RESEARCH ARTICLE

European Journal of Sport Sciences
www.ej-sport.org

Ankle and Knee Joint Kinematics Differ between Flat, Slice and Topspin Serves in Young Tennis Players

Christos Mourtzios, Ioannis Athanailidis, Vasilia Arvanitidou, and Eleftherios Kellis

ABSTRACT

The present study aimed to examine the differences in ankle and knee joint kinematics between the flat, slice, and topspin tennis serves. Twelve young tennis players (six boys, and six girls) aged 12-16 years old, performed flat, slice and topspin serve whilst three-dimensional body kinematics were recorded using an optoelectronic camera system. Ankle plantarflexion/dorsiflexion and knee extension/flexion angular positions were recorded at two-time instants: first, at the time of maximum knee flexion and, second, at time of ball to racket contact. Analysis of variance designs showed that the knee flexion angle of the back leg differed significantly between the three service types ($P < 0.001$). Further, the rear leg ankle angle at maximum flexion also significantly differed between the three serves ($P < 0.004$). It was observed that tennis players perform topspin and slice serves with smaller joint angles than flat serves, probably, because the former is being used as a second serve in the game. The ankle, which is the closest point of the kinetic chain at the start of power generation, plays an important and different role in the performance of the three serve types. Therefore, the synergy of the ankle joint is very important in the initial phase of serve for the transfer of forces. Coaches should review the technical issues of serve movement based on the flexibility of the ankle joint because the limited ankle range of motion does not help to transfer forces from the ground.

Keywords: Ankle, Biomechanics, Knee, Tennis serve, Young tennis athletes.

Published Online: April 20, 2022

ISSN: 2796-0048

DOI: 10.24018/ejsport.2022.1.2.13

C. Mourtzios *
Department of Physical Education and Sport Science, Democritus University of Thrace, Greece.
(e-mail: christosmourtzios@hotmail.gr)

I. Athanailidis
Department of Physical Education and Sport Science, Democritus University of Thrace, Greece.
(e-mail: gathanailidis@gmail.com)

V. Arvanitidou
Department of Physical Education and Sport Science, Democritus University of Thrace.Greece.
(e-mail: varvanitidou@yahoo.gr)

E. Kellis
Laboratory of Neuromechanics, Department of Physical Education and Sport Science at Serres,Aristotle University of Thessaloniki, Greece.
(e-mail: ekellis@phed-sr.auth.gr)

Corresponding Author

I. INTRODUCTION

Tennis serve has attracted the attention of researchers because it is the most important stroke that starts the game (Cross & Lindsey, 2005). The kinematic characteristics of the three main serve types flat, slice and topspin have been reported by many researcher studies (Bahamonde, 2000; Bartlett, Piller, & Miller, 1995; Elliott, Fleisig, Nicholls, & Escamilla, 2003; Elliot, Marshall, & Noffal, 1995; Fleisig, Nicholls, Elliott, & Escamilla, 2003; Marshall, & Elliott, 2000; Sakurai, Reid, & Elliot, 2013; Murata, & Fujii, 2013). The majority of these studies (Bahamonde, 2000; Bartlett, Piller, & Miller, 1995; Elliott, Fleisig, Nicholls, & Escamilla, 2003; Elliot, Marshall, & Noffal, 1995; Fleisig, Nicholls, Elliott, & Escamilla, 2003; Marshall, & Elliott, 2000; Sakurai, Reid, & Elliot, 2013; Murata, & Fujii, 2013), have investigated selected parameters of the racket and ball (such as speeds and spin) or upper limb joint kinematics.

Kovacs, & Ellenbecker (2011) commented that the tennis serve is a complex technique where players have to coordinate their upper and lower limb movement through muscle activations in a sequential movement which aims to accommodate energy transfer from the ground to the joints and finally to the ball. This coordinated movement is frequently called as “kinematic chain” and it is characterized by a sequential increase in maximum velocities of segments during the tennis serve (Kovacs, & Ellenbecker, 2011). Studies showed that the dynamic lower limbs drive from the middle-cocking to the acceleration stages of the serve motion is a key building block for high-speed upper limbs rotations and force production before ball contact. Hence, greater muscle forces created by the lower extremity muscles during the loading stage of a serve correlate with increased serve speed (Girard, Micallef, Millet, 2005; Reid, Elliott, Alderson, 2008). Lower limb muscle function is, therefore, important for an efficient tennis serve (Elliot, Marshall, & Noffal, 1995; Kibler 2014).

