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FILIP WOŁOSZYN

Measurement of Angular Parameters and Velocities of the Upper Limb Segments in Tennis Using Inertial Motion Sensors for the Purposes of the Didactic Process

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Abstract

The aim of the study is to show differences in accurate and missed forehand and backhand strokes in tennis, as a feedback for coaches, teachers and players. The main assumptions of the study are to show the values of angular parameters and velocity, as well as to analyse every phase of a stroke. The priority in the study is to show how the abovementioned parameters affect the accuracy and velocity of forehand and backhand strokes. Material and research methods: A professional tennis player was tested using the individual case method and kinematic analysis. The motion capture system (MCS) was used for research purposes using inertial motion sensors. Results: Strokes were analysed to demonstrate the angular parameters and velocities of selected upper limb segments. Three upper limb segments were taken into account, i.e. the right hand, the right forearm and the right shoulder. The results of the angles and velocities achieved by individual segments were analysed in three axes of the body: X, Y, Z. The results concern the beginning of the acceleration phase, the end of the acceleration phase, i.e. the moment of impact, and the final, follow-through phase. Conclusion: The results show that a stroke can be accurate despite a significant change in angle and velocity. This situation applies to both forehand and backhand strokes.

Keywords: biomechanics, motioncaputre, IMU, tennis, didactics

Introduction

Studies of motion techniques, kinetics and kinematics can contribute to a deeper understanding of the movement structure and thus to improving the performance of athletes and reducing the risk of injuries (Less, 2007). In present world, where adaptability, brainpower, and creativity, became crucial human stock for development, the coach can't conspicous, but as a promoter of constructive and productive thinking, of creative maintenance and attitude (Dobrescu, 2008). New technologies in sport expanding rapidly in last days. In the past, for instance gymnasts, were able only to analyse certain detail of their movement from video recordings, but now it’s possible to keep feedback from motion sensor suit (Xsens, 2017). Biomechanics in sports uses scientific methods of mechanics to explore the effects of various forces acting on athletes (Bartlett, 2007). In the biomechanics of racket sports, there are four principles describing how a movement should be performed based on the laws of biology and mechanics. This study focuses on ‘the principle of high-speed levers’ describing strong strokes. It says that in racket sports, longitudinal rotations of the upper limb segments are important. When the racket is held perpendicular to the forearm and the forearm is rotated, the displacements of the racket head are much larger as the radius of the racket rotation relative to the longitudinal axis of the arm is greater. The lever operating on the long arm is a force lever that affects the force acting on the object. It is similar to a speed lever which operates on the short arm and increases the velocity of the racket head (Less, 2007). Research in sport biomechanics has been divided into three areas:

1. Modification of technique to enhance movement

Technique analysis and modification are among the main objects of interest in biomechanics. Simple movement is not very important for research results, but movements which have not been assessed before are of importance. It is also important for research to clearly define the essence of the movement.

2. Reduction of stress and risk of injury

Biomechanical studies on stress and injuries require establishing a relationship between movement kinetics, the extent of pain and the place and type of injuries. They can correlate with poor physical preparation, unhygienic lifestyle and genetic determinants.

3. Equipment design

Sport equipment is designed in a way that optimises movement performance, ergonomics and results (Elliot, 1998).

The study focuses on the first area, which is the modification of technique to enhance movement because it is technique that largely affects the effectiveness of a tennis player. The study focuses on two types of strokes that are key in modern tennis, i.e. forehand and backhand. A forehand stroke is among the most effective techniques used by most tennis players (Królak, 2008). Backhands can account for more than 33% of all shots performed during a professional tennis game (Królak, 2007).

The aim of the study is to show differences in accurate and inaccurate forehand and backhand strokes in tennis. Examined variables, could be useful in teaching process, according to coaches, teachers, players, and for all who are participated in didactic process of tennis. The tests were carried out on a professional tennis player. The main assumptions of the study are to show the values of angular parameters and velocity, as well as to analyse every phase of a stroke. One of the main goal of the study is to show how the abovementioned parameters affect the accuracy and velocity of forehand and backhand strokes.

