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ORIGINAL ARTICLE

Analysis of Kinetic Chain Mechanism Affecting Energy Flow in Kick Topspin Tennis Serve in Elite and Amateur Tennis Players

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ABSTRACT

Background. Effective kick-topspin serving in tennis requires power to transfer mechanical energy through a kinematic chain from different parts of the body that is directly related to the kinetics of the joints. Energy flow analysis is a powerful tool for observing the mechanical energy transfer through the body parts. **Objectives**. This research aimed to study the correlation and predictive ability of the independent variables affecting the energy flow in a topspin kick serve. **Methods.** Ten male tennis players aged 19 - 25 were recruited by purposive sampling and consisted of elite and amateur tennis players. The movement patterns of the kinetic chain mechanism and the energy flow in kick topspin tennis serve were recorded with six motion cameras with a force platform and motion analysis program to analyze their 3D motion. The relationship and comparison with the independent variables affecting the dependent variable at seven joints were investigated using Multiple Analysis of Variance (MANOVA) and Stepwise multiple regression analysis for the predicted equation ($p<0.05$). **Results.** The results showed no significant differences in the seven body joints in both groups. The correlation and predictability revealed that the variables were used to transfer and release mechanical energy differently in three distinct phases. **Conclusion.** The effective kinetic chain and energy flow lead the mechanical energy to the segment of the body to achieve proper position and energy transfer; smooth coordination leads to greater speed in the acceleration phase to the follow-through phase in the tennis serve.

KEYWORDS: ***Mechanical Energy, Energy Flow, Tennis Serve.***

INTRODUCTION

The tennis serves are the most critical strokes in tennis and often have to gain an advantage over their competition. The key to tennis serves consisted of speed, power, and accuracy (1). Kick topspin tennis serves popular and effective tennis serves. The benefits of the kick serves are that the addition of ball spin allows for larger net clearance while still landing into the service box since spin creates aerodynamic forces that cause the ball to drop as it slows. This increase the percentage of serves that land in the services area with moderate velocity, and when performed properly, is effective for serves. The energy generated at the larger segments transfers to the throwing arm segments in a sequential manner that closely follows the summation of the speed principle (2). The tennis serves are a sequence of motion referred to as a kinetic chain that begins with lower limb action and is followed by trunk and upper limb rotations.

Consequently, joint and segmental rotation contributions to racket velocity greatly interest the literature (3). Energy flow analysis is an effective tool providing a quantitative assessment

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of the kinetic chain to understand better how energy moves through an athlete and how specific overhead throwing mechanics impact this movement (4). Therefore, this study's purpose was to compare the dependent variables at seven joints and investigate the independent variable's correlation and predictive ability energy flow affecting the dependent variable in kick topspin tennis serve between elite and amateur tennis players.

MATERIALS AND METHODS

Participants. Ten male tennis players competing in the Suranaree tennis tournament and at the club level volunteered to participate in this study during their season from 19 - 25 years of age were recruited by purposive sampling and consisted of elite and amateur tennis players. All players had a minimum of 3 years of prior tennis-specific training. Inclusion for all subjects required each participant to be a healthy tennis player with no history of upper extremity surgery, shoulder pain for the past 12 months, and no rehabilitation for the past 12 months. All participants were right dominant-handed. Based on a statistical power analysis performed with a freely available stand-alone program (G*Power 3.1.9.4) to calculated the sample size (effect size = 0.80 α = 0.05 power (1-β = 0.85) (5). Eight participants were computed at the minimum sample size for detecting a significant relationship between independent and dependent variables. According to the minimum recommended sample size, ten participants were used in this experiment, reducing the data's variance via increased sample size. A verbal overview of all experimental procedures and written informed consent before testing was given. The study protocol (SWUEC – G - 438/2563) was approved by the research ethics committee of Srinakharinwirot University.