It is well documented that the knees play an important role in transferring forces from the lower limbs upwards (Elliot *et al*., 1986). Also, Girard *et al*. (2007), reported the knee to be a significant contributor to

European Journal of Sport Sciences
www.ej-sport.org

serving effectiveness whatever the performance level is. However, many servers lose the potential to produce higher serve speeds because of a lack of energy flow from their lower limbs to their upper limbs.

Although it has been well documented that serve performance is related to upper extremity movement (Fleisig, Nicholls, Elliott, & Escamilla, 2003), very little is known about the impact of lower limbs and specifically on the ankle joint. To clarify the contribution of foot movement to tennis serve, it is clear that a more comprehensive assessment of both the knee joint and the ankle joint is necessary. The purpose of this study was to examine the kinematic characteristics of the knee and ankle joints during the three types of serve in young athletes. We assumed that by improving the functionality of the ankle joint, in combination with that of the knee joint, a better leg movement can be produced, which can enhance the rotation of the shoulder and, therefore, lead to a better transfer of forces, giving better and faster execution of the tennis serve.

II. Methods

Twelve (6 males, 6 females) right-handed young tennis players aged 12-16 participated in this study that is playing in tournaments of the Hellenic Tennis Federation Players and was ranked on top of the national list. They had a weekly training program of 12±2 hours on tennis-specific training (technical, tactical, and physical condition) with training experience from seven to eleven years, (age: 13.8±1.22 years, height: 167.5±10.11 cm, mass: 55.20±11.15 kg). All the players were right-handed. Considering the foot technique, they used the foot back technique. All participants were asked if they had a musculoskeletal injury the last year or other problems to participate in the research. This study was approved by the ethics committee of the Faculty of Sport Science of the Aristotle University of Thessaloniki, and all procedures conformed to the recommendations and guidelines of the Declaration of Helsinki. The players and parents were fully informed of all experimental procedures, and both players and parents provided written informed consent before participation. All subjects were proficient in executing each serve type, and at least three trials of each serve were performed.

