Journal of Physical Education and Sport ® (JPES), Vol 20 (Supplement issue 6), Art 446 pp 3288 – 3297, 2020
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Comparative analysis between subjective and instrumental quality assessment through advanced technology: a pilot study on tennis serve

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Published online: November 30, 2020
(Accepted for publication: November 22, 2020)
DOI:10.7752/jpes.2020.s6446

Abstract
The purpose of this study in the first instance is to evaluate objectively, with data provided by latest-generation inertial sensors, the dynamic qualities of the technical-sporting gestures such as serve in tennis. Furthermore, the possible correlation between the aforementioned data and the evaluation monitoring of the specialized technical staff (Italian Tennis Federation qualified Coach) was assessed, in essence, a comparison between objective instrumental data and quality technical analysis. The study is not based on probative statistical numbers, five athletes, but the interest of the research is focused on establishing the validity, reliability and reproducibility of the information deriving from the acquisition with inertial instrumentation in the sport of tennis. The work seemed useful also by virtue of the fact that in the literature not many works have been produced on the subject at the moment, and in any case not with the latest technologies as in our case (K-Track, K-Sport Universal, Stats Perform, Montecchio PU, Italy). As mentioned, the research took into consideration the technical fundamental of the serve, an element that has taken on more and more importance in modern tennis in the achievement of the point and therefore in the result of the game. The serve is the stroke that marks the beginning of each point and that can influence the continuance of the same. Moreover, due to the speed of the surfaces of the fields and the game, the serve became in effect a substantial percentage of the final victory of the match. This is the basic motivation that led us to analyse this fundamental and its biomechanical composition, however, highlighting those elements that best qualify the gesture in a performative sense, trying to establish parameters that can be considered helpful for the technical staff and for the tennis player,in order to improve their performance.
Keywords: IMU, tennis serve, comparative analysis, technical evaluation, professional evaluation, physical data

Introduction

Tennis is classified as an individual situation sport, alternate aerobic-anaerobic, and its fundamentals hits are the serve, forehand, backhand,volley, smash, drop shot, and lob. The situations are highly variable and unpredictable as in addition to the choices of the individual, the opponent's responses must obviously be evaluated, which obviously suggests and generate others[1]. In addition to the opponents, with their typicality the variations of the playing surfaces must be evaluated, the climatic circumstances (outdoors or indoors matches) and alsothe duration of the game, usually at the best of the three sets and in competitions while in the Grand Slam at the best of the five sets. The average duration of a point in tennis (the smallest subdivision of the match, the completion of which changes the score) is estimated between 4 and 8 seconds, with a fair variability due precisely, as mentioned above, to the playing surface, the level of the players and the intrinsic typology of the athlete [2]. In essence, the tennis player is therefore called to sustain repeated submaximal efforts made with continuous lateral movements, rarely frontal, performed with acceleration and deceleration sequences, rapid slips and changes of direction, on average 4 for each point played. During a match of the three sets, the tennis player performs about 300-500 high-intensity actions with movements that for 80% of cases remain within a radius of 2.5 meters from the athlete's starting position [3].

The characteristics of the game actions although multiple can be identified from the physical point of view, as mentioned above, mainly as actions of acceleration, deceleration, and changes of direction or less frequently of sense. These types of actions follow each other in times and in a random manner, requiring significant strength commitments and a considerable specific organic resistance capacity, which is a situation

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sport, "open skill" and acyclic like tennis are connected to a metabolic quality of aerobic-anaerobic alternating alactacid type [4,5]. According to the performance model (PM), the actual playing time is equal to 26.5% of the total amount of the match, on clay, 21.2% on the synthetic and 15% on the grass, showing marked differences in relation to the different playing surfaces[6]. Being characterized by the succession of a series of short game phases with a low number of strokes played for each point and a short time interval between one stroke and the next, it is clear that these characteristics are all the more accentuated the faster the playing surface[7]. In addition to having a marked influence on the duration of the exchanges and the number of strokes played on average for each point, the playing surface also influences the type of game actions and the conclusions, underlining the important performance evolution of the serve gesture. In fact, it appears that on clay, where the speed of the ball is relatively less and the duration of the exchanges greater, the game is characterized by actions that end from the back of the court and, above all, with descents on the net; on the grass, however, almost all the actions end with the descent to the net after the execution of the serve, the so-called "serve and volley". Synthetic surfaces represent an intermediate condition, in relation to the duration of the exchanges and pauses, but also for the type of game actions and conclusions.Although it is a discipline in which dexterity, coordination and technical-tactical skills are absolutely indispensable qualities, the athlete's athletic profile is marked by characteristics of explosive strength and power of high anaerobic mechanisms accompanied by medium-level aerobic qualities [8]. Following the primary performative importance of the serve in tennis, many technicians have obviously made it a point of emphasis in training plans. An anthropometric element that can prove to be decisive is the stature of the player, an excellent advantage for performing good serve[9]. It is a fact, however, that athletes with high stature and with an important serve have in fact changed the dynamics of the game in recent years, which has led the technical staff to a proper correction of the training plan, and of the game strategies, dedicating relevant fieldwork sections to the beat [10].