Procedures. Participants were videotaped using a six high-speed camera system (Qualysis camera oqus7+ series from QUALYSIS AB, Sweden) sampling at 300 Hz and electronically synchronized with a force plate (Kistler 9286BA, Kistler group) sampling at 1500 Hz. Three-dimension data were reconstructed by a visual 3D motion analysis program (C-Motion, Inc., Germantown, MD) and were smooth by a Butterworth digital filter which cut–off frequencies ranging from 6 Hz. The laboratory was a simulation of a 5.9 m half tennis court (6). According to informed consent, participants performed their non–throwing warm-up consisting of jogging, static, and dynamic stretching exercises for approximately 20 minutes and 10 minutes of tennis serve movement training to prepare for a whole serving. Participants were given as much time to familiarize themselves with the testing environment and the attached markers. After a 10 - min warm-up, each player was invited to perform successful kick topspin tennis serve to the target area. A 15 - s rest period was allowed between trials. Participants were instructed to serve the ball in the target area with the highest ball speed possible. Three of the five perfectly served were used in movement analysis (7). The selection criteria for kick topspin tennis serve consisted of precision and highest racket head velocity at ball impact (8). However, lower than 3 perfectly serves will be considered a failure.

Dependent variables in this study consisted of linear and angular velocity, acceleration, linear and angular momentum, force, and torque at the right ankle joint, knee joint, hip joint, shoulder joint, elbow joint, wrist joint, and torso of the body in three distinct phases. In this study, variables concerning energy flow were quantified from the resultant joint forces and torques using a joint power analysis detailed by Robertson, Winter, and Zatsiorsky (3). The data analyzed by kinetic to determine the energy flow from the variables of energy flow were the joint force powers (JFP), the segment torque powers (STP), the joint torque powers (JTP), and the segment powers (SP). All variables of the power flow were normalized by each participant's body mass (3).

Joint Force Power: Rate of energy transfer by the joint forces. The joint force power (JFP) was calculated at a dot product of the segment's joint force and linear velocity (9).

$$JFP = Fj \cdot vj$$

The positive joint force power at the joint of a segment indicates an increase in the mechanical energy of the segment, and the negative joint force power indicates a decrease in the mechanical energy (10).

Segment Torque Power: Rate of energy transfer by the joint torques. The segment torque power (STP) was calculated at a dot product of the joint torque and the angular velocity of the segment.

$$STP = Tj \cdot \theta s$$

The positive segment torque power at the joint of a segment indicates an increase in the mechanical energy of the segment, and the negative segment torque power indicates a decrease in the mechanical energy.

Joint Torque Power: Rate of energy absorption or generation by the joint torques. Joint Torque Power (JTP) was calculated at a dot product of joint torque (Tj) and angular velocity (α) of the joint.

$$JTP = Tj \cdot (\theta d - \theta p) = Tj \cdot \alpha$$

Where θ is the vector of the body segment's angular velocity, subscripts d and p refer to the distal and proximal segments adjacent to the joint.

The positive values of the joint torque power indicated that joint torque generates mechanical energy. The negative values of the joint torque power indicated that joint torque absorption mechanical energy. When one segment's torque power was positive, and the other segment's torque power was negative, the joint torque transferred mechanical energy (11).

Segment Power: Rate of energy output from or input or into the segments. Segment Power (SP) was the JFP and STP at each end of each segment were then summed to calculate.

$$SP = JFPd + JFPp + STPd + STPp$$

The positive values of the segment power indicated an inflow of energy into the segment at the joint. The negative of the segment power indicated an outflow of energy from the segment at the joint.

Statistical analysis. The relationship and comparison with the independent variable affecting the dependent variables at the ankle joint, knee joint, hip joint, shoulder joint, elbow joint, wrist joint, and torso of the body were investigated using multiple analysis of variance (MANOVA) and stepwise regression analysis for the predict equation. The level of statistical significance was set to $p<0.05$.

RESULTS

Ten right-handed male tennis players divided five elite tennis players (age = 19.2 ± 1.17 years; height = 174.6 ± 1.50 m; mass = 68.8 ±14.4 kg; BMI = 22.51 ± 4.42 kg/m2) and 5 amateur tennis players (age = 18.4 ± 0.1 years; height = 175.6 ± 5.68 m; mass = 71.0 ± 9.29 kg; BMI = 22.91 ±1.66 kg/m2). The mean (± SD) of the individual characteristics of the players are presented in Table 1. There were no significant differences in age, mass, height, and BMI between elite and amateur tennis players.

The results showed no significant difference in the independent variable affecting the dependent variables at seven joints between elite and amateur tennis players. The dependent variables at the wrist, elbow, shoulder, torso, and hip showed significance in three distinct phases. In contrast, the variables at the ankle and knee had no significant differences. The interaction test between the group and three distinct phases that did not influence the body's seven joints of the body are presented in Table 2.