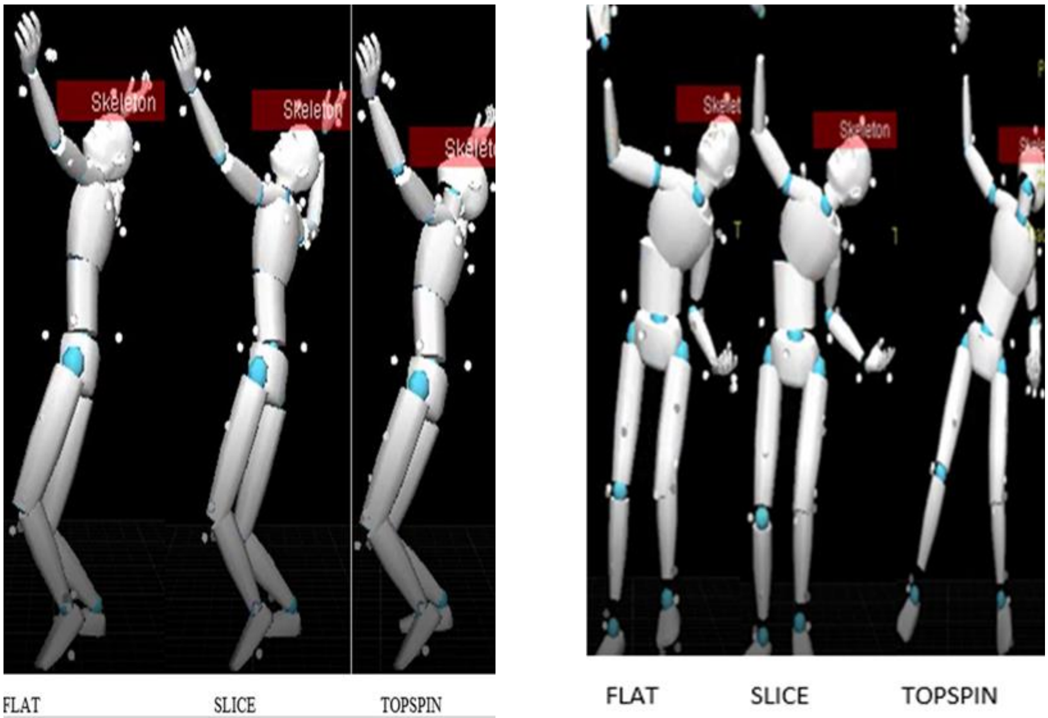
A. Instrumentation

The Optitrack kinematic optical analysis system (Natural point Systems Inc., USA) was used to measure joint kinematics. The system used 9 infrared cameras (Flex 3, Natural Point Systems, USA) with a sampling frequency of 100 Hz, 0.3 Megapixel resolution (640×480 pixels). The cameras were synchronized directly to the PC via USB with the ability to directly manipulate and view the image from the PC software. The system software Arena (V.1.15, Natural Point Inc., USA) was implemented for all measurements. Before the start of the measurements, the space was calibrated as follows: a) Static calibration. A triangular calibration object, with three markers on it, was placed so that it could be seen by all nine cameras, and after recording by all the cameras, it was then removed from the space, b) Dynamic calibration. A bar, with three markers on it, was suspended for a few seconds by the examiner in all directions of the room to record the movement from all the cameras. The calibration process was preceded by each measurement with a measurement error of less than 1%. 10mm diameter spherical markers were placed at selected anatomical points on both sides of the athlete's body to determine the joints and body parts: a) in the head of the fifth (5th) metatarsus, b) on the heel, c) on lateral malleolus, d) on the tibial tubercle, e) in the iliac crest, f) on 2/3 of the distance of the tibia and g) on 2/3 of the femur distance.

B. Experimental Set-up

The subjects performed a standard warm-up before starting their efforts. The warm-up included stretching for all parts of the body, then dynamic warm-up for the legs, for the torso, and exercises with elastic tubes for the arms. Then the players performed 10 serves for each type of serve flat, slice, and topspin, a total of 30 serves, to be prepared for the test. The athletes then performed the three serves, flat, slice, and topspin with three attempts each, which were recorded. The total distance of baseline from the central tennis net was 11.89 m. The best attempt that was considered representative to analyze was that the ball had to pass over the line of a 0.914 m-high tape.

The three-dimensional space was first calibrated using a calibration wand. A total of 34 markers were placed on the head, the trunk, the shoulders, the elbow, the wrists, the pelvis, the hip, the knee, the shank, and the feet. Based on the 3D coordinates of the reflective markers, the skeleton was represented in all frames of motion throughout the 3-D space. Skeleton motion was digitally stored in video format. Hence, video files were then used to calculate the duration and the phases of each type of serve. Subsequently, for each type of serve, the maximum knee flexion angle and ankle plantarflexion angles in the sagittal plane were calculated and used for further analysis. Further, angular position values were captured at two time points: at maximum knee flexion and at the time of racquet-ball contact. For reference, when the knees were fully extended the angle was 180 degrees and when the ankles were in the neutral position it was 90 degrees.



(a) (b)

Fig. 1. Digital representation of (a) maximal knee flexion and (b) contact of the racket with the ball when performing flat, slice, and topspin serves.

III. Results

The angles of both knee joint and ankle joint at maximum knee flexion of the knee are presented in Table I. The analysis of variance showed a statistically significant "foot" X "serve" interaction ($F2.22=11.63$, $p=0.001$) on knee flexion angle. Post-hoc Tukey tests showed that flat and slice serve knee flexion angle values were greater than topspin serves ones (Fig. 2). In contrast, no difference in the knee flexion angle of the front leg was found ($p > 0.05$). The results also showed a significant "leg" X "serve" interaction effect ($F2,22 = 7,10$, $p=0.004$) on ankle angular position at the maximum knee flexion time point (Fig. 3). Post-hoc Tukey tests showed that, that the ankle angle was greater in the flat and slice serve compared to the topspin serve. No differences in ankle angle of the front foot between serve types were found ($p > 0.05$).