Material and research methods

The research method used in the study was the individual case method. This method enabled comprehensive and multi-faceted exploration of the research subject. The individual case method provides up-to-date information about the tennis player studied and the results can have a significant practical significance. It made it possible to select flexible techniques and research tools (Błażejewski 2009). A multi-module motion capture system (MCS) consisting of inertial measurement units (IMU) served as a research tool. All registration data and export data were sent directly to the recording equipment via inertia motion sensors. The “Axis Neuron” software used in the study consisted of a communication interface, a power supply, a three-axis gyroscope, an accelerometer and a magnetometer, as well as an analogue-digital converter and signal processor (Kopniak, 2014). The professional tennis player tested was a multiple Polish champion participating in inter-university andInternational Tennis Federation (ITF) tournaments in both singles and doubles. The tests took place during one training session and participation was voluntary. The tennis player was thoroughly informed and instructed about the research concept.

The tests were conducted on a tennis court. Initially, the device was calibrated in order to produce reliable results. After taking the basic tennis position, the subject performed 36 forehand and 36 backhand stokes at a fixed place on the tennis court starting 1 m from the baseline on the court. In the case of forehand stokes, it was the right corner and in the case of backhands, it was the left corner. After the tennis ball was dropped by an assistant from a height of two metres and bounced off the ground, the subject performed a stroke. After the stroke, he returned to the starting position. After six strokes, the subject was obliged to recalibrate the sensors.

Results

The strokes were analysed to demonstrate the angular parameters and velocities of selected upper limb segments. Three upper limb segments were taken into account, i.e. the right hand, the right forearm and the right shoulder. The results of the angles and velocities achieved by individual segments were analysed in three axes of the body: X, Y, Z. The results concern the beginning of the acceleration phase, the end of the acceleration phase, i.e. the moment of impact, and at the final, follow-through phase. Velocities are given in cm/s and angles are shown in degrees. The angle and velocity results should be interpreted in absolute values. For the purposes of descriptive statistics, the presented data take into account the changing directions of velocity vectors. Angles and velocities presented in the tables show how individual upper limb segments should move to optimise their positioning and normalise the velocities they achieve.

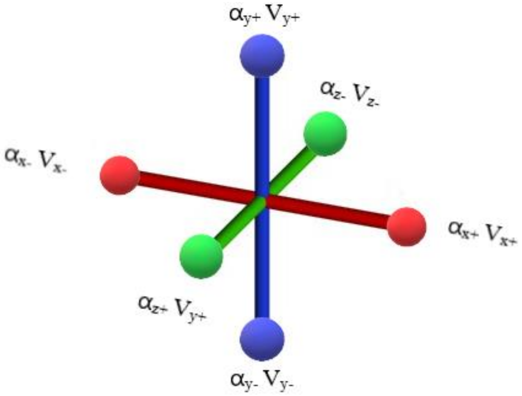

Fig.1.Conformation presenting axis adjustment of velocity. Source: Own elaboration

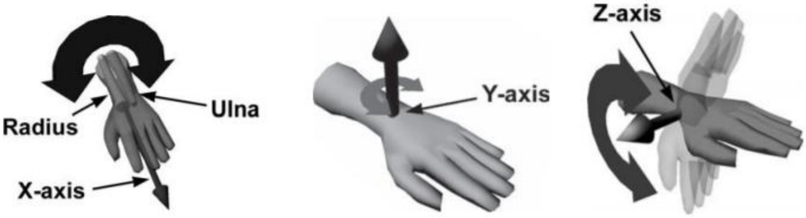

Fig 2.1, 2.2, 2.3 Hand rotation in X, Y, Z axes. Source: (Kitagawa 2008)

Table 1. Data of right upper limb angles and velocities during accurate forehand stroke

