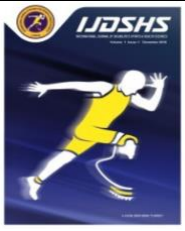

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RESEARCH ARTICLE

Tennis Flat Serve Kinematic Features in Young Athletes: A Feasibility Study

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Abstract
The aim of this study is to examine body kinematics in tennis straight serve. 5 elite male tennis players (mean age 18.4±3.3 years, mean height 182.3±5.6 cm, mean weight 72.2±7.9 kg) were included in the study. We determined the angle of inclination from the ball to the body and the impact position of the ball during serve movements of young male tennis players at the center and sideline. The collected data on ball impact height, front and back distance of the front foot from ball impact, angle of incidence, and overall inclination using a motion head device (i.e., Dartfish motion program). Repeated measures ANOVA was used to determine the athletes' serve performance. Result: tennis serve skill with player A, B and C, the angle of incidence showed a significant main effect in both performances ($p<.05$) and training period ($p<.001$), and the interaction between performance and training period was also significant ($p<.01$). Tennis serve skill with player D and E, the angle of incidence did not show a main effect in the performance, and the main effect was significant in the training period ($p<.001$). However, the interaction between performance and training period was not significant. In conclusion, the result showed that young players improved their tennis serve success rates and ball striking heights after training. These findings show that tennis serve training and kinematic analysis can improve tennis serve skills.

Keywords
Tennis, Centerline, Sideline, Flat Serve, Impact Height, Ball-To-Body Tilt, Incidence Angle

INTRODUCTION

The tennis serve is considered one of the most complex and challenging techniques in the sport. It is difficult to learn the most accurate technique because upper and lower extremity movements require complex coordination (Bingul et al., 2016). Accordingly, the tennis serve is both the most important and the most difficult shot to master and comes in three basic types: straight, topspin and slice. Straight shot (topspin) and slice (sidespin) use similar upper body temporal and kinematic properties to produce large translational ball speeds (Sheets et al., 2011).

The straight serve (i.e., flat serve) is potentially the fastest, while the topspin serve is generally the most consistent. Although speed production is critical for straight serve performance, the boundaries and dimensions of the serve box require that an accuracy component be maintained (Whiteside et al., 2014). Serving at high speed generally provides a great advantage in tennis (Chow et al., 2003). The important key factors of the serve are the speed and direction of the racket, the height of the ball at the time of impact, the weight of the racket, the angle of the racket at the moment of impact, and the speed and direction of the ball at that moment.

Player skill explains 31% of the variation in serve speed. In conjunction with player height, player skill contributes approximately 60% of serve speed variance (Martin et al., 2014). Yet, because it places a great deal of strain on young athletes' shoulder and elbow joints, this technique has been

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linked to severe injuries (Abrams et al., 2012). In tennis competition, the repetitiveness of the serving motion throughout the course of a player's career has a traumatic effect (Martin et al., 2014). There is no quantitative research on tennis serves that raise the success rate of serves and lower the risk of injury, despite the increased risk of injury when games last between 50 and 150 minutes. Hence, in order to assist young tennis athletes, a developmental and kinematic approach to tennis serves is required. According to several research, tennis matches of all sizes are affected by a prevalent medical condition known as repetitive abuse injuries to the upper limb joints of tennis players (Abrams et al., 2012; Hjelm et al., 2012; Marx et al., 2001). At the sub-stage, excessive anterior shoulder force that is applied repeatedly produces ligament relaxation. Excessive humeral head translation and external rotation cause pain and discomfort during the arm cocking stage. So, it is favorable in competition and helpful in preventing player damage to reduce the frequency of serving by raising the serve's success rate.