TABLE I: Means and Standard Deviations of the Knee and the Ankle Angular Positions at the Time of Maximum Knee Flexion of the Serve, in the Three Different Services Flat, slice, and Topspin (P values Indicate significant differences between serves)

Variable	FLAT	SLICE	TOPSPIN	P
Back knee	114,33°±14,53°	106,91°±15,71°	97,08°±12,80°	0.001
Front knee	120,83°±17,83°	117,08°±19,39°	113,75°±17,86°	0.221
Back ankle	90,25°±22,28°	91,58°±25,93°	70,17°±3,43°	0.004
Front ankle	96,75°±22,00°	98,66°±15,48°	98,34°± 19,03°	0.993

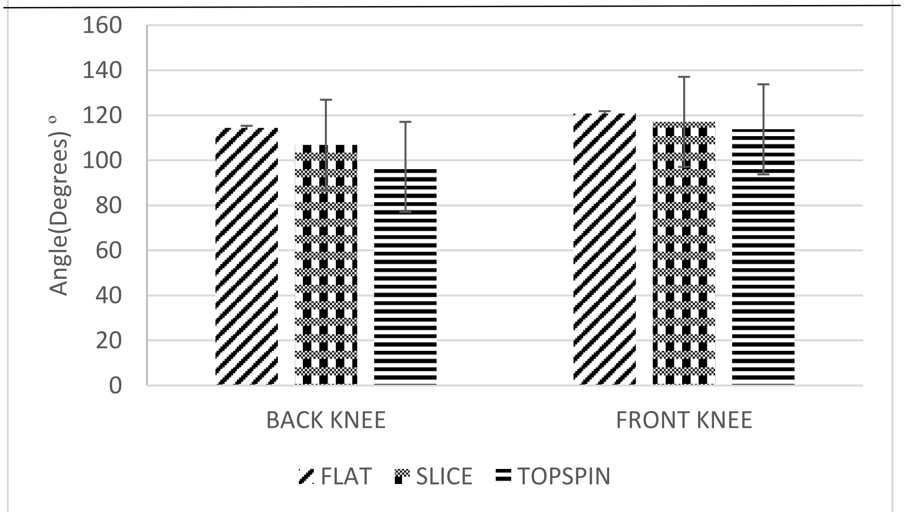


Fig. 2. The angles in ° of the back knee and the front knee during their maximum flexion, in the three different services flat, slice, and topspin (n = 12).

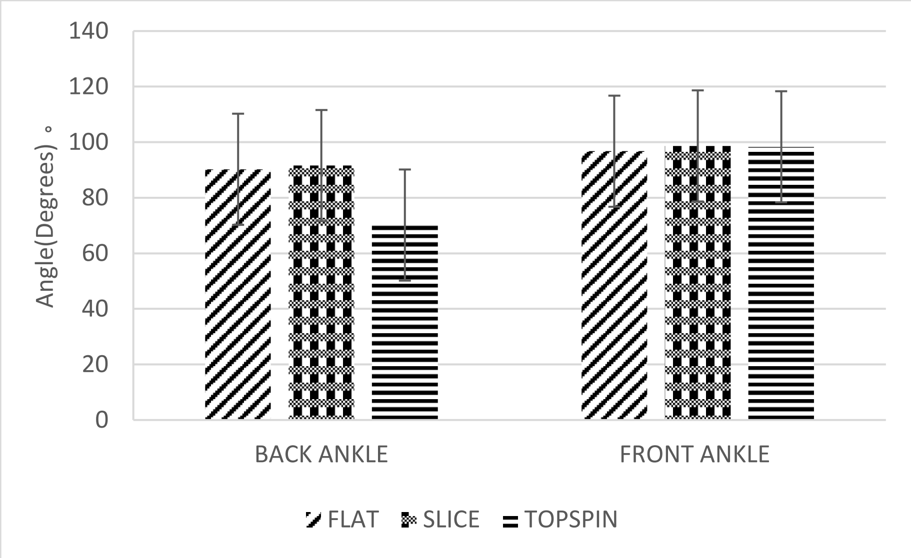


Fig. 3. The angles in ° of the back ankle and the front ankle during their maximum flexion, in the three different services flat, slice, and topspin (n = 12).

Table II presents group angle values at racquet-ball contact. The analysis of variance did not show statistically significant interaction effects (p>0.05). There was a main effect of serve type, as topspin serve showed significantly greater knee flexion angles than flat serve and slice serve while slice serve angle values were lowest than the other two serve types (Fig. 4). Ankle angles of both legs were greater in the flat serve, less in topspin serve, and lowest in the slice serve (Fig. 5).

