

Original Article

Biomechanical substantiation of motor and punch action formation in tennis by taking into account the formation of promising skills and abilities

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Published online: January 30, 2021

(Accepted for publication January 22, 2021)

DOI:10.7752/jpes.2021.01035

Abstract:

Modern tendencies of the game are determined by the speed-power orientation of the tennis player's activity, which manifests itself in a high rate of strokes, high speed of the ball flight, lack of time when performing motor actions. The search for tennis players in the direction of imparting greater strength and speed to the game and overcoming significant time constraints for the execution of strokes led to significant changes in the technique of performing almost every tennis stroke. It should be noted that modern tennis is progressing very quickly, which is worth reviewing its concepts at least every five years. New approaches have been obtained using biomechanics, describing human movements based on the laws of traditional rigid body mechanics. In the article, based on the analysis of the literature and the results of the study, the changes in the biomechanics of tennis movements in the performance of tennis strokes in a supporting and unsupported position are revealed. The opinions of leading tennis experts on the support and unsupported strokes are given. The components of a tennis stroke, their execution time and their percentage are given. The information can be used for those who are interested in the problems of tennis and for future coaches and teachers of physical education during the initial training period. Innovative technologies are given that were introduced into the work of the tennis section of the sports club of the Kiev National University of Culture and Arts and during the work of children's tennis sections in sports institutions.

Key words: tennis, strokes, shock action, jump, analytics.

Introduction

The modern stage of development of tennis is characterized the considerable height of popularity of game and attention to this type of sport. At the same time a game improves continuously. Public interest to the successful performances of the Ukrainian tennis players causes the necessity of exposure, study and scientific ground of conformities to law, accelerating the process of mastering a game. Modern tennis it is an athletic game with elements inherent to acrobatics, gymnastics, and other types of sport. The gap between professional and amateur tennis has become so huge that it has become impossible for amateurs to relate their game to that of professionals. At the level of ordinary life, tennis can and should be a sport accessible to the general population, as, for example, in developed countries, when it is taught in schools. Student age is favorable to bringing in of man the permanent engaging in tennis during all life. The introduction in work with students of an innovative technology for the development of motor qualities based on playing tennis, teaching the basics of the game found a sincere response among students of university.

Employments on tennis with students were conducted according to the methodology and program developed by the author, contributed to the introduction of young people to a healthy lifestyle, the acquisition of sustainable interest and interest in physical activity in the fresh air.

Improving the biomechanical parameters of tennis stroke is discussed in a number of publications (Ilnytsky, Okopnyy, Palatnyy, Pityn, Kyselytsia, Zoriy, 2008; Babichev, Zihareva, 2017; Ivanova, 2017; Kozina, Yevtyfiyeva, Muszkieta, 2020 etc). This should be reflected in the initial training phase. Until now, the authors working in the system of primary education technologies and explaining its essence do not associate them with the stage of primary education (Kanaryukov, Muzyka, 2016; Sokur, 2019 etc), but attribute them to the results of improvement. The task of systemic orientation on the formation of promising technical skills for primary education was not set.

Material & methods

The following methods were used: theoretical analysis and generalization of literary sources of scientific and methodical literature; sociological methods (evaluation of the performance of a flat filing among juniors and leading players; analytical method for calculating motion parameters using kinematics; pedagogical observation. The tennis section was attended by students from various faculties: design and advertising, journalism, film and television, international relations, choreography and other faculties.

Results

A tennis shock action is examined as a difficult motive system in that motion is included for providing of acceleration of racket on the way of taking away to the point of contact with a ball and to ensure dynamic stability of the body at any moment and in any phase of the striking action (Ivanova, 2017). The pedagogical observation of the playing activity of tennis players of various qualifications showed that the nature of the interaction of the tennis player's legs with support in the contact phase is different.

From the point of view of physics (mechanics), if it is simplified to take the movements of a tennis player for the movement of a material point at a certain moment, then he simultaneously participates in a few simple movements.

It is motion with a permanent acceleration forward and upward motion and spin (spin may not be). Spin can only provide additional acceleration and speed.

We will consider the case of jump without a rotation. As speed, acceleration and force, are vectors, then they can be made on the laws of vector addition (Fig. I).

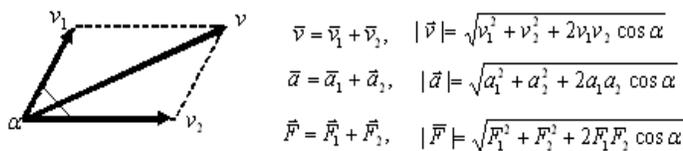


Fig. I. Vectors distribution of speeds in the unsupported position where:

- V_1 – speed up-forward;
- V_2 – forward speed;
- V – resulting speed.