Table 1. Individual characteristics (mean ± SD)

	Elite tennis players	Amateur tennis player
	M ± SD	M ± SD
age (yrs)	19.2 ± 1.17	18.4 ± 0.8
mass (kg)	68.8 ± 14.4	71 ± 9.29
height (cm)	174.6 ± 1.50	175.6 ± 5.68
BMI (kg/m^2)	22.51 ± 4.42	22.91 ± 1.66
Arm strength (kg)	37.4 ± 6.70	39.47 ± 2.59
Leg strength (kg)	149.4 ± 29.39	158.53 ± 27.15
Dominant hand	Right	right

Table 2. Multiple Analysis of Variance (MANOVA) in kick topspin tennis serves on three distinct phases in elite and amateur tennis players.

Joint	Group (sig)	Phase (sig)	Group * phase (sig)
Wrist	0.561	0.000	0.387
Elbow	0.783	0.000	0.625
Shoulder	0.124	0.000	0.804
Trunk	0.835	0.000	0.719
Hip	0.680	0.006	0.418
Knee	0.089	0.080	0.896
Ankle	0.419	0.092	0.719

The results showed the correlation and predictability revealed that the variables were used to transfer and release mechanical energy differently of the joint force power (JFP) at the knee joint, hip joint, shoulder joint, elbow joint, wrist joint, and trunk of the body in elite tennis players in three distinct phases are presented in Table 3. In amateur tennis players, the correlation and predictability (Table 4) revealed that the variables were used to transfer and release mechanical energy differently of the joint force power (JFP) at the knee joint, hip joint, shoulder joint, wrist joint, and trunk of the body in three distinct phases.

Table 3. The correlation and predictability of the Joint Force Power (JFP) on three distinct phases in elite tennis players.

Phase	Joint	Constant	Sig	Equation	R^2
Preparation Phase	Wrist	0.223	0.022	Y = - 4.57 (Linear Velocity) + 0.22	0.866
	Shoulder	-2.422	0.044	Y = 0.21 (Force) + 6.082 (Momentum) -2.42	-2.422
	Trunk	12,615	0.003	Y= 6.56 (Momentum) + 19.02 (Angular Velocity) + 0.11 (Force) + 12.62	1.000
	Knee	0.571	0.013	Y = -223.64)Linear Velocity (+ 0.57	0.905
Acceleration Phase	Trunk	- 12.116	0.009	Y = 255.59 (Linear Velocity) -2.686 (Acceleration) - 12.12	0.991
Follow Through Phase	Wrist	4.894	0.050	Y = 93.88 (Torque) + 4.894	0.903
	Elbow	-13.798	0.002	Y = - 984.29 (Angular Momentum) -13.80	0.968
	Shoulder	1347.793	0.003	Y = 393.62 (Torque) + 1347.79	0.966
	Hip	17.755	0.026	Y = -277.96 (Linear Velocity) +17.76	0.850
	Knee	- 3.571	0.000	Y = 12.36 (Angular Velocity) -3.57	0.995

Table 4. The correlation and predictability of the Joint Force Power) JFP(on three distinct phases in amateur tennis players.

Phase	Joint	Constant	Sig	Equation	R^2
Preparation Phase	Shoulder	-3.732	0.011	Y = 99.97 (Linear V) - 3.73	0.912
	Hip	21.676	0.023	Y = -3.45 (Torque) + 21.68	0.955
Acceleration Phase	Wrist	5.322	0.019	Y = -2.78 (Force) + 5.32	0.877
	Hip	- 50.949	0.006	Y = -2.39 (Torque) - 112.71 (Angular Momentum) - 50.95	1.000
Follow Through Phase	Wrist	14.491	0.001	Y = -9.92 (AV) - 7036.6 (AM) + 0.01 (Acceleration) + 14.49	1.000
	Trunk	- 64.090	0.001	Y = 21.52 (Force) -122.22 (Momentum) - 64.09	0.999
	Knee	- 57.372	0.000	Y = -24575.490 (Angular Momentum) - 57.372	0.995

AV: Angular Velocity, AM: angular Momentum

The segment torque power (STP) and joint torque power (JTP) in elite tennis players showed the correlation and predictability revealed that the variables were used to transfer and release mechanical energy differently at the ankle joint, knee joint, hip joint, shoulder joint, elbow joint, wrist joint and trunk of the body in elite tennis players (Table 5 and Table 7). While, amateur tennis players showed the variables were used to transfer and release mechanical energy differently of the segment torque power (STP) and joint torque power (JTP) at the ankle joint, knee joint, hip joint, shoulder joint, elbow joint, and wrist joint of the body in amateur tennis players in three distinct phases (Table 6 and Table 8).