According to Chaw et al., (2003), kinematic data were used to examine the features of the first and second serves. As a result, the first serve's average impact ball forward position was substantially further forward than the second serve's value. The ball was said to be moving faster (Chaw et al., 2003). Martin et al., (2014) also demonstrated that while limb movement speed decreases, the speed of the ball increases with the energy quality of the hand segment-racquet segment in the trunk. This finding implied that the injured athlete had a high ratio of energy absorbed by the shoulders and elbows, decreased ball speed, and a low quality of energy flow across the upper limb exercise chain.
The serve action begins with the feet, employs the knees and legs, the butt and weight, and impacts the ball with the upper body and arms while enhancing serve performance and minimizing damage. Hence, all body components and a chain of exercises can be effectively utilised to generate strokes (Goktepe et al., 2009). For instance, some research on tennis serve motions focused on how better approaches can result in high efficiency and fewer accidents (Aguinaldo et al., 2007; Aguinaldo et al., 2007, 2009). The most efficient server is one that can optimize power (ball speed) while putting the least amount of strain on the joints, and kinematic variables are a fantastic way to confirm this difference (Martin et al., 2014). Yet, a lot of players differ individually in their sub- actions depending on their strength, size, gender, position, and on-field ability. Athletes and leaders can benefit from standardized kinematic data that enables the performance of appropriate sub- movements during training and competition.

Previous studies showed that using the whole body in an integrated way can improve the power of the sub (Goktepe et al., 2009), angular momentum (Fleisig et al., 2003), joint angle (ankle, shoulder, elbow) (Goktepe et al., 2009), lower limb coordination, and shoulder joint (Reid et al., 2008), elbow, shoulder rotation angle, and ball speed (Martin et al., 2013). However, in order to assess the integrated whole-body approach for ball impact motion, it is important to examine the inclination angle between the ball and the body.

The purpose of this study was to quantitatively analyze the kinematic features related to the impact position of the ball and the ball-to-body tilt angle, examining their association with serve success (targeted at the center and sideline) and failure during a flat tennis serve in young athletes. More specifically, the front- to-back distance between the heel and the ball was computed as the height ratio, the vertical height of the ball at the time of ball impact was determined, and the inclination angle for the two coordinates was quantitatively determined. Also, it was done to compute the angle of incidence using the dimensions of the tennis court and the vertical coordinates of the ball. This gave each player access to quantitative information. Also, we looked at whether each player's flat serve performance had improved following a 12-week training period. The goal of the drill is to contact the ball as accurately and quickly as possible at a high point.

MATERIALS AND METHODS

Participants

Five male tennis players participated our study. Table 1 lists their demographic details. They were all athletes who competed in national competitions. The research was approved by the Institutional Review Board and conformed to the Declaration of Helsinki. All aspects were conducted in accordance with the relevant guidelines and regulations of the institution. Participant provided informed consent, with the volunteer form covering research details, risks, benefits, confidentiality, and

participant rights before participation in the experiment.

Table 1. Demographic characteristics

Subject	Gender	Age (Years	Height (cm)	Weight (kg)
A	Male	18	189.1	84.9
B	Male	12	143.5	40.6
C	Male	12	156.7	56.6
D	Male	12	152.3	43.3
E	Male	12	160.8	78.7

Test Procedure

The training program in this study was conducted five days a week for a total of 12 weeks. This specialized tennis serve training program adopted an individualized approach, taking into consideration the technical abilities and physical conditions of the players. Each training session was focused on improving specific tennis serve skills, centering on the technical execution of various serve types (flat, slice, and kick serves), and aimed at enhancing each player's serve mechanics, launch angles, and swing speeds. The sessions included a variety of serve practices and technical approaches. Players performed a specific 10- minute warm-up before each session and executed two serves to adapt to the protocol. The tennis balls used in training were regularly replaced to maintain high quality. Players strived to achieve maximum speed and accuracy in each session, with clear objectives set. Regular target practice and speed measurements were conducted to increase the accuracy and consistency of serves. Advanced video analysis tools and speed measuring equipment were utilized to thoroughly analyze and propose improvements for each player's serve motion. Throughout the training period, players repetitively practiced various serve techniques, focusing on improving the accuracy and speed of their serves. The training also emphasized physical training related to serving, particularly strengthening the upper body and core muscles. This systematic approach played a significant role in enhancing the players' serve performance.