TABLE II: Means and Standard Deviations of the Knee and the Ankle at the Racquet-ball Contact during the Serve, in the Three Different Services Flat, Slice, and Topspin (P-values Indicate Significant Differences between Serves)

Variable	FLAT	SLICE	TOPSPIN	P
Back knee	164,08°±15,45°	160,66°±17,45°	166,08°±14,53°	0.522
Front knee	162,00°±13,19°	160,75°±10,77°	164,25°±8,67°	0.540
Back ankle	142,17°±13,43°	131,50°±18,29°	138,58°±12,92°	0.089
Front ankle	141,33°±16,86°	133,83°±22,63°	139,33°±15,14°	0.358

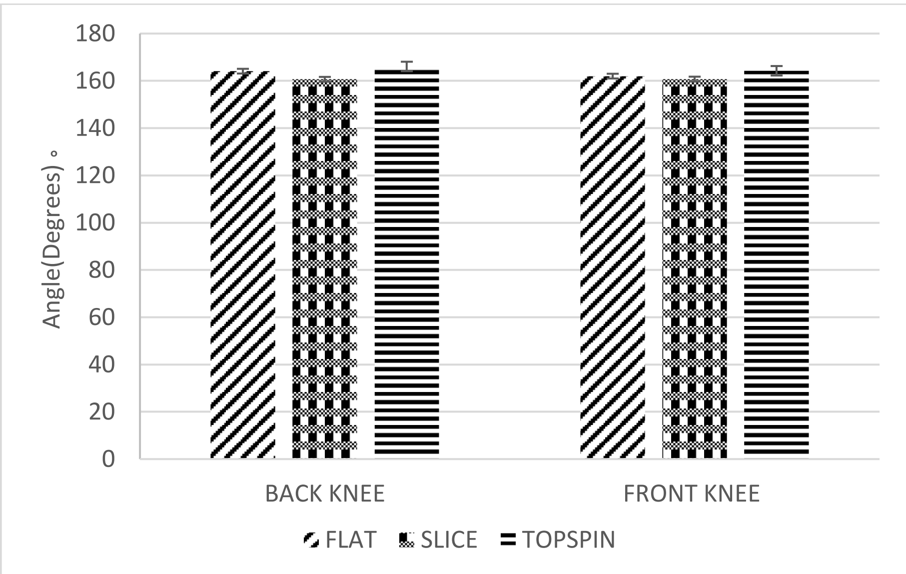


Fig. 4. The angles in ° of the back knee and the front knee during the contact of the racket with the ball, in the three different serves flat, slice, and topspin (n = 12).

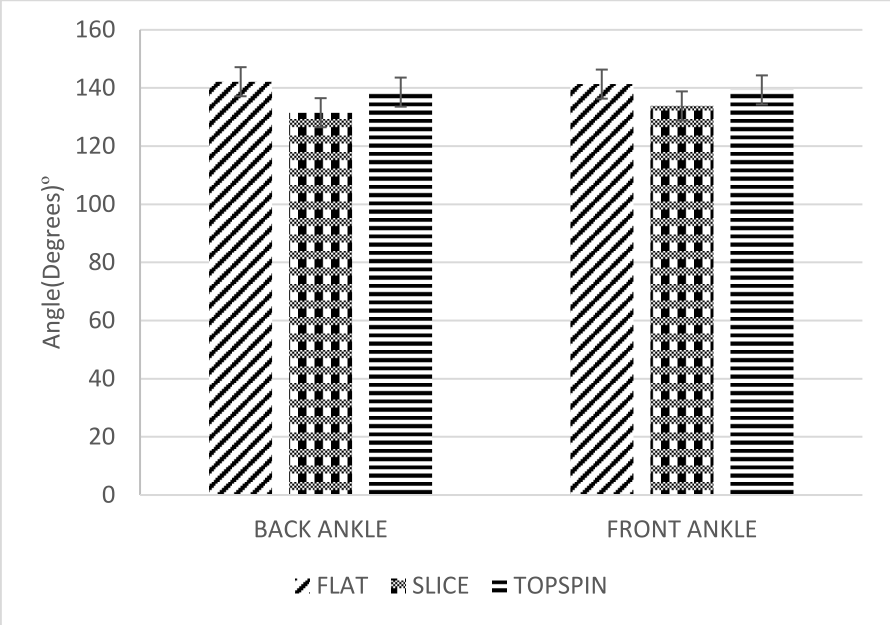


Fig. 5. The angles in ° of the back ankle and the front ankle at the contact of the ball with the racket, in the three different serves flat, slice, and topspin (n = 12).