Elements of serve technology for effective biomechanics

It seemed necessary to draw a sequential description of the execution technique in anatomical-functional as well as performative function of the studied gesture[11]. This is to detect which were the essential elements and points where to place the markers which in our case were the inertial sensors in order to define a functional data collection for the purposes of the work itself. The handle represents a fundamental technical prerequisite, as each of them has certain peculiarities, considering right-handed and left-handed tennis players. Another fundamental is the arm-racket asset, it means the optimal angle of the body segments such as the arm, forearm, and hand with respect to the racket gripped during the various stages of carrying out the technical skills.

The union of the previous technical fundamentals lead to the technique of the serve, it is considered a closed ability, it does not suffer like the other strokes of the situational context and therefore it is easier to carry out more accurate investigations, although it must be considered the mental aspect that can become an element of difficulty. The key points of this fundamental to be considered effective, obviously starting from the adequate handle on the racket, are the loading position, the pushing action of the legs, the external and internal rotation of the arm around the shoulder, the rotation of the trunk, the ball throw at 12 o'clock, flexion of the hand around the wrist. As for the preparation, it is worth remembering the continental grip as a reference handle, the neutral stance starting from the right sector and the semi-closed stance mostly closed from the left sector. Taking into consideration the technique of the feet, two types are distinguishable: the foot up and the foot back[12]. Moving to the point of impact with the ball, the arm-racket attitude will be brought behind the back by pushing the lower limbs with the forearm in a parallel position with respect to the ground. The racket must be far from the athlete's back and very low with a forearm-arm angle of 90 ° to allow the stretching of the shoulder muscles and create an acceleration space to be able to hit with maximum energy afterwards.

The racket will then fall behind the tennis player's back to the "lowest racket point", which is the point of maximum fall, through which it is possible to determine how much acceleration space will be created. Immediately following will be the moment of maximum external rotation of the shoulder, therefore the maximum phase of stretching that will take place when the athlete's body has started to rise. The arm will rotate around the shoulder joints both internally and externally to produce energy. The forearm will make pronations and supinations around the elbow joint with the task of bringing the stringbed behind the ball. With the acceleration phase of the racket, a linear moment and angular momentum are generated[13].

The line of the hips and that of the shoulders will be inverted and the dominant hip will move higher than the non-dominant one and this reversal will be favored by the thrust generated by the rear foot. The trunk will have a first longitudinal rotation action, when the racket is brought behind the back there will be a rotation of the trunk around the sagittal axis and shortly before the impact, the rotation of the trunk around the longitudinal axis will occur again to allow the tennis player not to hit frontally. To remember, however, will be the rotation of the trunk around the transverse axis that will take place simultaneously with the aforementioned actions. The subsequent extension of the elbow will not have the task of producing energy, but that of going to hit the ball as high as possible, as well as the pronation action of the forearm around the elbow which will have the purpose of allowing the impact with the ball with the strings and not with the frame. The so-called "shoulder over shoulder action", or the angular momentum around the sagittal axis will determine most of the thrust generated by the action of the legs and the dominant hip, which will pass over the non-dominant hip, also causing the overturning of the shoulders. The shoulder is the channel for transferring energy from the trunk to the arm, receiving all the energy created by the trunk and producing additional energy. In summary, during the starting phase, the non-dominant hand has the task of supporting the ball and the tool. Subsequently, during the ball launch phase it will support the rotation of the trunk by launching it over the body rotation axis (at 12 o'clock). After the throw, the non-dominant hand will determine the inclination of the shoulders.

Therefore, during movement, it will approach the axis of rotation of the body favouring rotation. During the end of the movement it will move outwards to block the rotation of the trunk. During the impact phase, the racket will move upwards, continuing its run from outside to inside and at this moment the action of flexing the hand around the wrist is relevant. During the serve, a series of eccentric and concentric phases can be detected at the level of the muscles of the shoulder joint. During the fall phase of the racket head there will be an eccentric phase of the front shoulder muscles, a subsequent concentric phase and a last eccentric phase of the rear shoulder muscles which will have the task of blocking the front muscles.The final phase of the movement will take place with the left foot, a natural consequence of the correct rotation around the sagittal axis and not on the longitudinal one. The dominant elbow can remain more or less high; the higher the elbow, the easier will be the internal-external rotation of the arm around the shoulder.

IMU an Tennis nowadays

The Inertial measurement units (IMU) combine accelerometers, gyro meters/gyroscopes andmagnetometers. The IMU systems are highly portable and allow to perform kinematic evaluations directly on the court, however, are also affected by errors such as skin movement and subsequentially sliding of the sensorand by the weight and position of the instrument itself [14]. Recently, IMU device were integrated to the racket or externally attached or the wrist, in order to provide information such as number of most common type of stroke and measure power, speed, impact location in the racket, ball spin, number of shots, energy cost or play time [15].Important to notice that the validity and reliability of IMU devices are not yet demonstrated in the literature, also the available parameters may be too basic for the coaches as for the biomechanical researchers, as shown (Figure 1) by Tubez et al. (2018) Pics, videos and 3D Motion Capture result to be more profitable when the main purpose is to develop technique[16].