Data Collection

The measurement subjects per in warm-up activities and tennis serve drills for 30 minutes prior to measurement after being briefed on the process and intended outcome. Following that, the flat serve process was repeatedly tried on the T line and the W line until it was successfully completed five times (Figure 1). The serve movement was accomplished in a high-speed film with an iPhone XS MAX model capable of high speed capable of up to 240 fps in order to precisely measure a very rapid serve action.

The video was filmed in real time and took place in the court opposite the serve. The participants tennis serve was filmed from start to finish. Each trial was filmed, and the camera angle was adjusted according to the participant serve motion before being filmed for each trial. After that, the measurement image was calculated by the height of the ball at the time of serving impact using the Dart Fish Analyzer program. Vertical Displacement (V: Vertical Displacement) and Front Distance (H: Horizontal Displacement) were divided into the height of each subject. Furthermore, using a two-dimensional coordinate to calculate the tilt angle from the front of the foot to the ball. The incident angle of the ball was calculated using the vertical height and the horizontal distance to which the ball is impacted. For the pre-post measurement of this study, a flat serve training of 12 weeks after the first measurement was performed, followed by the second measurement. The reason we need to compare success from the centerline and the sideline is because the performance of an opposing player returning a serve can vary depending on the position. The formula is follows (i.e., this formula used to calculate the impact during content to ball)

$$\theta = \tan^{-1}\left(\frac{V}{H}\right)$$

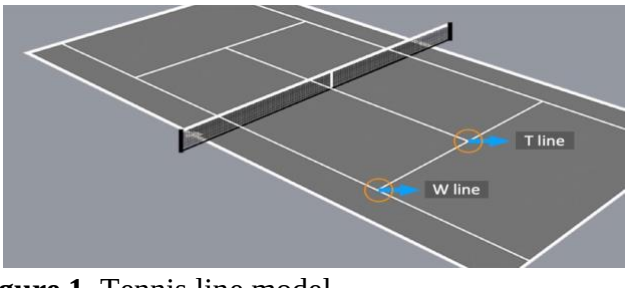

Figure 1. Tennis line model

Statistical Analysis

Statistical analysis was performed separately for variables of the tennis serve. Each serve variables was performed repeated ANOVA. Repeated measures ANOVA is data that measures the same subject multiple times over time. For all analyses, statistical significance was set at a level of 0.05. We performed all analysis using SPSS 18.0.

RESULTS

In this study, five male tennis players measured the success-centerline serve, success-sideline serve, failure impact height of the ball, anterior and posterior distance between the front foot and the impact ball, angle of tilt between the ball, and angle of incidence. The values from each person's analysis findings are listed below.

Characteristics of Tennis Serve Skill With Player A

Repeated measures ANOVA was performed to verify the interaction effect between performance and training period on the characteristics that affect the serve-performance of player A (Table 2). As a result, the main effects of performance ($p<.05$) and training period ($p<.001$) were significant on impact height. Also, the interaction effect between performance and training period was significant ($p<.01$). Next, the main effect of the anterior and posterior distance did not show a significant difference in performance, and the main effect was significant in the training period ($p<.001$). Also, the interaction effect between performance and training period was not significant. The main effect on the tilt angle of the whole body was found during the training period ($p<.001$), and the interaction effect between the performance and the training period was significant ($p<.05$). Finally, the angle of incidence showed a significant main effect in both performances ($p<.05$) and training period ($p<.001$), and the interaction between performance and training period was also significant ($p<.01$).