The correlation and predictability of the segment power (SP) revealed that the variables were used to transfer and release mechanical energy differently from the segment power (SP) at the ankle joint, knee joint, hip joint, shoulder joint, elbow joint, wrist joint and trunk of the body in elite tennis players (Table 9). While the amateur tennis players showed that the variables were used to transfer and release mechanical energy differently of the segment power (SP) at the knee joint, hip joint, shoulder joint, and wrist joint of the body in three distinct phases (Table 10).

DISCUSSION

Joint Force Power (JFP). The result showed that elite tennis players had efficient knee joint linear velocity that important to reducing the generated elbow force and wrist force by trunk rotation to create energy storage. The energy flow between the throwing arm segments helps accelerate the effective tennis ball by the generate mechanical energy at the trunk and shoulder, which have a greater capacity for generating mechanical energy than the distal (12). The rotation of the torso is important for generating and transferring energy to the arm in the form of momentum, which can generate the resultant velocity in the acceleration phase. Amateur tennis players found rapid hip rotation in the acceleration phase, which is reverse of right– dominant-handed tennis players from excessive stretching and lateral flexion from right to left. This clockwise movement transfer torque to the spinal column. Tennis serve may place stress in the hip from trunk hyperextension as a predisposing mechanism for osteoporosis (13).

Table 5. The correlation and predictability of the Segment Torque Power (STP) on three distinct phases in elite tennis players.

Phase	Joint	Constant	Sig	Equation	R^2
Preparation Phase	Wrist	0.005	0.003	Y = - 2.05 (Torque) + 0.01	0.967
	Elbow	- 1,237	0.007	Y = -1.70 (Torque) – 1.10 (Angular Velocity) – 1.25	0.993
	Hip	1.590	0.006	Y =-5.42 (Acceleration) - 1759.97 (Angular Momentum) + 1.59	0.994
	Knee	-4.299	0.004	Y = 513.49 (Linear Velocity) -4.30	0.959
	Ankle	- 4.156	0.000	Y = 57.32 (Angular Velocity) + 0.04(Torque) - 4.16	- 4.156
Acceleration Phase	Trunk	3.064	0.008	Y = -16.87 (Momentum) +0.34 (Torque) +3.06	0.992
	Ankle	32.604	0.005	Y = -99.95 (Momentum) – 2356.72 (Angular Momentum) +3.06	1.000
Follow Through Phase	Wrist	0.897	0.013	Y = 16.62 (Torque) + 0.90	0.975
	Shoulder	597.783	0.002	Y = 172.38 (Torque) + 597.78	0.973
	Trunk	4.659	0.019	Y = 533.01 (Linear Velocity) + 4.66	0.877
	Knee	1.584	0.000	Y = -1.703(Torque) + 1.58	0.995

Table 6. The correlation and predictability of the Segment Torque Power (STP) on three distinct phases in amateur tennis players.

Phase	Joint	Constant	Sig	Equation	R^2
Preparation Phase	Wrist	- 0.152	0.021	Y = 2.93 (Momentum) - 0.15	0.869
	Elbow	2.615	0.041	Y = - 6.69 (Torque) + 2.62	0.797
	Shoulder	-7.614	0.015	Y = 140.58 (Linear Velocity) - 7.61	0.967
	Hip	-9.289	0.004	Y = 1.64 (Torque) - 0.010 (Force) - 9.29	1.000
Acceleration Phase	Elbow	- 22.841	0.048	Y = 40.79 (Torque) - 22.84	0.797
	Shoulder	-16.980	0.005	Y = 10.78 (Torque) -16.98	0.947
	Hip	8.963	0.014	Y = 15.51 (Acceleration) + 8.96	0.973
Follow Through Phase	Wrist	2.083	0.000	Y = -1.47 (Angular Velocity) +2.08	0.994
	Elbow	25.427	0.006	Y = - 16.46 (Torque) + 25.43	0.942
	Shoulder	1.434	0.045	Y = 68.74 (Momentum) + 1.43	0.785
	Knee	85.635	0.001	Y = -35272.80 (Angular Momentum) + 85.63	0.998
	Ankle	-2.176	0.002	Y = 1345.73 (Angular Momentum) -2.18	0.996

Table 7. The correlation and predictability of the Joint Torque Power (JTP) on three distinct phases in elite tennis players.