Table 1; Use of different hardware and usefulness ("+" suitable system and "-" unsuitable system), source from Tubez ed al. 2018 adapted from Elliot et al. 2008.

	Improve technique	Improve performance	Prevent injury	Scientific research	Return-to-play criteria
Photo	+	+	–	–	–
2d Vidéo	++	++	+	–	–
3d Motion capture	++	++	++	++	+
Radar	–	++	–	+	–
Forceplate	+	++	+	++	+
EMG	–	–	++	++	++
Dynamometer	–	+	++	++	++
Racket sensors	–	–	–	–	–

Subsequently Pardo et al. in 2019, develop astudy in order to determinate the influence of body type, gender and anthropometry in the detection of tennis actions using IMU sensor system, finding out an accuracy greater than 96.5% to recognize the tennis strokes of a new player never analysed before by the system[17].Then concluding that will be necessary to synchronize the data obtained by the sensors with a video capture system capable to tracking the player's skeleton,in order that, not only stroke statistics could be obtained, but also information on the execution technique of the movement performed. Following the most recent research, our goal was to try to combine two different types of evaluation for the qualitative definition of the fundamental of the serve in tennis, the objective one of the IMU and the subjective technical/qualitative one provided through kinematic analysis by a qualified FIT coach. The final purpose of the study is to try to establish reference parameters for sports operators, for the objective and not just experiential evaluation of the serve in tennis. With elements related to the sequence of movements that constitute it, to establish the quality of the same and what was the entity of the physical and biomechanical elements, such as the accelerations that develop[18,19]. As mentioned above, we have considered very important for the planning of the study and the analyses that derive from it, the biomechanical elements linked to the specific technique of the serve. The scientific evidence must be connected and supported by an in-depth knowledge of the technique and its performance motivations, therefore the support provided by the FIT qualified coach was crucial for the development of the research process.

Means and Methods

The aim objective of this research is to establish a list of physical elements indicative and qualifying of the performance of serve in tennis. The study of the results derived from the use of advanced instruments such as in our case the inertial sensors, placed in different body segments, still have little application even at a high level, the objective is to evaluate a possible correlation with the data detected with these instruments and the usual qualitative analysis carried out by the technical staff, which, although of a good technical-professional level, are observational-notational as well as largely experiential. The results on parameters such as, for example, the accelerations and the angular speed of rotation, are a necessity to step into the state of the art of technology applied to sport, thanks to which we can achieve a more adequate, scientific training programming. Being able to monitor the progress of the training process of athletes with unquestionable objectivity and with irrelevant margins of error of measurements, will be a considerable contribution both for the coaches and the athletes themselves. Of course, this application will not perhaps be decisive in achieving the final result, but it certainly establishes crucial details for the technical staff for a well-designed job.

The specifications of the instruments used for this study are as follows: the video-analysis was filmed with a Sony Handycam HDR-CX100E 50 Hz, positioned on the serve side on the field line and a K-Track (K-Sport Universal Stats Perform, Montecchio, PU, Italy) was used as an inertial sensor, with a size similar to a USB flash drive, which, given its specifications and versatility, allowed an non invasively useon the athlete that can easily wear in the selected points of interest. The K-track instrument has a weight of 13 g, a size of 70/20/7 mm and is composed of three inertial sensors such as a 3D 16G 100Hz accelerometer, a 3D 100Hz gyroscope and a 3D 100Hz magnetometer. The battery of the instrument has an autonomy of 3 hours, in addition to a large recording memory for any problems of wireless connection with the PC and therefore allows you to store data even later simply via USB port. The points of interest on which the instrument was positioned were the chest, the wrist and the racket itself. The devices were worn inside an intrascapular pocket of a shirt suitable for the chest, while for the wrist a band was used and for the racket a plaster, however all the positions that made the movement of the sensors reduced to zero and stabilize them better safely (Fig. 1).

Fig. 1; Example of sensors positioning, 1 Racket, 2 Wristband 3 Chest.

The working group in this pilot study was composed of 5 athletes (Age 21.2 ± 3.8, Height 179 ± 7.4, Weight 59.6 ± 5.2, Years of activity "YA" 8.8 ± 5.2 and Italian Federation Ranking "IFR" 3.1 ± 0.3) 3 boys (Age 22.7 ± 4.6, Height 180 ± 8.7, Weight 62.3 ± 2.1, YA 10.0 ± 7.0 and IFR 3.1 ± 0.4) and 2 girls (Age 19.0 ± 0.0, Height 177.5 ± 7.8, Weight 55.5 ± 12.0, YA 7.0 ± 0.0 and IFR 3.2 ± 0.1). Certain that the non-consistent number of individuals tested does not constitute a statistical sample, for us it was useful to establish a connection between a new tool applied to the training methodology in tennis, based on objective findings that marked a basis on the which to discriminate real progress or not of the athletes in relation to the training project, so as to re-modulate the external load and the types of exercises proposed in the most appropriate way and not only with experiential notes. The protocol used in the study provided that each subject performed a standard warm-up before performing the test which included:Explanation of the working protocol to the subjects; explanation of the technical objectives and qualitative parameters that will be analysed; explanation of the positioning of the instruments on the body and the tool and safety instructions, such as, for example, be careful of any falls or blows on the devices, do not touch the instruments; test simulations at a mild pace for 5 minutes and subsequent 3-minute break and execution of the test consisting of 3 series of 10 serves (5 flat serve and subsequently 5kick serve) with two minutes of pause between one series and another.