Table 2. Serve-characteristics of player A

Division	Period	Serve Performance				Source	F	P
		Success Centerline	Success Sideline	Failure	Total			
Impact Height (%)	Pre	128.5±5.75	125.12±1.22	119.62±2.52	124.41±3.2	Performance	5.556	.010*
	Post	129.5±3.09	125.86±1.98	129.88±1.48	128.43±2.83	Period	12.852	.001***
	Total	129.0±4.39	125.49±1.60	124.75±5.75	126.41±3.91	Performance X Period	7.749	.003**
A-P Distance (%)	Pre	81.3±1.57	22.63±2.49	23.8±2.95	22.03±3.31	Performance	.174	.841
	Post	82.52±1.3	15.34±3.8	14.49±3.16	15.62±3.27	Period	30.659	.001***
	Total	81.91±1.5	18.99±2.21	19.14±5.69	18.83±4.59	Performance X Period	2.900	.074
Whole-Body TilAngle(Degree)	Pre	81.3±1.57	79.76±1.11	78.74±1.52	79.93±1.7	Performance	.640	.536
	Post	82.52±1.3	83.06±1.72	83.64±1.4	83.07±1.46	Period	35.112	.001***
	Total	81.91±1.5	81.41±2.21	81.19±2.93	81.5±2.23	Performance X Period	4.034	.031*
Incidence Angle (Degree)	Pre	6.42±0.39	6.05±0.17	5.66±0.29	6.05±0.42	Performance	3.417	.049*
	Post	6.64±0.26	6.52±0.26	6.81±0.22	6.66±0.26	Period	37.732	.001***
	Total	6.53±0.33	6.29±0.32	6.23±0.65	6.35±0.46	Performance X Period	7.740	.003**

Characteristics of tennis serve skill with player B

Repeated measures ANOVA was performed to verify the interaction effect between performance and training period on the characteristics that affect the serve-performance of player B. As a result, the main effect was significant in the training period ($p<.001$) for impact height. However, it did not appear during the performance. Also, there was a significant interaction effect between performance and training period ($p<.01$). Next, the main effect of the anterior and posterior distance did not show a significant difference in performance and the training period. Also, the interaction effect between performance and training period was not significant. The main effect on the tilt angle of the whole body was not found during the performance and training period. Also, the interaction effect between the performance and the training period did not appear significantly. Lastly, the angle of incidence showed a significant main effect in the training period ($p<.01$) and was not significant in

the interaction between performance and training period.

Table 3. Serve-characteristics of player B

Division	Period	Serve Performance: Success Centerline	Success Sideline	Failure	Total	Source	F	P
Impact Height (%)	Pre	116.53±3.08	121.12±2.04	121.12±1.83	119.59±3.14	Performance	1.609	.221
	Post	127.63±1.56	126.36±2.34	125.21±1.23	126.4±1.94	Period	78.875	.001***
	Total	122.06±6.29	123.74±3.45	123.17±2.61	123.99 ±4.12	Performance X Period	8.042	.002**
A-P Distance (%)	Pre	9.57±3.29	10.6±4.48	16.98±13.94	12.38±8.71	Performance	1.732	.198
	Post	12 ±5.16	8.93±2.89	13.02±2.5	11.32±3.87	Period	.191	.666
	Total	10.79±4.27	9.77±3.66	15±9.67	11.85±6.64	Performance X Period	.589	.563
Whole-Body Tilt Angle (Degree)	Pre	85.32±1.57	85±2.15	82.08±6.45	84.13±4.02	Performance	1.674	.209
	Post	84.63±2.32	85.95±1.38	84.07±1.12	84.88±1.76	Period	.442	.513
	Total	84.98±1.9	85.48±1.78	83.08±4.49	84.51±3.08	Performance X Period	.475	.628
Incidence Angle (Degree)	Pre	5.24±0.2	5.41±0.27	5.1±0.74	5.25±0.45	Performance	1.475	.249
	Post	5.66±0.28	5.75±0.24	5.49±0.13	5.63±0.24	Period	8.107	.009**
	Total	5.45±0.32	5.58±0.3	5.3±0.54	5.44±0.41	Performance X Period	.038	.963

Characteristics of tennis serve skill with player C

Repeated measures ANOVA was performed to verify the interaction effect between performance and training period on the characteristics that affect the serve-performance of player C. As a result, there was no main effect in the training period on impact height, and the main effect was significant in performance ($p<.01$). Also, the interaction effect between performance and training period was not significant. Next, the main effect was significant in the training period on the anterior-posterior distance ($p<.001$) and the tilt angle of the whole body ($p<.001$). The main effect in the angle of incidence was significant in the training period ($p<.001$). However, the interaction between performance and training period was not significant.