IV. Discussion

The present study examined the joint of the ankle in the three different serves to provide data for the young athletes and for the knowledge of coaches, on the lowest joint of the motor chain, which has been poorly investigated. In the sport of tennis, there are no specific reports of ankle joints, and coaches are completely overlooked, especially in serve. The tennis serve is a complex multi-joint movement that requires improved muscle coordination and the development of specific skills. A well-executed serve is determined by a complex interaction between many factors, including the maximum force that can be produced by the muscles involved and their joints. Much of the force developed during a serve in tennis, comes from the stretch-shortening cycle by activation of the gastrocnemius, soleus, tibialis anterior, and quadriceps muscles which enhances muscular strength and uses the elastic energy stored in stretched tissues (Komi, & Nicol, 2011). Therefore, the synergy of the ankle joint is very important in the initial phase of the serve for the transfer of forces.

The results of this study showed that back knee angle at maximum knee flexion was greater in flat, and slice serve than topspin serve. This means that young athletes should assume a more flexed knee when attempting to spin the ball when performing slice and topspin serves (which are often used as second serves). To the best of our knowledge, this was the first study to evaluate the kinematic changes of the ankle and knee joints in young athletes. Also, our results showed in Table I, that in flat serve the front knee was greater 6.5° than the back knee, in slice serve was greater 10.17° and in topspin serve was greater 16.67°, that were similar to those reported by Bartlett *et al*. (1994), approximately 111° and Reid *et al*. (2008).

There back ankle joint at the time of maximal knee flexion was greater in the flat and slice serve compared to the topspin serve. At this instant phase of maximum knee flexion, the ankle joint was also in maximum plantar flexion. In flat serve the front ankle angular position was 6.5° greater than the back ankle angle, in slice serve this difference was 7.08° and in topspin serve it was even greater (28.17°). At this moment, the weight of the body was on the toes in plantar flexion of the ankle, which created the conditions for good balance, so that the feet pushed the ground with the best possible result, reinforcing the leg drive, possibly, transferring the maximum forces to the serve movement. Hence, the present findings show the involvement of the ankle in the transfer of forces from the ground up to the next joints of the kinetic chain, showing significant differences between the flat, slice and topspin serves during maximal knee flexion, as the topspin serve showed the smaller angles, then the flat serve and finally the slice with the greatest angles. The differences in knee and ankle angles between the three serve types are probably the result of different coordinated movements that occur when performing each serve type.

During the tennis serve, the muscles of the hip, knees, and ankles generate a great number of forces at a very fast rate in an effort to produce the maximum possible speed of the body as it leaves the ground during the loading phase of the serve. Therefore, a smaller range of motion of the ankle may result in some loss of power. Restriction in one or more joints' movement can deteriorate the coordinated action of the other body segments (Miller, 1980), resulting in a less good serve execution. At the start of the serve, there is a sudden and great increase in plantar flexion, which is accompanied by activation of the gastrocnemius, soleus, and tibialis anterior muscles. The activation of the ankle muscles coincides with the high torque development around this joint during active plantar flexion before and during take-off (Spagele *et al*., 1999). Therefore, it makes sense to look at the locus of the kinetic chain that is closest to the object of power (ground) production and to find ways to improve serve. The importance of the ankle joint power for achieving maximum bounce height was reported by Luhtanen & Komi (1978); Hubley & Wells (1983), as they found that the foot-flexural bending contribution to take-off speed was approximately 23%. The contribution of the ankle joint muscle power to a vertical jump depends on the magnitude of the force developed by the plantar flexors, the differences in excitation start times (Bobbert, & Zandwijk, 1999), and the range of motion (Wilson, Elliot, & Wood, 1991). Subsequently, the range of motion depends on flexibility. Coaches should review the technical issues of serve movement based on the flexibility of the ankle joint because the limited ankle range of motion does not help to transfer forces from the ground.