The Protocol included the following steps: Positioning of the sensors on the athlete's chest, wrist and racket, switching on of the sensors and execution of 3 sets of 10 serves (5 first serve and 5second serve) with a two-minute break between one set and the next. The qualitative analysis was performed in post by video analysis, by FIT qualified coach, who could associate a score from 1 (low accuracy) to 5 (high accuracy) with 7 different technical elements that make up the serve, or:

1. Ball Toss: Throwing the ball at 12 o'clock;
2. Maximum elbow flection: angle between forearm and arm of 90 ° (in the development of the movement this angle remains constant at 90 °;
3. Shoulder Abduction: Moment of maximum external rotation of the "serve shoulder", when the push of the feet and legs extends the body

4. Lowest racket point: point of maximum fall, when the racket descends behind the back of the tennis player, important for understanding how much space (amplitude) of acceleration is created;
5. Shoulder over shoulder action: angular momentum of the trunk around the sagittal axis, which determines a large part of the thrust that was generated by the action of the legs and the dominant hip;
6. Ball impact: Optimal point of impact with the ball which has fallen about 10 cm;
7. Wrist Flexion: Flexion-closing action of the hand around the wrist by 10/15%.
The quantitative analysis was performed using three K-Track placed in the athletes' racket, wrist and chest, the data were analysed by K-Fitness software (K-Sport Universal, Ita) and the accelerations (x, y, z axis) were derived and divided into three decisive phases of the movement of the tennis serve:
• Vertical Charge (VC), in which acceleration data are developed on the vertical axis (y axis), and is characterized by loading from the starting point then from the starting position until the arm is brought behind (reaching the maximum elbow flection)
• Pre-Stroke acceleration (Pre-A), in which acceleration data are developed on the sagittal axis (z axis) towards the front, characterized by the point where the arm is behind up to the point of impact with the ball
• Closing acceleration (Clo-A), in which acceleration data are developed on all three axes (x, y, z) and is therefore the resultant calculated with a square root of the sum of the accelerations of x^2, y^2 and z^2. This phase is characterized by the point of impact of the racket with the ball at the highest point until the stroke is closed.
Following the collection of data provided by the qualitative analysis via video analysis and by IMU sensors, the analysis of the collected data was carried out. The linear correlation method was implemented between the total average of the qualitative technical assessments and the acceleration data derived from the IMU, dividing the assessment into first (Flat Serve) and second (Kick Serve) serve and according to the phases.

Data Analysis
The video analysis, performed through a technical evaluation of the serve performed on experiential judgment by a qualified coach at the highest level of the FIT, was correlated with the data collected through the inertial sensors, in order to highlight performance indicators. Table 2 and Table 3 show the average technical evaluation data relating to the Flatand Kick serves.

Table 2; Average ratings divided into the different technical elements for the Flat Serve (value from 0 to 5)

Flat Serve						
Technical elements	**Athlete 1**	**Athlete 2**	**Athlete 3**	**Athlete 4**	**Athlete 5**	**Avg.**
Ball Toss	3.80 ± 0.68	4.33 ± 0.62	4.40 ± 0.83	4.73 ± 0.59	4.20 ±0.77	4.29 ± 0.74
Maximum Elbow Flection	4.73 ± 0.46	2.87 ± 0.64	2.73 ± 0.46	3.13 ± 0.35	4.20 ± 0.56	3.53 ± 0.93
Shoulder Abduction	3.53 ± 0.52	3.33 ±0,49	3.27 ± 0.46	3.87 ± 0.64	3.60 ± 0.51	3.52 ± 0.55
Lowest racket point	4.27 ± 0.59	3.87 ± 0.52	3.47 ± 0.52	3.40 ± 0.51	4.47 ± 0.74	3.89 ± 0.70
Shoulder over shoulder action	3.80 ± 0.56	2.93 ± 0.26	3.60 ± 0.51	3.87 ± 0.64	4.33 ± 0.49	3.73 ± 0.75
Ball impact	4.00 ± 0.65	3.53 ± 0.52	3.47 ± 0.52	3.80 ± 0.68	4.20 ± 0.56	3.73 ± 0.62
Wrist flexion	1.87 ± 0.35	3.60 ± 0.51	3.53 ± 0.52	3.67 ± 0.49	3.53 ± 0.52	3.24 ± 0.83
Avg.+DS	3.71 ± 1.00	3.50 ± 0.70	3.50 ± 0.71	3.78 ± 0.72	4.05 ± 0.74	3.70 ± 0.80