Table 4. Serve-characteristics of player C

Division	Period	Serve Performance: Success Centerline	Success Sideline	Failure	Total	Source	F	P
Impact Height (%)	Pre	130.17±3.8	122.09±3.32	130.59±3.36	127.62±5.19	Performance	6.357	.006*
	Post	130.73±5.54	128.22±3.23	129.89±2.63	129.62±3.86	Period	2.114	.159
	Total	130.45±4.49	125.16±4.47	130.24±2.87	128.62±4.61	Performance X Period	.118	.118
A-P Distance (%)	Pre	20.35±4.14	20.63±4.26	20.63±7.47	20.53±5.1	Performance	.007	.993
	Post	13.38 ±4.36	13.24±6.94	12.68±3.35	13.1±4.74	Period	14.684	.001***
	Total	16.86±5.44	16.93±6.68	16.66±6.88	16.82±6.14	Performance X Period	.979	.979
Whole-Body Tilt Angle (Degree)	Pre	81.16±1.56	80.43±1.92	81.08±3.1	80.89±2.15	Performance	.128	.880
	Post	84.21±1.73	84.16±2.94	84.44±1.43	84.27±1.98	Period	17.527	.001***
	Total	82.69±2.24	82.29±3.06	82.76±2.88	82.58±2.73	Performance X Period	.942	.942
Incidence Angle (Degree)	Pre	4.93±0.06	4.55±0.23	4.93±0.28	4.81±0.27	Performance	5.055	.015*
	Post	5.27±0.14	5.16±0.23	5.26±0.15	5.23±0.17	Period	36.618	.001***
	Total	5.1±0.21	4.86±0.38	5.1±0.27	5.02±0.31	Performance X Period	.224	.224

Characteristics of tennis serve skill with player D

Repeated measures ANOVA was performed to verify the interaction effect between performance and training period on impact height among the characteristics that affect the serve- performance of player D. As a result, there was no main effect in performance on impact height, and the main effect was significant in the training period (p<.001). Also, there was no significant interaction effect between performance and training period. Next, the main effect of the anterior-posterior distance was significant in the training period (p<.001), and the main effect was not significant in the performance. The interaction effect between performance and training period was not significant. In addition, the main effect of the tilt angle of the whole body was significant in the training period (p<.001), and the main effect was not significant in the performance. The interaction effect between performance and training period was not significant. The angle of incidence did not show the main effect in performance, and the main effect was significant in the training period (p<.001). However, the interaction between performance and training period was not significant.

Table 5. Serve-characteristics of player D

Division	Period	Serve Performance				Source	F	P
		Success Centerline	Success Sideline	Failure	Total			
Impact Height (%)	Pre	127.36±2.26	127.36±2.74	128.86±2,9	127.62±5.19	Performance	1.094	.351
	Post	119.65±3.8	121.76±2.22	129.89±2.63	121.89±3.02	Period	42.811	.001***
	Total	123.51±5.02	124.56±3.69	130.24±2.87	125.37±3.86	Performance X Period	.359	.072
A-P Distance (%)	Pre	0.75±7.26	5.6±5.44	0.62±7.77	2.32±6.82	Performance	1.539	.235
	Post	11.82 ±4.33	13.43±2.87	10.42±2.42	11.89±3.32	Period	23.478	.001***
	Total	6.28±8.11	9.52±5.82	5.52±7.49	7.11±7.14	Performance X Period	.227	.799
Whole-Body Tilt Angle (Degree)	Pre	89.66±3.3	87.48±2.55	89.67±3.43	88.93±3.08	Performance	1.438	.257
	Post	84.33±2.18	83.73±1.28	85.12±1.18	84.39±1.6	Period	25.131	.001***
	Total	87±3.85	85.6±2.74	87.39±3.41	86.66±3.33	Performance X Period	.251	.251
Incidence Angle (Degree)	Pre	6.36±0.4	6.12±0.39	6.44±0.52	6.3±0.43	Performance	1.090	.352
	Post	5.42±0.37	5.44±0.11	5.6±0.21	5.49±0.25	Period	38.320	.001***
	Total	5.89±0.62	5.78±0.45	6.02±0.58	5.9±0.55	Performance X Period	.350	.350