The extension of the knees, which is a sequence of their maximum flexion, is one of the most important movements in performing the serve in tennis. The present results showed that the knee angle of both feet at the instant of racket contact with the ball did not differ between the three serve types. Previous results reported by Elliot *et al*. (1986) are consistent with the findings of the present study, as they report a mean knees angle of 171 ± 3 ° at the contact with the ball. Due to the large degree of extension of the knees in a minimum of time, it is reasonable to suggest that high speeds of movement of the joints are created (Reid *et al*., 2008). Thus, the lack of strong knee extension after the phase of maximum knee flexion would reduce the speed of the racket and therefore the speed of the ball after contact (Reid *et al*., 2008). Therefore, the increase in knee extension speed seems to be very important in the early stages of development of tennis athletes, so that the pace of serve movement is automated and with the development of young athletes more burdens and pressures are added in order to increase the efficiency of the serve, but also to facilitate the transfer of forces from the ground to the contact hand, thus increasing the speed of movement and reducing injuries.

The knee and ankle angles of the rear leg were smaller with the corresponding angles of the front leg. This is in line with findings that the pressure and forces exerted on all three serves are greater in the rear leg (Mourtzios, 2019). That means the rear leg provides the bulk of the upward and forward push, while the front foot provides a stable position to allow angular momentum development. Consequently, it appears that when right-handed tennis junior athletes perform tennis serve, the right foot displays the highest plantar pressures, which results in the initiation of the sequence of serve movements as the foot contacts the ground, therefore subsequently contributing to the leg drive. So, coaches have to explain to their athletes for this phase of loading the importance of the rear foot, so they can achieve a better result of the upward and forward push and a better transfer of forces.

V. Conclusion

Back and front foot knee and angle angular positions at the point of maximum knee flexion of the movement differed between slice, topspin, and flat serves. Ankle angular position of both legs at the racquet – ball contact point was greater in the flat serve, less in topspin serve, and lowest in the slice serve. Amongst the three serve types, topspin serve showed greatest and slice serve, the lowest knee flexion at ball contact. These findings support the idea that young athletes and coaches should focus on the importance of ankle and knee joints in the loading phase of the tennis serve. When attempting to spin the ball during a slice and topspin serves (which are used as second serves), for example, young athletes should adopt a more knee flexion position than a flat serve.

References

Abrams, G. D., Sheets, A. L., Andriacchi, T. P., & Safran, M. R. (2011). Review of tennis serves motion analysis and the biomechanics of three serve types with implications for injury. *Sports Biomechanics*, 10, 378–390. DOI:10.1007/s10439-011- 0418-y.

Bahamonde, R. E. (2000). Changes in angular momentum during the tennis serve. *Journal of Sports Sciences*, 18,579–592. DOI: 10.1080/02640410050082297.

Bartlett, R., J. Piller, and S. Miller. A three-dimensional analysis of the tennis serves of National (British) and county standard players. In: *Science and Racket Sports 1*, Reilly and M. H. T. E. LEES (EDS.). LONDON: E & FN SPON, 1995, PP. 98–102.

Bobbert, M., van Zandwijk, J. Sensitivity of vertical jumping performance to changes in muscle stimulation onset times: a simulation study. *Biological Cybernetics* 81, 101–108 (1999). DOI:10.1007/s004220050547.

Cross, R., & Lindsey, C. (2005). Technical Tennis: Racquets, strings, balls, courts, spin, and bounce (pp. 119–152). Vista, CA: *Racquet Tech Publishing*.

Elliott, B.C., & Wood, G.A. (1983). The biomechanics of the foot-up and foot-back tennis service techniques. *Australian Journal of Sport Sciences.* 3: 3-6.

Elliott, B.C., Marhs, T., & Blanks, B. (1986). A three-dimensional cinematographical analysis of the tennis serve. *International Journal of Sports Biomechanics.* 2: 260-270.

Elliot, B. C., R. N. Marshall, and G. Noffal. Contributions of upper limb segment rotations during the power serve in tennis. *Journal of Applied Biomechanics.* 11:433–442, 1995.

Elliott, B., Fleisig, GS., Nicholls, R., & Escamilla, R. (2003). Technique effects on upper limb loading in the tennis serve. *Journal of Science and Medicine in Sport.* 6 (1):76-87. DOI: 10.1016/s1440-2440(03)80011-7.

Elliott, B., Reid, M., & Crespo, M. (2009). Technique Development in Tennis Stroke. Production. London, UK: *International Tennis Federation.*

Fleisig, G, R. Nicholls, B. and Elliott, R. Escamilla. Kinematics used by world class tennis players to produce high-velocity serves. *Sports Biomechanics.* 2:51–64, 2003. DOI: 10.1080/14763140308522807.