The directions of the force and acceleration vectors acting upon shot coincide with the direction of the speed vector upon shot. From the formulas it follows that the magnitude of the speed, acceleration and force of the tennis player's action on the ball in the unsupported position grows due to the vertical component. It ensues from formulas, that the size of speed, accelerations and force of action of the tennis player's action on the ball in the unsupported position grows due to the vertical component.

Taking away of hand with a racket to meet the ball coincides in the direction with the shift of the center of gravity of the body from the right supporting leg to the left unsupported leg (forehand in motion). Due to the straightening of supporting leg motion of centre of gravity of body is directed forward-upwards. An important element should be considered the mechanism for converting translational motion into rotational (spin), formed on the basis of the supporting right leg. The dynamic stability combined with the effective racquet acceleration mechanism makes the forehand, when the support is moved to the left foot, both reliable and powerful.

In the stroke of tennis player the forward is incorporated and spin motions of both whole body and its individual parts are combined. During rectilinear forward motion a stroke depends on the speed of shot at the movement in the moment of collision of racket with a ball and from the body weight used in a shot (Arhipov, 2017).

Formula of kinetic energy during rectilinear forward motion:

$$E_{kin.for} = \frac{mv^2}{2},$$

where:

- m – body weight;
- v – his linear speed.

But in the blow of tennis player forward motion combines with spin, where linear speed of spin movement $v = w \times R$ and kinetic energy of spin motion determined by the formula:

$$E_{kin.spin} = \frac{m(wr)^2}{2} = \frac{(mr^2)w^2}{2} = \frac{Iw^2}{2},$$

where:

- m – body weight (shock weight);
- r – radius of rotation;
- w – angular speed;
- I – moment of inertia ($I = mr^2$).

The energy of a tennis hit is determined by the sum of these two energies.:

$$E = E_{kin.for.} + E_{kin.spin}$$

$$E = \frac{mv^2}{2} + \frac{I\omega^2}{2},$$

where in both cases, the linear and angular speed are squared

Material given below (Fig. II.) – attempt of spatio-temporal analysis of motion using video-computer processing of a specific shot.

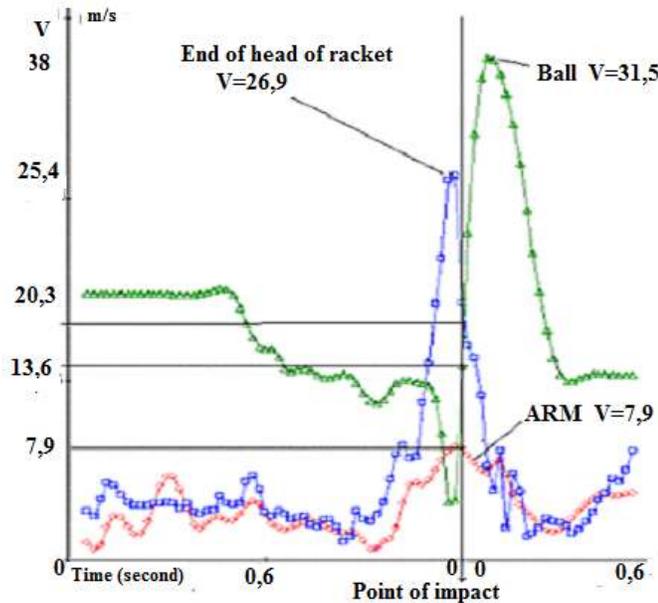


Fig. II. Andre Agassi. Linear speed of hand, racket, ball during impact (Gideon, 2005).

Difference of speed of end of head of racket $V = 26,9 \text{ m} \cdot \text{s}^{-1}$ and hand $V = 7,9 \text{ m} \cdot \text{s}^{-1}$ during contact point ($V = 31,5 \text{ m} \cdot \text{s}^{-1}$) shown in Fig. II

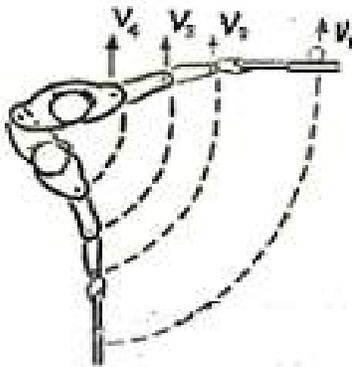


Fig. III. Linear speed of arm and torso sections.