Table 3; Average ratings divided into the different technical elements for the Kick Serve (value from 0 to 5)

Kick Serve						
Technical elements	**Athlete 1**	**Athlete 2**	**Athlete 3**	**Athlete 4**	**Athlete 5**	**Avg.**
Ball Toss	4.00 ± 0.65	4.27 ± 0.70	4.13 ± 0.74	4.67 ± 0.49	4.45 ± 0.52	4.30 ± 0.65
Maximum Elbow Flection	4.60 ± 0.51	2.73 ± 0.80	2.87 ± 0.35	3.40 ± 0.51	4.13 ± 0.52	3.54 ± 0.90
Shoulder Abduction	3.60 ± 0.51	3.47 ± 0.52	3.33 ± 0.49	3.47 ± 0.52	3.67 ± 0.49	3.50 ± 0.50
Lowest racket point	4.07 ± 0.59	3.80 ± 0.41	3.33 ± 0.49	3.87 ± 0.64	4.40 ± 0.51	3.89 ± 0.62
Shoulder over shoulder action	3.27 ± 0.46	3.00 ± 0.00	3.33 ± 0.49	4.33 ± 0.49	3.87 ± 0.64	3.65 ± 0.70
Ball impact	3.20 ± 0.56	3.47 ± 0.52	3.40 ± 0.51	4.40 ± 0.74	3.53 ± 0.52	3.73 ± 0.74
Wrist flexion	1.40 ± 0.51	3.40 ± 0.63	2.53 ± 0.64	3.67 ± 0.49	3.20 ± 0.41	2.84 ± 0.97
Avg.+DS	3.45 ± 1.09	3.45 ± 0.72	3.28 ± 0.70	3.97 ± 0.71	4.06 ± 0.65	3.64 ± 0.85

The data deriving from the IMU sensors were significant only at the wrist level, as at the racket level the data were very similar to those found on the wrist and at the back level, no consistent accelerations were found, which means that the device placed on the wrist is the qualifying one in the acquisition of probative data in the studied element. Taking into consideration only the results provided by the sensor positioned at the level of the wrist, it provided very detailed information on movement and was divided into three phases. Table 4 and table 5 show the average results derived from the IMU divided by each phase of the movement, the acceleration (m/s^2) is analysed in three different serve phases and divided into flat and kick strokes.

Table 4; Average accelerations divided into the different phases for the flat serve (m/s^2)

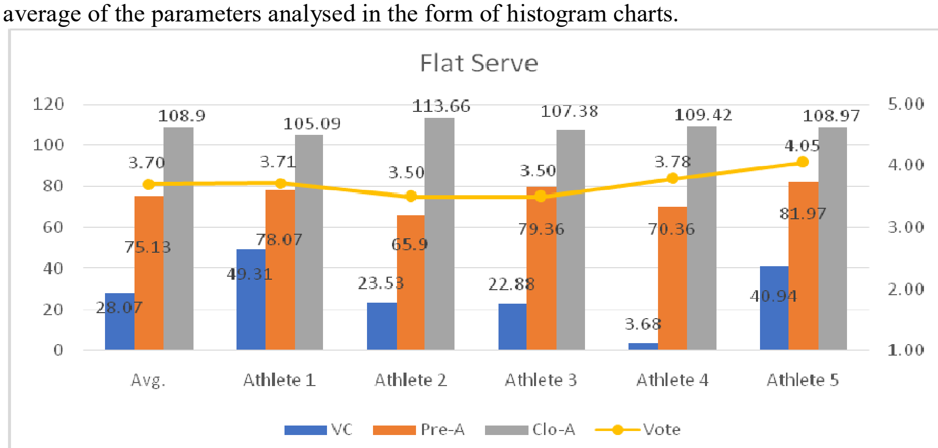
Flat Serve						
Serve Phase	**Athlete 1**	**Athlete 2**	**Athlete 3**	**Athlete 4**	**Athlete 5**	**Avg.+DS**
VC	49.31 ± 3.31	23.53 ± 1.13	22.88 ± 3.92	3.68 ± 1.25	40.94 ± 10.87	28.07 ±16.82
Pre-A	78.07 ± 3.58	65.90 ± 1.29	79.36 ± 4.55	70.36 ± 10.80	81.97 ± 15.38	75.13 ± 10.50
Clo-A	105.09 ± 7.52	113.66 ± 6.46	107.38 ± 9.54	109.42 ± 15.68	108.97 ± 12.66	108.90 ± 10.99

Table 5; Average accelerations divided into the different phases for the kick serve (m/s^2)