Characteristics of tennis serve skill with player E

Repeated measures ANOVA was performed to verify the interaction effect between performance and training period on impact height among the characteristics that affect the serve- performance of player E. As a result, there was no main effect on impact height, and the main effect was significant in the training period (p<.01). Also, there was no significant interaction effect between performance and training period. Next, the main effect of the anterior-posterior distance was significant in the training period (p<.001), and the main effect was not significant in the performance. The interaction effect between performance and training period was not significant. Also, the main effect of the tilt angle of the whole body did not show a significant difference in performance and the training period. Also, the interaction effect between performance and training period was not significant. Finally, the angle of incidence did not show a main effect in the performance, and the main effect was significant in the training period (p<.001). However, the interaction between performance and training period was not significant.

Table 6. Serve-Characteristics of player E

Division	Period	Success Centerline	Success Sideline	Failure	Total	Source	F	P
Impact	Pre	117.92±2.21	117.53±3.35	117.94±2,99	117.79±2.68	Performance Period	1.351	.278
Height (%)	Post	119.63±2.2	119.89±2.21	123.31±4.14	120.94±3.27	Performance	8.619	.007**
	Total	118.78±2.26	118.71±2.95	120.62±4.43	119.37±3.21	X Period	1.112	.345
A-P Distance	Pre	2.89±1.1	2.89±2	2.63±2.83	2.8±1.98	Performance Period	1.017	.377
(%)	Post	5.65 ±4.75	7.09±2.5	9.46±1.71	7.4±2.99	Performance	20.256	.001***
	Total	4.27±3.67	4.99±3.1	6.04±4.22	4.49±3.66	X Period	1.359	.276
Whole-Body	Pre	91.39±0.81	91.42±1.01	91.3±1.36	91.37±1.06	Performance Period	.987	.388
Til Angle	Post	128.71±7.85	93.37±1.19	94.38±0.84	105.49±3.29	Performance	1455	.239
(Degree	Total	110.05±5.59	92.39±1.46	92.84±1.94	98.43±8.99	X Period	.987	.389
Incidence	Pre	5.75±0.17	5.73±0.1	5.74±0.17	5.74±0.14	Performance	2.578	.097
Angle	Post	5.95±0.21	6.04±0.2	6.31±0.19	6.1±0.24	Period	31.369	.001***
(Degree)	Total	5.85±0.21	5.89±0.22	6.02±0.35	5.92±0.26	Performance	2.838	.078

DISCUSSION

In tennis, serve is one of the most important components of scoring performance. Due to this importance, a number of studies have been conducted on the specific biomechanics of tennis serves (Abrams et al., 2011; Shim et al., 2006; Sheets et al., 2011; Whiteside et al., 2014). Tennis players have the most control over the game during the serve, which is probably the most significant stroke in the sport. For young tennis players, the goal of the current study was to measure the vertical height of the ball at the moment of ball impact and the front-to-back separation between the heel and the ball. The outcome demonstrated that there was no significant difference between the factors that affected the five tennis players' serves, both successfully and unsuccessfully. These outcomes are a result of the varying tennis levels and expertise of each player.

A comparison investigation of each player's sub-characteristics revealed that players A, B, and C had varying vertical impact heights based on their successes and failures. The varied pattern in the trend of changing the height of impact shows that each athlete has various sub-characteristics. Since the service motion is dependent on the storage and release of elastic energy, the dynamic nature of the stroke cannot be explained by a single, independent performance factor. The results of this study are consistent with the idea that player skills influence serve performance.