Running shot gives an increase to kinetic energy as a result of addition of speed of the forward moving of player and speed of final movement of racket. In a stroke, in which the legs "push" the torso forward (with separation from the support) and help to accelerate the arm with the racket, each link (arm-shoulder, forearm and hand) increases the total speed of the racket head (Fig. III).

The parts of the tennis player's body are actively involved in the movement until the end. A tennis player moves on the arc of variable curvature. At the moment point of impact, the body rotates about the instantaneous center of rotation, which is outside the body. It gives as a result of increase of moment of inertia due to the increase of radius of rotatory motion. In the moment of shot all weight of body is necessary to be carried from a right foot to left, that together with the acceleration of motion influences on the speed given to the ball. For this reason it is not necessary to do large swing, and divert a racket back. Impact in motion (with tearing away from support) increases not only from addition of speeds of links of body (torso and all links of the arm V_1, V_2, V_3, V_4), but also due to an increase in the moment of inertia of links of body and racket. The use of the addition of the speeds of different links of the body and the racket, an increase in their moment of inertia, primarily due to an increase in the radius of rotation, characteristic of powerful strokes.

The chart (Fig. IV) shows the cycle of tennis movements according to the recommendations of the specialists of the International Tennis Federation (ITF).

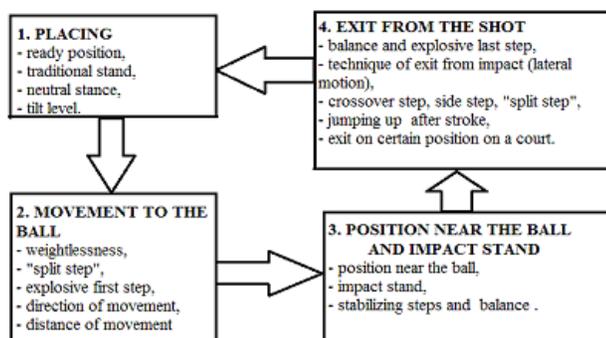


Fig. IV. The cycle of movements in tennis according to the scheme (ITF, Crespo, Miley, 2007)

The mechanism of construction of shock action of skilled tennis players differs in considerable variation of descriptions of motion. Composition of shock action in tennis consists of separate parts-phases. Simplifying, in a blow it is possible to distinguish three basic parts - preparatory, basic and final.

For qualified players a preparatory phase makes 44,5-48,6% basic - 19,3-25,9% final - 30,4-32,1% of general duration of shock motion.

Preparatory phase begun starts from the initial defined body position.

Initial position: a head is put straight and immobile. The optical axis of vision is parallel to the court, the gaze is turned forward, the back is straight and tense, the arms are bent at the elbow joints, the pelvic line is parallel to the grid, the legs are wider than the shoulders, and the knees are slightly bent. In ankle resilient-shake is looked over motion back. The line of general centre-of-mass passes in the area of the metatarsophalangeal joints. From the starting stance, the tennis player performs a racket swing. The limit of completion of phase is movement of racket to maximally remote from a body point in a front-back plane the change of direction of motion of beating hand registers in that. This movement includes a turn of the upper body and shoulders around the vertical axis of the body and some forward movement with the lowering of the general center of mass towards the right leg. A head is in previous position, a look is directed toward a rival. Work of muscles in a preparatory phase is related to tension of large muscles that take and bend a hand and right part of trunk with the accumulation of resilient energy. The preparatory phase for qualified players is about 0.35-0.9 s.

Basic phase begins with the maximum pose of the end of the swing of the racket and completed by the moment of it contact with the ball. A phase is characterized development of high speed of racket to the contact at a considerable acceleration her in the middle of phase (to 400 m/s). Position of head of player does not change, hips begin rotations forward first. The common center of mass rises upward with increasing speed, characterizing the beginning of pushing away. The duration of the phase is about 0.15-0.5 s. The final part of the main phase - contact of the racket with the ball. During this period, the motor problem of the entire impact is solved (briefness of collision is about 0.012-0.040 s - according to G.P. Ivanova, or about 0.003-0.005 s - according to V. Braden). At the moment of collision, the position of the head is the previous one. The hips, torso and shoulders are the main elements that create resistance to working muscles and counteract impact forces to maintain body balance. A collision coincides with the moment of the most unloading of legs (Gideon, 2005).