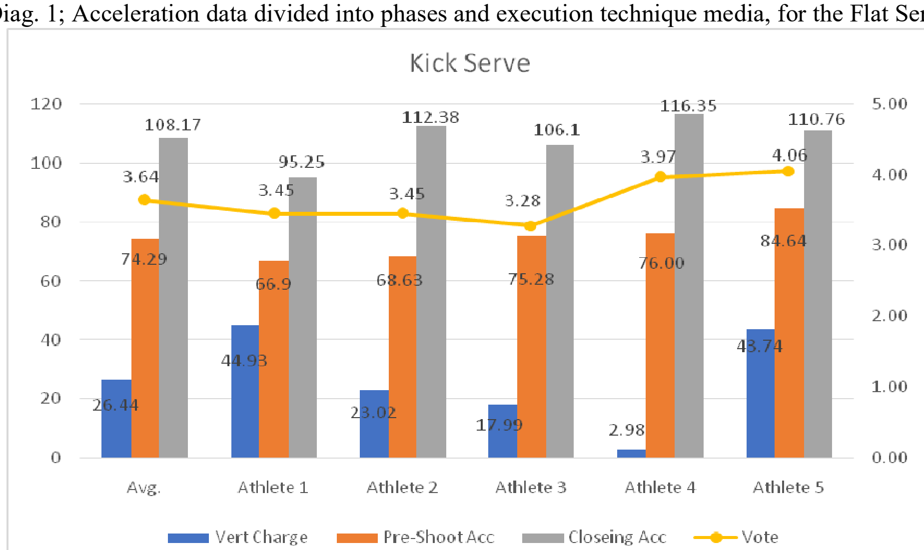
Kick Serve						
Serve Phase	**Athlete 1**	**Athlete 2**	**Athlete 3**	**Athlete 4**	**Athlete 5**	**Avg.+DS**
VC	44.93 ± 7.22	23.02 ± 1.64	17.99 ± 2.46	2.98 ± 0.92	43.74 ± 4.21	26.44 ± 16.43
Pre-A	66.90 ± 21.17	68.63 ± 3.53	75.28 ± 3.09	76.00 ± 9.25	84.64 ± 1.59	74.29 ± 12.07
Clo-A	95.25 ± 23.22	112.38 ± 9.07	106.10 ± 1.78	116.35 ± 7.20	110.76 ± 8.10	108.17 ± 13.91

Discussion

From the data provided by the qualitative analysis through video-analysis and from the IMU sensors positioned on the athletes' wrist, the data analysis was carried out, in Diag. 2 and Diag. 3 it is possible to see the resulting average of the parameters analysed in the form of histogram charts.



Diag. 1; Acceleration data divided into phases and execution technique media, for the Flat Serve



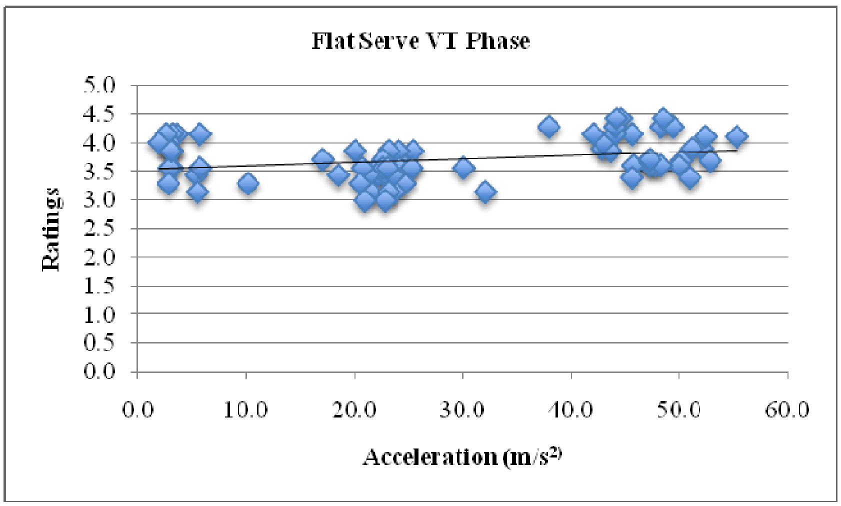
Diag. 2 Acceleration data divided into phases and average execution techniques, for the Kick Serve.

After the collection of data provided by the qualitative analysis through video analysis and by the IMU sensors positioned on the athletes' wrist, a linear correlation was carried out. The correlation indicates the tendency that two variables, in this case called X for accelerations and said Y for qualitative technical evaluations, vary together. By examining the type of study taken into consideration, it seemed appropriate and interesting to research the linear correlation between the two variables considered, precisely to verify whether the objective analysis of a technological tool can be compared to the subjective evaluation of a qualified technical staff.

