips of subjects were extracted for analysis which was done by appropriate motion analysis software. The software provides to identify the required angles, displacement, time and number of frames.

Preparatory Phase

Force generation Phase

Follow Through Phase

Results

The main objective of this scientific venture was to determine the relationship between players' kinematic variables and ball velocity of the serve. The results of the study are presented in the given tables below;

Table No.: 1 Mean, SD & relationship among players' kinematic variables and ball velocity of serve during Preparation Phase.

Variable	**Mean**	**SD**	**Correlation (r)**
Toss Angle (TA)	9.21	4.05	0.02
Wrist Velocity (V_w)	138.61	26.56	0.04
Elbow Velocity (V_E)	96.42	18.66	0.30
Shoulder Velocity(V_S)	86.23	13.89	0.31
Hip Velocity (V_H)	73.22	15.63	0.15
Knee velocity (V_K)	60.98	14.80	0.13
Ankle Velocity (V_A)	37.01	11.79	0.39
Toe Velocity (V_T)	35.42	14.58	0.40
Wrist Angular Velocity (AV_W)	422.84	148.74	0.50*
Elbow Angular Velocity (AV_E)	428.04	182.18	0.15
Shoulder Angular Velocity (AV_S)	91.79	21.17	0.41
Hip Angular Velocity (AV_H)	189.99	167.36	-0.01
Knee Angular Velocity (AV_K)	761.41	553.10	0.35

Ankle Angular Velocity (AV_A)	245.31	203.75	0.17
Elbow Angular Acceleration (AA_E)	8234.71	4269.75	0.19

*Significance level at 0.05
Tab $r_{0.05}$ (22) = 0.42

A critical evaluation of table 1 shows that no significant relationship exists between the ball velocity and the Toss angle, the linear and angular velocities of toe, ankle, knee, hip, shoulder, elbow, wrist and also angular acceleration of elbow, except the wrist angular velocity which was found significantly correlated with the ball velocity ($r = 0.50; p < 0.05$).

Thus, the above statistical findings reveal that all the selected kinematic variables except the wrist angular velocity show insignificant relationship and hence do not influence on ball velocity at preparation phase during match conditions.

Table No.: 2 Mean, SD & relationship among players' kinematic variables and ball velocity of serve during Force Generation Phase.

Variable	**Mean**	**SD**	**Correlation (r)**
Toss Height (TH)	4.79	0.55	0.12
Reach Height (RH)	3.47	1.15	0.07
Wrist Velocity (V_W)	815.86	106.94	0.52*
Elbow Velocity (V_E)	678.69	59.41	0.17
Shoulder Velocity (V_S)	387.27	31.80	0.45*
Hip Velocity (V_H)	184.95	45.75	-0.30
Knee velocity (K_K)	167.27	34.14	-0.11
Ankle Velocity (V_A)	150.97	32.70	-0.13
Toe Velocity (V_T)	225.92	71.20	-0.02
Wrist Angular Velocity (AV_W)	2063.39	582.69	-0.13
Elbow Angular Velocity (AV_E)	1625.09	393.57	0.43*
Shoulder Angular Velocity (AV_S)	440.14	98.46	-0.20
Hip Angular Velocity (AV_H)	1651.55	556.84	0.42
Knee Angular Velocity (AV_K)	1726.06	491.01	0.12
Ankle Angular Velocity (AV_A)	1593.29	457.01	-0.01
Elbow Angular Acceleration (AA_E)	32543.77	7023.61	0.45*

*Significance level at 0.05
Tab $r_{0.05}$ (22) = 0.42

Readings of Table 2 shows a significant relationship exists between the ball velocity and wrist velocity ($r = 0.52; p < 0.05$), shoulder velocity ($r = 0.45; p < 0.05$), elbow angular velocity ($r =$

0.43; p < 0.05) and elbow angular acceleration (*r = 0.45; p < 0.05*). Insignificant relationship is observed in the remaining selected variables in this study.

The above statistical findings reveal that except wrist linear velocity, shoulder velocity, elbow angular velocity and elbow angular acceleration (which show significant relationship), all selected kinematic variables exhibit insignificant relationship and hence do not have influence on ball velocity at force generation phase during match conditions.

Table No.: 3 Mean, SD & relationship among players' kinematic variables and ball velocity of serve during Follow Through Phase.