Final phase solves the problem of extinguishing the energy of the racket and the body and quickly returning to the starting position. The phase begins at the moment of contact and ends when the racket crosses the shoulder line; the eyes follow the ball, the shoulders slow down, the hips complete their forward rotation, the leg is behind, becomes the pivot. The time of the final phase is about 0.3-0.6 s. So, shock actions can be considered as a multi-stage system of actions concerted in time. The generation of force in a rebound, serve, begins with a movement directed against the surface of the court on which the tennis player is located. Force of unbending of leg depends on the projected shock speed, as, for example, at the first / second serve or at a shot on flight. The force generated by the legs is transmitted further along the chain. The knees become straight, but not to the end, large work of the buttock muscles is thus required, the concentric work of the quadriceps (which straightens the knees) then the muscles of the body enter the process (the muscles of the lower, after upper part of the body), shoulder, hand, enter into a process. The transition goes from powerful muscles to fast. Kinematics, as in any sport (boxing, karate, javelin throwing, etc.). What better for a man the co-ordinating chainlet of motions is developed, the anymore shock speed, as a sum of all powerful impulses that were mine-out by turns in a chainlet consists of sum of previous values. Upward pushing create muscles during the rotation of step forward. The players' shoulders rotate up to 220 ° during the groundstroke.

This lift is the result and consequence of strong body pressure (through the knees to the court), exactly it pushes players at the beginning of shot motion, creating the yet greater acceleration of shot. During a game at a high tempo, the player often does not have time to put his feet correctly. A shot in a jump, in unsupported position, eliminates the effect of setting the legs on shot motion. The results of observations, research and analysis of literature data show that most of the shots are really executed afoot at the diminished pressure on support (Ivanova, 2017).

According to our pedagogical observations revealed:

1. Most often, stroke are in an open stance.
2. A jump in a closed stance is, as a rule, an extension of the back leg with a turn, that is, a quick exit from the stroke, and not the stroke itself.

In shots can happen three fundamentally different operating forces: forward movement, rotation of body (thighs and shoulders), up-stroke. Forward movement is the typical case of the closed stance, when weight is carried from a back leg to front leg. Rotations of thighs and shoulders - it, as a rule, a stance is open. The up-stroke works in both stances, but anymore in open. Turn of thighs usually from 60 ° to 120 °; as a rule, it a sort of 90°. Turn of shoulders - it too about 90°, but in relation to thighs. If all is done by right, then, taking into account the rotation of thighs, shoulders will turn around no less what on 180° in relation to position during swing of racket. Mostly on this rotation the up-stroke is laid on. Forward motion in an open stance is minimum or he in general is not present, as here basic force is a rotation of body plus speed of hand in relation to shoulders. There is even such concept "Rapid hands". Not all shots in an open stance require a jump, but almost all shots in jumps are shots in an open stance.

Quite often, a blow to an open stance ends with a landing or simply ending on a supporting leg (right-handers at a blow on the right is a right foot). At play in a high tempo a player often does not have time correctly to put feet. Jumping shot, in an unsupported position, eliminates the effect of setting the legs on shock motion. Most often, at the moment of shot a tennis player is in a state of transfer of body weight in the direction of blow from a push leg to other (in flight). For many students a blow in open position is wrong. They early carry weight from a right foot to left, what diminishes force that is involved in a shot. Only those, who really got it right mechanics of shot in an open stance, get advantage from the use of this shot. The transmission of impulse of forces with minimum losses is possible at creation of hard communication of links of body network. Forming of hard properties of muscles and joints requires their permanent development.

From the first days of employments entered: exercise for strengthening of muscles of back, stomach and overhead humeral belt; stance of "readiness" and "shock stance" with moving of general centre-of-mass for creation of readiness to rapid and resilient motion in any direction and transmission of mechanical wave on all biodynamic chain. The programs for teaching motor skills of tennis with support and unsupported strokes are different. The program for unsupported shots must be other, what in modern literature is not present.

Discussion.

The retrospective analysis of technique of shock and actions in tennis (Tab. I) allows to assert that is presently observed transition from shots from support, to the shots in unsupported position.

Tab. I. Comparison of traditional and modern shot on the right (*Roeters & Groppe*, 2004)

Parameter	Traditional shot	Modern shot
Recommended Grip:	Eastern grip	Semi-western or western
Stance:	Lateral stance	Open stance
Initial footwork:	Forward step	Small step to the touch-line
Swing:	Flat backswing (a racket runs around to perpendicular position 90° in relation to the back line of court)	Circular backswing (a racket often turns on 135° in relation to the back line of court)
Thighs and shoulders:	Must as possible longer remain in lateral position	Try as quick as possible to develop in relation to a net
Motion of hand on a ball:	The center of rotation must be a humeral joint	Many links of biokinetic chain take part
Work of joints:	A similar action aimed at providing sufficient swing power in both variants of the shot from the right.	
Zone of impact:	More precise adherence to the trajectory of the racket in the horizontal plane of the contact zone	Reducing the time interval during which the ball can be successfully processed
Position of knees:	Arcuated in the procession of contact	Straightening during a contact
Risk of injuring:	Analogical for both variants of shot	
Coverage of court:	Relatively slow	Relatively anymore rapid
Follow through:	Anymore forward	Mainly over a shoulder
The position of the legs in shot:	Both feet are firmly attached to the court surface	In the air
Footwork:	Takes more execution time	Allows the tennis player to take a shot on the move