According to the United States Tennis Association (USTA; 2021), depth, height, direction, speed, and spin are the ball's five main controls, (Martin et al., 2013). The ability to produce tennis strokes with practice depends on mastering these controls. According to prior research, expert players (i.e., professionals) display more developed neuromuscular coordination patterns during the serve action than less experienced players (i.e., young athletes) do (Martin et al., 2014). In light of this, it is likely that a number of factors, including skilled players, contribute to serve skill. With regard to success and failure, the sub of A in particular displayed a difference in the body's overall tilt angle.

The failure chance was discovered to be approaching when the ball was excessively positioned in the forward-upward orientation. The height of the ball hit is directly related to the difference in angle of incidence according to success and failure in players A and B. In addition to comparing the distance between the ball and the net while serving, the angle of incidence is hypothesized to have an impact on the opponent's defensive strategy. The impact height had a tendency to be lower at successful serves than unsuccessful ones after 12 weeks of training, and the whole body's angle of inclination and incidence had a bigger angle at successful serves than at unsuccessful ones. Given that serving is among the hardest abilities to master, it would appear that skill level and serve performance are associated. Before to contact, tennis players must compensate at the distal (elbow, wrist) joints, which helps them adjust to the impact position and manage the projection angle (Whiteside et al., 2013).

Hence, in order to acquire the mechanical or perceptual skills necessary for the tennis serve, the

player must modify the server's performance and control the stochastic unpredictability of the ball contact position (Whiteside et al., 2013). As a result, the two-dimensional coordinate system used in this study was used to monitor the impact position of the ball according to the success (center, sideline) and failure of the serve, and the tilt angle of the entire body was examined. Also, based on the results of this study, it might be related to the stability required of a similar end position encountered at the tennis serve's ball contact stage. Participants in this study who played tennis demonstrated that, as in the previous study, positioning the ball forward enhanced the likelihood of success. The standardization of the height ratio should also be taken into consideration, even though the results of this study are similar to those of earlier investigations. It is clear that posture correction is necessary or has a greater chance of improving when athletes demonstrate statistical significance in each variable in serving time. Thus, the results of this research imply that tennis players, coaches, and associated researchers can easily develop models that can successfully serve and apply them in the real world.

In order to increase the vertical height of the ball, the distance between the heel and the front-to-back distance between the heel and the ball at impact, it is necessary to quantitatively measure the impact position of the ball and the inclination angle between the ball and trunk according to success (center and sideline) and failure in the tennis serve action. It was determined using a ratio. Using the two coordinates, the inclination angle was determined. Also, the tennis court standard and the ball's vertical position data were used to compute the angle of incidence.

Conclusion

In conclusion, the serve is a shot in a tennis game that initiates a point. The objective was to give each player useful quantitative information. Also, each player's measurement results were statistically presented in this study to identify the features of each player's tennis serve and the variables that influence that player. The success rate of the serve increased with the height of the ball's impact, however it varied for each player during the tennis serve. Despite the fact that the participants' ability levels varied greatly, there was not a statistically significant difference when taken as a whole.

It is believed that it is vital to check many variables through 3D analysis rather than 2D analysis and that further research on players with high sub-skills will provide more trustworthy data. Also, the outstanding players demonstrated results that were more evident than those expected after 12 weeks of flat serve instruction, whereas the less-than-excellent players exhibited outcomes that were comparable to those of the exceptional players. However, there was no statistically significant difference; as a result, the flat serve talent can be improved if trained using more extensive training and the traits discovered in this study. Future research might similarly train coaches on how to offer both autonomy-supportive and structured coaching programs focused on improving tennis serve skills (Cheon et al., 2024a,b).

Conflict of Interest

No potential conflict of interest was reported by the authors.

Ethics Statement

The research was approved by the Institutional Review Board. And informed consent was obtained from each subject before participation in the experiment (No, 1266/February/2022).

Author Contributions

Conception and design of the study, SH and YG; Data collection, SH; Data analysis and interpretation, SH; Drafting article and critical revision, YG; All authors have read and approved the published version of the manuscript.

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