To express the correlation existing between the variable X of the accelerations and the variable Y of the subjective evaluations, the Pearson correlation coefficient r was used.For the direct correlation and similarly for the inverse one, a weak correlation can be distinguished if the coefficient is between 0 and 3, a moderate correlation if the coefficient is between 0.3 and 0.7, and a strong correlation if the coefficient is greater than 0.7.The value measured by this coefficient is directly proportional to the covariation between X and Y and inversely proportional to the product of the variations of X and Y:

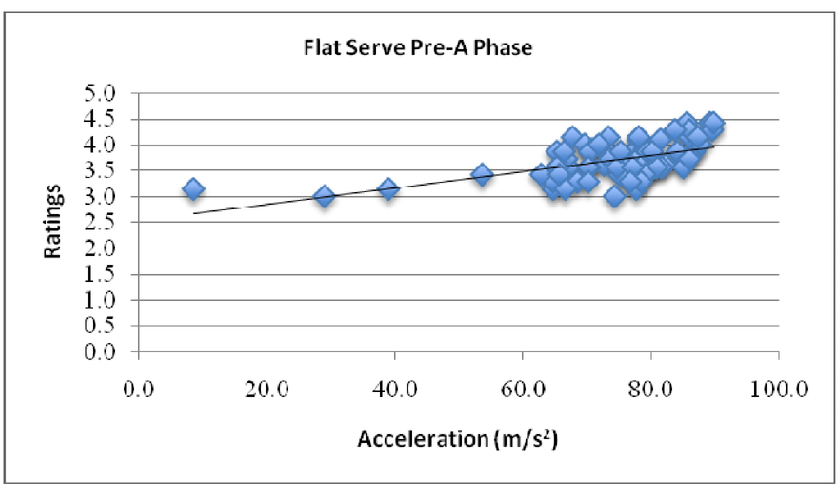
$$Y{:}r_{xy} = \frac{covxy}{\sqrt{varx * vary}}$$

Furthermore, the standard deviation provides an idea of what the dispersion of data is, in particular of what is the detachment of all values from the correlation network. As regards the shape of the correlation, it is possible to distinguish the slope of the straight line, and the positive or negative number value in reference to the Pearson correlation coefficient. Then the graphs of the data collected on the basis of the Flat Serve and the Kick serve during the three phases of the movement are reported.

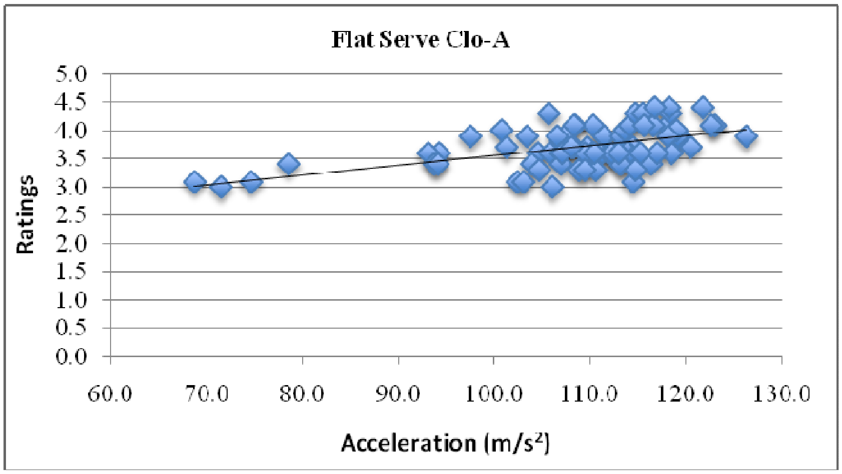


Diag.3; Flat serveVT Phase correlation

From Diag.3 it is possible to deduce that in the VT phase in the flat serve there is a positive correlation (0.28 r). Diag. 4 shows the Pre-A phase during the flat serve have a positive moderate correlation (0.57 r). Diag. 5 shows the Clo-A phase during the flat serve have a positive moderate correlation (0.53 r).