Phase	Joint	Constant	Sig	Equation	R^2
Preparation Phase	Wrist	0.010	0.011	Y = -0.18 (Torque) + 0.03 (Linear Velocity) + 0.010	0.989
	Elbow	-0.031	0.000	Y = -0.63 (Angular Velocity) + 0.27 (Torque) -0.03	1.000
	Trunk	1.095	0.003	Y = - 0.25 (Torque) – 2.34 (Angular Velocity) + 1.10	0.997
	Knee	- 1.139	0.001	Y = 0.63 (Acceleration) - 0.03(Torque) - 1.14	0.999
	Ankle	0.375	0.000	Y = -4.93 (Angular Velocity) + 21.40 (Momentum) + 0.38	1.000
Acceleration Phase	Trunk	5.310	0.000	Y = 0.41 (Torque) +5.31	0.997
	Hip	7.050	0.035	Y = -137.81 (Linear Velocity) +7.05	1.000
Follow Through Phase	Shoulder	56.096	0.003	Y = 15.43 (Torque) + 56.10	0.963
	Hip	- 0.449	0.014	Y = -70.70 (Angular Momentum) - 0.45	0.899
	Knee	- 9.215	0.004	Y = - 4.46 (Acceleration) - 47.53 (Linear Velocity) - 9.22	0.996
	Ankle	0.225	0.032	Y = 0.18 (Acceleration) + 0.22	0.937

Table 8. The correlation and predictability of the Joint Torque Power (JTP) on three distinct phases in amateur tennis players.

Phase	Joint	Constant	Sig	Equation	R^2
Preparation Phase	Wrist	0.028	0.043	Y = - 0.000 (Acceleration) + 0.004	0.793
	Elbow	0.736	0.003	Y = - 4.22 (Linear Velocity) + 1.64 (Momentum) + 0.74	0.947
	Shoulder	- 0.137	0.027	Y = 0.35 (Torque) - 0.14	0.846
	Hip	3.294	0.008	Y = -0.06 (Force) - 4.98 (Momentum) + 3.30	1.000
	Knee	2.118	0.015	Y = -107.21 (Linear Velocity) + 2.12	0.895
Acceleration Phase	Wrist	0.064	0.012	Y = -0.06 (Force) + 0.06	0.907
	Hip	8.550	0.012	Y = 0.50 (Torque) +8.55	0.975
Follow Through Phase	Wrist	-0.252	0.029	Y = -0.40 (Linear Velocity) -0.25	0.840
	Elbow	4.440	0.003	Y = 14.08 (Linear Velocity) +4.44	0.966
	Knee	3.912	0.001	Y =1483.06 (Angular Momentum) +3.91	0.986
	Ankle	- 0.223	0.035	Y = 7.72 (Momentum) - 0.22	0.931

Table 9. The correlation and predictability of the Segment Power (SP)on three distinct phases in elite tennis players.

Phase	Joint	Constant	Sig	Equation	R^2
Preparation Phase	Wrist	0.458	0.023	Y = -9.08 (Linear Velocity) + 0.46	0.861
	Shoulder	-7.188	0.002	Y = 0.53 (Force) + 20.923 (Momentum) -7.19	0.998
	Trunk	3.762	0.006	Y = -1466.24 (Linear Velocity) + +3.76	0.911
	Knee	2.151	0.014	Y = - 683.36 (Linear Velocity) + 2.15	0.902
	Ankle	- 2.359	0.006	Y = -2107.72 (Angular Momentum) - 2.36	0.941
Acceleration Phase	Wrist	0.010	0.007	Y = 0.11 (Momentum) +0.003 (Angular Momentum) + 0.01	1.000
	Trunk	15.035	0.003	Y = -2.61 (Torque) + 15.04	0.963
Follow Through Phase	Elbow	-1.471	0.019	Y = - 5.17 (Force) -1.47	0.875
	Shoulder	2647.288	0.003	Y = 772.99 (Torque) + 2647.29	0.966
	Trunk	-9.409	0.006	Y = - 1691.24 (Linear Velocity) - 9.41	0.943
	Hip	30.944	0.021	Y = -506.94 (Linear Velocity) +30.94	0.867
	Knee	-5.881	0.000	Y = 36.98 (Angular Velocity) – 5.88	0.998
	Ankle	-1.154	0.019	Y = -0.18 (Acceleration) -1.15	0.962

Table 10. The correlation and predictability of the Segment Power (SP)on three distinct phases in amateur tennis players.