Variable	**Mean**	**SD**	**Correlation (r)**
Racket velocity at Impact (V_{RI})	1457.24	205.44	0.53*
Racket velocity at post Impact (V_{RPI})	1498.38	288.19	0.03
Wrist Velocity (V_W)	754.03	102.34	0.26
Elbow Velocity (V_S)	399.37	32.77	0.12
Shoulder Velocity (V_S)	218.75	28.51	0.10
Hip Velocity (V_H)	178.06	33.50	0.02
Knee velocity (V_K)	78.86	22.18	0.11
Ankle Velocity (V_A)	331.78	54.92	0.09
Toe Velocity (V_T)	405.85	64.57	-0.11
Wrist Angular Velocity (AV_W)	140.35	11.55	-0.06
Elbow Angular Velocity (AV_E)	142.51	24.57	-0.03
Shoulder Angular Velocity (AV_S)	134.51	20.09	-0.03
Hip Angular Velocity (AV_H)	160.63	6.02	0.09
Knee Angular Velocity (AV_K)	213.68	191.17	-0.10
Ankle Angular Velocity (AV_A)	124.87	14.01	-0.05
Elbow Angular Acceleration (AA_E)	1640.80	869.68	0.44*

*Significance level at 0.05

Tab $r_{0.05}$ (22) = 0.42

From the critical analysis of above table, it is evidenced that the velocity of racket at impact (*r = 0.53; p < 0.05*) and elbow angular acceleration (*r = 0.44; p < 0.05*) are significantly correlated with the ball velocity. Further no significant relationship exists between the ball velocity and other selected kinematic variables and hence does not influence the ball velocity at follow through phase during match conditions.

Discussion

The fast and powerful serve has a determining role in the outcome of the match (Sun, Lui & Zhou 2012), therefore every player tries to develop fast and accurate serve to gain advantage during the match. The tennis serve involves a complex coordination of lower and upper body segments to provide a kinematic chain for the transference of force from proximal to distal end of the body and thereby to the ball resulting in its greater velocity.

The results of the statistical analysis of data showed significant relationship of ball velocity to the linear and angular velocity of wrist, angular velocity and angular acceleration of elbow, linear velocity of shoulder and racket velocity at impact. No significant relationship existed between the ball velocity and other selected kinematic variables in all the three phases of serve. Sweany, Reid & Elliot (2012) reported that the increased vertical linear velocity from lower limbs enhances the linear velocity drive of racket side shoulder, hence leading to greater ball velocity. The greater force of vertical drive is the contribution of pushing the ground downwards with the feet and flexion of knee which acts as link to transfer this force to upper limbs.

Gordan & Dapena (2006) also reported the increased racket head speed and hence ball velocity came sequentially from greater shoulder abduction, elbow extension, ulnar rotation at wrist, wrist flexion and twist rotation of upper trunk and further more the study showed that elbow extension is the second largest contributor of racket velocity at impact. Elliot (1998) also reported that the linear velocities of various joints increases progressively from the lower limbs and gets transferred to the upper extremities i.e. shoulder, elbow and wrist and the summation of these maximum linear velocities produce maximum angular velocity of the racket. In a subsequent study Elliot, Marshal & Noffal (1995) reported that internal rotation of shoulder was found to generate approximately 50 percent of linear racket head velocity. Fleisig, Nicholls, Elliot & Escamilla (2003) further reported that high shoulder internal rotation velocity measurement was critical for producing high ball serve velocity.

The faster ball velocity can be linked to the key role played by the lower limbs in creating a vertical drive during the execution of serve. The toe, ankle, knee, trunk creates a link system which transfers the force to upper limbs in such a coordinated way that one segment energy decreases and the next participating body segment energy increases, thereby making the ball to gain maximum velocity.

Hence, it is suggested that in producing high velocity serves, coaches while imparting training, should focus on movement specifics like joint angles and velocities. In particular, the results suggest that special focus should be on wrist, elbow and shoulder extensions for greater ball velocities.

Conclusion

In our study of body kinematic analysis, various velocities and accelerations of specific joints were identified which were significantly related to ball velocity. These include linear and angular velocities of wrist and elbow, shoulder velocity, angular acceleration of elbow and racket velocity at impact. So we can conclude that the serve kinematics can be adjusted to improve ball velocity and may allow players to enhance the serving skill.

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