Girard, O., Micallef, J.P., & Millet, G.P. (2005). Lower-limb activity during the power serve in tennis: effects of performance level. *Medicine and Science in Sports and Exercise.* 37 (6):1021-1029. DOI: 10.1249/01.mss.0000171619. 99391. Bb.

Girard, O., Micallef, J.P., & Millet, G.P. (2007). Influence of restricted knee motion during the flat first serve in tennis. *Journal of Strength Conditioning Research.*21: 950–957. DOI :10.1519/R-20876.1.

Hubley, C.L. & Wells, R.P. (1983). A work energy approach to determine individual joint contributions to vertical jump performance. *European Journal of Apply Physiology*, 50, 247- 254. DOI: 10.1007/BF00422163.

Kibler B. Understanding the kinetic chain in tennis performance and injury. *Aspetar Sports Medicine Journal*. 2014; 3(1):492-7.

Komi, P.V., & Nicol, C. (2011). Stretch-Shortening Cycle of Muscle Function. In: *Neuromuscular Aspects of Sports Performance, 1st edition*. Edited by Paavo V. Komi. *Published by Blackwell Publishing Ltd.*

Kovacs M, Ellenbecker T. An 8-stage model for evaluating the tennis serve: implications for performance enhancement and injury prevention. *Sports Health* 2011; Nov.3(6). 3. DOI:10.1177/ 1941738111414175.

Lo, K. C., Wang, L. H., Wu, C. C., & Su, F. C. (2004). Kinematics of lower extremity in tennis flat and spine serve. *Journal of Medical and Biological Engineering*, 24, 209–212.

Luhtanen, P. & Komi, P.V. (1978). Segmental contribution to forces in vertical jump. *European Journal of Apply Physiology*, 38, 181-188. DOI: 10.1007/BF00430076.

Marshall, R. N., and B. C. Elliott. Long-axis rotation: the missing link in proximal-to-distal segmental sequencing. *Journal of Sports Sciences.* 18:247–254, 2000. DOI: 10.1080/026404100364983.

Miller, D.I. Body segment contributions to sport skill performance: Two contrasting approaches. *Research. Quarterly for Exercise and Sport.* 51:219–233. 1980. DOI: 10.1080/02701367.1980.10609284.

Mourtzios, C., Kellis, E., & Salonikidis, K. (2019). Plantar pressures differences between flat, slice and topspin serves. *ITF Coaching & Sport Science Review* Issue 78, August 2019, 28-30. DOI: https://doi.org/10.52383/itfcoaching.v27i78.92.

Murata, M., & Fujii, N. (2013). A biomechanical analysis of the relationship between tennis service motion and ball spin. *31 International Conference on Biomechanics in Sports.*

Reid, M., Elliott, B., & Alderson, J. (2008). Lower-limb coordination and shoulder joint mechanics in the tennis serve. *Medicine and Science in Sports and Exercise.* 40 (2):308-315. DOI: 10.1249/mss.0b013e31815c6d61.

Sakurai, S., Reid, M., & Elliot, B. (2013). Ball spin in tennis serve: Spin rate and axis of rotation. *Sports Biomechanics*, 12, 23– 29. DOI: 10.1080/14763141.2012.671355.

Spagele, T., Kistner, A., Gollhofer, A. (1999) Modelling, simulation and optimization of a human vertical jump. *Journal of Biomechanics,* 32, 521-30. DOI: 10.1016/s0021-9290(98)00145-6.

Wilson, G.J., Elliot, B.C. & Wood, G.A. (1991α). Performance benefits through flexibility training. *Sports Coach*, *April-June 1991*, 7-10.

Christos Mourtzios is University professor specializing in tennis and biomechanics, in Department of physical Education and Sport Science of Democritus University of Thrace. Doctor of the Department of Physical Education and Sports Science of Aristotle University of Thessaloniki. Research Field: Tennis, Biomechanics. 2009 - 2020 National Coach in Hellenic Tennis Federation.

Eleftherios Kellis is a professor of Kinesiology at the Department of Physical Education and Sports Sciences of Serres at the Aristotle University of Thessaloniki, where currently teaches kinesiology and biomechanics. His main research interests include the examination of architecture, activation and force generation of the hamstring muscles. He acts as reviewer for several scientific journals in the field of sport and exercise sciences.