Phase	Joint	Constant	Sig	Equation	R^2
Preparation Phase	Shoulder	-7.171	0.009	Y = 207.82 (Linear Velocity) -7.17	-1.139
Acceleration Phase	Wrist	11.026	0.014	Y = - 5.38 (Force) + 11.03	0.901
	Hip	- 88.812	0.002	Y = - 4.31 (Torque) - 88.81	0.995
Follow Through Phase	Wrist	24.144	0.010	Y = -17.19 (Angular Velocity) - 12008.11 (Angular Momentum) + 24.14	0.990
	Knee	- 163.761	0.000	Y =- 67496.78 (Angular Momentum) - 163.76	0.993

Segment torque power (STP). The correlation analyses show the relationship between the elbow and trunk angular velocity in the preparation phase of elite tennis players. It can be concluded that the trunk rotation’s angular momentum may increase the elbow angular velocity. On the other hand, the correlation analyses show the shoulder force during the cocking phase to the acceleration phase in amateur tennis players. This study found the large elbow torque in both groups a significant component of the potential for an elbow injury. The similar peak of elbow varus torque generated during the cocking phase by elite and amateur tennis players may imply that these two groups are at the same risk for elbow tension injuries, such as ulnar collateral ligament injury, as well as lateral compression pathologies, such as a capitellar osteochondral lesion (14). Moreover, the combination of varus torque and elbow extension during the tennis serve may produce the 'valgus extension syndrome' in elite and amateur tennis players (13-15).

Joint Torque Power (JTP). This study showed that torque generating during cocking and acceleration phases in elite tennis players generates more shoulder and elbow angular velocity (16). This result supports the main hypothesis and reinforces that trunk and shoulder rotation torque during cocking arm has the greatest effect on lateral elbow loading development (17, 18). The trunk plays an important role as a torque generator to increase the mechanical energy because the torque generated by the ground reaction force (GRF) will be the resistance causing segment rotation. If segment rotation can continue sequence will lead to linear motion in the distal segment of the body (19). In a throwing motion pattern, the increase in the mechanical energy of each segment causes from the proximal to the distal segment. The variation of mechanical energy indicates the energy flow between segments. Quantifying the generation, absorption, and transfer of energy allows the researcher to determine the direction and method of energy flow and the efficient kinetic chain in the overhead throwing (4).

Segment power (SP). In the preparation phase, the force acting from the position of each segment of the body generates potential energy by the created ground reaction force from appropriate leg drive and flexibility to lateral arm rotation, which an important for efficiency and speed in the tennis serve. This study has shown that it produces similar compression force at the shoulder in both groups but higher torque during the follow-through phase in amateur tennis players. It may increase the risk of wrist injury (20). Tennis injuries often affect the trunk and upper extremities. The force of large muscles creates joint torque to accelerate the racket before impact (21).

In contrast, the power associated with the ankle joint moment is the largest absolute. The hip joint moment has the greatest effect on the power at non–the dominant leg (22). Leg drive is the first component of the participants in the kinetic chain to create momentum that can be transferred to the trunk (23).

CONCLUSION

Playing tennis to the greatest potential requires a proper movement through the kinematic link to achieve the appropriate force. A kick topspin tennis serves a service with a fast-forward spin movement, and this will cause the tennis ball to move at high speed and a steep angle. The main purpose of kick topspin tennis serves to increase the number of spins. Body orientation in the manner given athlete to reach a greater amount of rotation in the body. It will result in an increased greater generated force which can be achieved through the specific mechanical energy from the effective kinetic chain and energy flow leading the elastic potential energy to the part of the segment to achieve proper body positioning and energy transfer; smooth coordination leads to greater speed in acceleration phase to the follow - through a phase in the tennis serve.

APPLICABLE REMARKS

- Kinematic analysis should be utilized with energy flow analysis to understand how energy flows through the kinetic chain on specific movement patterns in each sport.

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