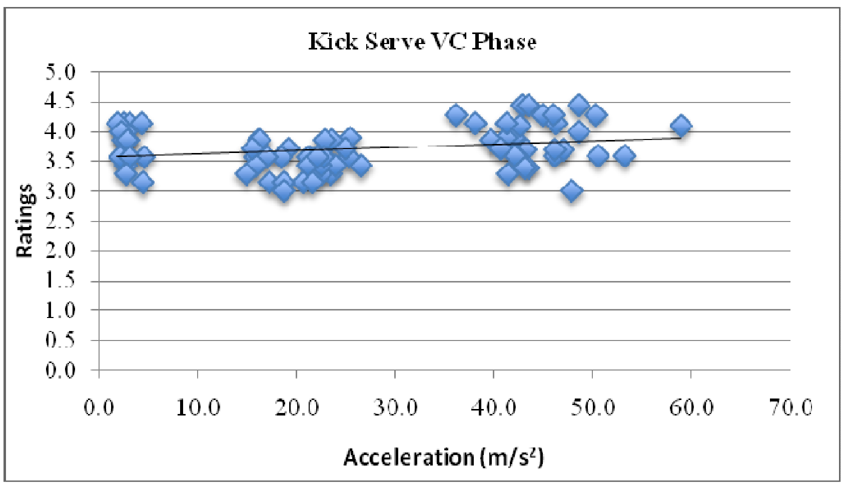


Diag. 4; Flat serve Pre-A phase correlation

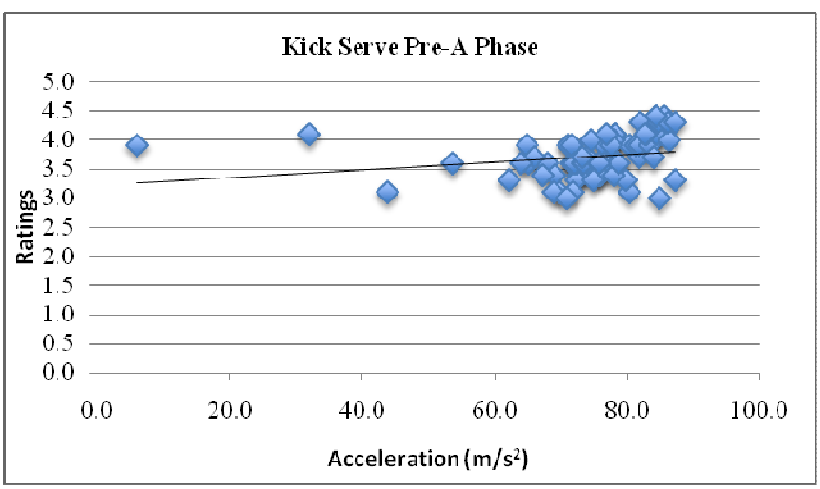


Diag.5;Flat serve Clo-A phase correlation

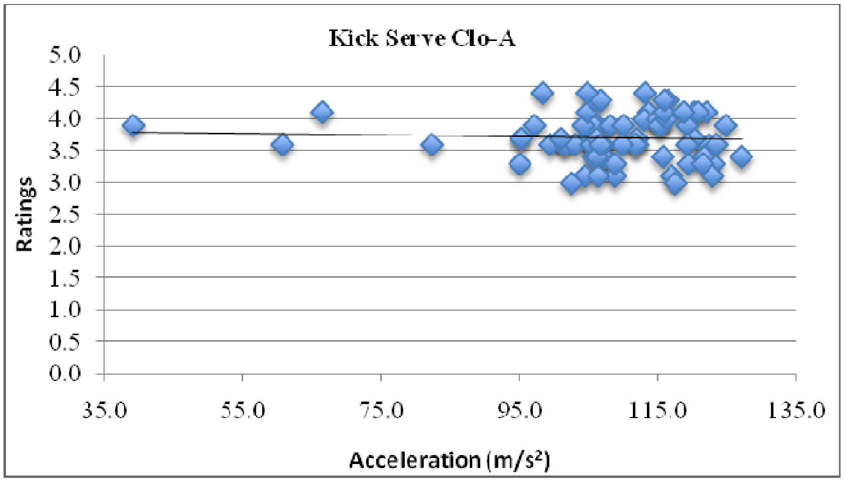
From Diag.6 it can be deduced that a weak positive correlation (0.24 r) exists during the VT phase during the Kick Serve. Diag.7 shows that in the Pre-A phase were found a weak positive correlation (0.22 r).Diag. 8 shows a very weak negative correlation (-0.05)in the Clo-A phase.



Diag. 6; Kickserve VC phase correlation



Diag. 7; Kickserve Pre-A phase correlation



Diag. 8; Kickserve Clo-A phase correlation

Conclusion

The aim of this research was to try to understand if the accelerations developed during the serve movement and provided by the IMU sensors, positioned on the wrist, having excluded the data deriving from the sensor on the chest and that on the racket because they proved to be insignificant, could be correlated with a technical analysis defined by the subjective evaluation of a qualified coach. Rest assured that the use of these instrumental and mathematical databases can affect effectively the training plan. From the video analysis it appears that the vertical charging phase can be correlated with the ball toss at 12 o'clock and the maximum elbow flection, the pre-stroke acceleration phase can be correlated with the moment of maximum external rotation of the shoulder, the lowest racket point and shoulder over shoulder action, and finally the closing acceleration phase can be correlated with the optimal point of impact with the ball and the flexion-closing action of the hand around the wrist. The calculation of the correlation coefficients shows that the most relevant variables are found during the pre-stroke acceleration phase and during the closing acceleration phase in the flat serve. Probably this could be due to the fact that if in the preparation phase of the movement the parameters taken into consideration are optimally satisfied, therefore above all the moment of maximum external rotation of the shoulder and the lowest racket point and the shoulder over shoulder action where it is created the space of acceleration, then there will be consistent accelerations that can be correlated with suitable evaluations. This could also apply to the stroke closing phase, since during this last transition, if the technical constraints such as the optimal point of impact with the ball and the flexion-closing of the hand around the wrist are performed in an optimal way, then above all even greater accelerations will occur at this stage.The analysis of the serve through the use of IMU, provided a positive correlation between the dynamic data and qualitative evaluation. Utility was also highlighted, using the analysed parameters for the improvement of the training proposals, with analytical method.Future developments may be to enlarge the study sample, both by age, gender, and category and also consider other strokes.

Acknowledgments: This study did not receive any financial support or other assistance. Conflicts of Interest: The authors declare no conflict of interest.
All subjects were informed on the benefits and risks of the investigation.
The data collection followed the principles outlined by the Declaration of Helsinki.

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