Shot on the right (forehand, running forehand) the most effective tennis players in the process of exchange by shots on a back line and helps players substantially to limit an opponent in time and in space, and also allows to dictate the scenario of drawing of glasses to him. The analysis of the technique of striking and throwing actions in sports games states that at present there is a transition from strokes from a support, which were considered stronger and more reliable until the 90s, to strokes in an unsupported position.

V.A. Golenko and sports scientist SH.A. Tusevich have an opinion that the area of hit of ball can increase in a jump, therefore he can change the area of shot of ball, that is expediently at a serve. At shots from a rebound the loss of contact with support is possible, but undesirable (Golenko, 2001; Tarpishchev, 2020).

D. Ralston says that the separation from the support will not give an opportunity to control the ball

J. Groppe writes about energy losses during separation from the support

Vic Braden and D. Cramer note that it is very difficult to make a jump with a backhand (it reaches 50% of the normal speed of the ball

Another point of view is held by G. P., Ivanova : most shots are performed during a period when the pressure on the support is significantly reduced or equal to zero, and the body obeys the principle of free movement (Ivanova, 2017).

Metzler P. back in 1967, offered to perform smash in a jump.

The leading specialists of world tennis adhere to next opinions in relation to tearing away of stroke from court surface (Roeters & Groppe, 2004) :

- M. Krespo writes, that most players of world level carry out shots in mid air;
- H. Higueros states that high-speed play requires maintaining balance during all stages of the stroke and it is not always possible to shift the body weight forward, which gives rise to jumping during defensive strokes;
- G. Brody notes that pivoting movements of the body force the player to break away from the support during contact or at the end of it;
- F. Freienhoven and M. Scheiper write, that a jump arises up in the bounce process of powerful shot on the right, at a shot with in a high point (high volley).

Ivanova G. P. and Knyazeva T. I. consider that now most players of major league tear away feet from the surface of court at execution of shots (Ivanova & Knyazeva, 2015).

The biomechanics of the interaction of a tennis player with a support is described by G.P. She notes the 4 main options for a tennis player's unsupported position in different types of main strokes and unsupported positions for topspins and volley (Ivanova, 2017).

Pedagogical observation of the game of tennis players showed that the nature of the interaction of the tennis player with the support in the contact phase is ambiguous. The duration of the climbing phase in tennis lasts 0.1-0.6 s. Impact action can occur at different moments: at the beginning, during or at the end of the flight.

The advantages of an unsupported shot include the following characteristics:

- an important condition for freedom and speed of movement. The leg muscles relax in an unsupported state and do not interfere with the accelerated bending movement of the body in the direction of the impact;
- a short strong push of the elastic legs forward and upward (in motion) gives the body and all its components and the racket additional speed (the linear speed of rotation is added to the forward speed). Racket speed before contact with the ball for the world's leading tennis players is 50-62 m/s (180-220 km/h);
- rotations of body in unsupported position takes place about vertical axis conducted through the center of body weight. Shots on support come true by the long chain of links bodies that is subject to influences to force of reaction of support. Absence of action of force of reaction of support allows better to correct direction and the power of a shot on a ball, increases reliability of game.

The comparative spatio-temporal analysis of technique of forehand for beginners and technique of adult master shows that methodology of the elementary training must be based on the models of technique of the best players and take into account front-rank progress of tennis trends.

Conclusions.

In tennis presently there are not recommendations about that, on what aspects of preparedness it is necessary to pay attention at training. The theoretical analysis of modern scientifically-methodical literature and own researches show that used presently in an educational process the facilities sent to forming of motive actions and skills necessary for tennis on the initial stage of educating of students does not provide connection with the modern state of game.

Modern teaching methods are based on mastering the stroke in the support position. It results in future in teaching again of technique of shots with tearing away from the surface of court. This takes extra time and effort and slows down the learning process. The use of the new approach to initial learning to play developed in this study has shown their effectiveness and reliability.

They will allow to extend the arsenal of pedagogical facilities substantially influencing on developing coordinating flairs and motive skills for students, will accelerate the process of educating in future retraining will allow to give up the stage at implementation of modern stroke. The effectiveness of the developed approach has been proven in the work of the tennis section of the Kiev University of Culture and Arts.

Conflicts of interest

No conflicts of interest.

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