Hand	Beginning of acceleration phase	Stroke	Follow-through phase
α_{x1}	-14^0	-52^0	-2^0
α_{y1}	-20^0	56^0	-23^0
α_{z1}	-32^0	-103^0	-35^0
V_{x1}	0,64	1,51	1,18
V_{y1}	0,09	0,33	0,10
V_{z1}	-0,04	0,27	-0,12
Forearm	Beginning of acceleration phase	Stroke	Follow-through phase
αx2	10^0	-18^0	75^0
αy2	25^0	21^0	143^0
αz2	12^0	-94^0	83^0
Vx2	0,61	1,84	1,07
Vy2	0,06	0,34	-0,05
Vz2	-0,40	0,41	-0,28
Shoulder	Beginning of acceleration phase	Stroke	Follow-through phase
αx3	5^0	-8^0	12^0
αy3	-17^0	5^0	9^0
αz3	6^0	3^0	16^0
Vx3	2,12	1,39	0,51
Vy3	0,06	-0,77	0,90
Vz3	0,20	-0,09	0,20

Source: Own elaboration

Table 2. Data of right upper limb angles and velocities during inaccurate forehand stroke

Hand	Beginning of acceleration phase	Stroke	Follow-through phase
α_{x1}	-22^0	-39^0	-10^0
α_{y1}	16^0	8^0	11^0
α_{z1}	-30^0	-35^0	-4^0
V_{x1}	1,13	1,94	1,37
V_{y1}	1,01	0,37	-0,07
V_{z1}	-0,42	-0,01	-0,43
Forearm	Beginning of acceleration phase	Stroke	Follow-through phase
αx2	11^0	-52^0	53^0
αy2	26^0	-8^0	68^0
αz2	2^0	2^0	-2^0
Vx2	1,09	2,10	1,29
Vy2	0,94	0,52	-0,1
Vz2	-0,41	0,08	-0,52
Shoulder	Beginning of acceleration phase	Stroke	Follow-through phase
αx3	-5^0	-5^0	-11^0
αy3	-15^0	-10^0	18^0
αz3	0^0	0^0	-15^0
Vx3	2,98	1,44	-0,38
Vy3	0,25	-0,57	1,06
Vz3	0,00	-0,25	0,47

Source: Own elaboration

Two out of 36 forehand strokes were selected for the purposes of the study. The first was an accurate stroke and the other was a missed stroke. Differences in the angular parameters of the hand in the accurate and inaccurate strokes are visible in the results in each axis. In the X axis, the difference was eight degrees and in the Z axis the result obtained in the analysis was very similar because the difference was only two degrees. The largest discrepancy in results was evident in the Y axis because the vector took the opposite direction and the difference was 36 degrees. The velocities of particular segments were higher in missed strokes at the beginning of the acceleration phase. The velocities of the hand were also higher at impact excluding the Z axis, where the difference was 0.28 cm/s, taking the opposite direction in the Y axis. During the most important part of the whole stroke, i.e. the moment of contact between the strings of the racket and the ball, the differences in values were significant. The upper limb segments took different angles when the ball touched the strings of the racket. During the follow-through phase, the differences were smaller yet stillsignificant. When describing the beginning of the forearm acceleration phase, it is worth paying attention to the difference in velocity in the Y axis. In this axis, during the acceleration phase, the forearm was practically still in the accurate stroke, while the value was estimated at 0.94 cm/s in the missed stroke. It was noted that at each moment of impact tested, the angular parameters were unchangeable in the Z axis of the inaccurate stroke. The velocities of the upper limb segments during accurate forehands were usually the highest at impact. The velocities of segments in the inaccurate stroke deviated from the highest value at impact.

Table 3. Data of right upper limb angles and velocities during accurate backhand stroke

Hand	Beginning of acceleration phase	Stroke	Follow-through phase
α_{x1}	-19^0	6^0	-37^0
α_{y1}	5^0	-9^0	49^0
α_{z1}	-16^0	31^0	-47^0
V_{x1}	1,34	0,63	-0,03
V_{y1}	0,19	-0,94	-0,03
V_{z1}	-0,35	-0,23	0,03
Forearm	Beginning of acceleration phase	Stroke	Follow-through phase
αx2	-3^0	3^0	31^0
αy2	2^0	40^0	98^0
αz2	-1^0	-30^0	-48^0
Vx2	1,42	0,00	-0,09
Vy2	0,26	-0,65	-0,31
Vz2	-0,43	-0,41	0,05
Shoulder	Beginning of acceleration phase	Stroke	Follow-through phase
αx3	1^0	1^0	-4^0
αy3	12^0	3^0	-6^0
αz3	-8^0	-8^0	-3^0
Vx3	2,39	0,89	-0,21
Vy3	-0,02	3,48	-0,71
Vz3	0,60	-1,76	0,02

Source: Own elaboration

Table 4. Data of right upper limb angles and velocities during inaccurate backhand stroke

Hand	Beginning of acceleration phase	Stroke	Follow-through phase
α_{x1}	-23^0	16^0	-54^0
α_{y1}	-3^0	4^0	34^0
α_{z1}	17^0	26^0	-76^0
V_{x1}	0,86	-0,03	-0,71
V_{y1}	0,03	-0,02	-0,76
V_{z1}	0,04	-0,10	0,17
Forearm	Beginning of acceleration phase	Stroke	Follow-through phase
αx2	-7^0	1^0	49^0
αy2	4^0	39^0	92^0
αz2	-2^0	-26^0	-59^0
Vx2	0,84	-0,07	-59
Vy2	0,07	-0,81	-56
Vz2	-0,05	-0,12	0,12
Shoulder	Beginning of acceleration phase	Stroke	Follow-through phase
αx3	3^0	3^0	-9^0
αy3	13^0	3^0	-2^0
αz3	-8^0	-10^0	-5^0
Vx3	1,04	1,27	-0,13
Vy3	-0,07	4,47	0,63
Vz3	0,77	-2,41	-0,23

Source: Own elaboration

Similar to forehands, two out of 36 backhand strokes were selected for in-depth analysis. As was the case with the forehands, angular parameters had different vectors in the backhand strokes. The smallest differences in angles concerned the forearm and the shoulder. It can be assumed that in these segments, the X, Y, Z axes had similar values. Parameters regarding the velocities of the upper limb segments during the accurate and inaccurate backhand strokes did not have the highest value at impact.

Discussion

The inertial MCS has a number of advantages over optical systems. It is portable and can be used, for example, to study the movement of athletes practising sports or to examine patients in orthopaedic or rehabilitation clinics (Kopniak, 2014). Differences in the parameters of subjects may prove that professional tennis players optimise the angles of the right-hand segments and modulate the velocities of these segments. The tests carried out on volleyball players proved that angular parameters achieved by them during attacks differed markedly compared to professional volleyball players (Przednowek, 2016). A study conducted using the 'Xbus Kit' research tool confirmed the accuracy of the system measuring the deflection angles in the joints with an accuracy of 1-2 degrees in real time. High measurement frequency enables accurate motion analysis even in the case of strokes. The data obtained do not require post-processing. Measurements performed using IMU are reproducible and reliable (Kopniak, 2014).

Conclusion

The results show that despite a significant change in angle and velocity, a stroke can be accurate. This situation applies to both forehands and backhands. A tennis player adjusts and corrects the position and velocity of his hand, as shown by the variables analysed, i.e. the height and duration of a stroke, and this ability helps him to direct the ball towards the target area. The velocities of the upper limb segments during accurate forehand strokes were usually the highest at impact. The velocities of segments in missed strokes deviated from the highest value at impact. The phenomenon was not observed in the case of backhands where the velocities in the axes during accurate and inaccurate strokes had the highest values without exact indication of the segment, the moment of impact and the axis. In some cases, the velocity vectors took a different direction than in the other phases analysed. The knowledge of proper tennis stroke, awareness of technique and using possible technologies for teaching process, canhelp in players assessment and training individualization of didactic process for institutionseg. Sport Institute, Academy of Physical Education, Tennis Club, School. It could be usefullalso for coaches, teachers and players to cognize better their abilities of body, optimalization of traning process and adjustment to personal needs of a single tennis player.

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