Biomechanical Determinants And Their Relationship To Effectiveness Index Of Performing Backhand Stroke In Tennis As A Basis To Plan Specific Training Methods

[1]Mustafa Waleed Al-Obaidi, [2]Firas Qahtan Rajab, [3]Wisam Awni Saleh

*Corresponding author: mustafa.waleed@tu.edu.iq
[1,2,3]Faculty of Physical Education and Sports Sciences, Tikrit University

Abstract

The aim of this case study is to investigate kinematic determinants of ball, racket, and body center of gravity during backhand stroke in tennis, and their relationship to ball's launch and exit speed. It also examines angular kinematic determinants of body (body angles) during moments of performance and their relationship to ball's launch and exit speed. This study investigated kinematic determinants of body and striking arm during performance moments and their relationship to speed of ball release and release. The study sample consisted of a junior-level player (age 18, height 1.82 m, weight 75 kg, 10 years of training experience). Backhand stroke in tennis was filmed and analyzed using three high-speed GoPro Hero 6 cameras set to frequencies of 120 fps and 60 fps. Cameras (1) and (2) were set to 60 fps to study details of body connections, while camera (3) was set to 120 fps to study details of ball and release indicators from the racket. Three-dimensional analysis was performed using Skillspector software to extract kinematic variables of body, ball release indicators, kinematics of torso and striking arm connections, and center of gravity. Key findings height of ball at the moment of impact is affected by increasing ball's launch and exit velocity. The ball's launch velocity is affected by rate of the racket's basic horizontal acceleration distance. Increasing the racket's vertical acceleration distance leads to an increase in the ball's exit angle. Increasing the racket's net acceleration distance leads to an increase in the ball's exit angle, noting that the racket's net acceleration distance is affected by rate of the racket's basic vertical acceleration distance. The ball's launch and exit velocity are affected by angle of right ankle during initial basic acceleration of the racket and angle of right knee joint during the ball's launch and exit from the racket.

Introduction

The backhand drive stroke is the second fundamental stroke in tennis. It involves swinging the racket forward across the body and using the back of the racket to hit the ball, with the palm facing away during the follow-through. There are two commonly used variations of the backhand drive stroke : the one-handed backhand and the two-handed backhand. Each stroke has its

advantages and disadvantages, but professional players often use the two-handed backhand due to its effectiveness. (Rusdiana, Abdullah, Syahid, & Sport, 2022)

During the backhand drive stroke We observe several factors that contribute to effectiveness, such as speed of execution and directing the ball to land it in a location difficult for the opponent to reach. Executing the move quickly requires several factors, including body position, the movement of the torso and arms backward, applying Newton's Third Law by returning in the opposite direction to the ball, striking the ball with proper direction from the center of the racket, and follow-through (Akutagawa & Kojima, 2005; Rusdiana et al., 2022).

To direct the ball effectively, it's essential to adjust the angle at which the ball leaves the racket, as well as its speed. The duration of the stroke also plays a significant role in the ball's speed; the longer the stroke, the slower the speed, and vice versa. This is particularly important in tennis, especially with the backhand drive stroke . To achieve effective execution, proper technique must be observed during the backhand stroke. The player holds the racket from below, placing their thumb on the wide side, with their arm extended and the racket head above their wrist . The player then swings the racket backward, rotating their legs and shoulders to the left of the net, shifting their weight onto the back leg. This backward swing is followed by a forward swing, shifting the weight onto the front leg. The player swings forward again at the moment the ball touches the racket and continues the forward swing with force. Therefore, the most important points to consider for the backhand stroke skill are: proper sideways position ; early backswing ; short swing ; long forward swing ; no wrist twist ; hitting the ball at the right moment (racer parallel to the net and the ball at the highest point) ; natural arm position with the racket head not drooping downwards (approximately hip height) ; careful ball control ; and observing the opponent and their movements. (Bahamonde, 2005; D. Knudson, 2006; Stępień, Bober, & Zawadzki, 2011)

Previous studies have shown that only a few studies have analyzed the complete biomechanical performance of the variables of launch indicators, body center of gravity positions relative to the front foot, and the appropriate principal acceleration distance for the backhand skill in tennis – and the complete angular kinematic variables to describe the performance model during the critical moments of performance in the backhand skill, along with describing the kinematics of the quantities of motion of the trunk and arm joints (upper arm, forearm, and hand), body center of gravity, and the relationship of all of this to the speed of ball release (B. Elliott, Reid, & Crespo, 2003; BJBJSM Elliott, 2006; Reid & Elliott, 2002).

Research problem

A review of scientific studies and journals reveals a lack of research on the biomechanical determinants of the ball and racket, the position of the body's center of gravity, and body angles during performance. It is difficult to obtain comprehensive quantitative data on the kinematic and kinetic determinants and to study their relationship to the ball's release speed from the racket. Biomechanics plays a crucial role in evaluating athletic movements, which contributes to the training processes of both coaches and athletes.

Research Objectives

- Determining the kinematic parameters of the ball, racket, and the position of the body's center of gravity during the performance of the backhand stroke skill in tennis, and its relationship to the ball's launch and exit speed index .
- Analyzing the angular kinematic determinants of the body (joint angles) during moments of performance, and clarifying their relationship to the ball's launch and exit speed index .
- Studying the kinematic determinants of the body and striking arm during different performance phases, and their relationship to the ball launch and exit speed index .

Research Methodology

Descriptive-analytical method was used in field study style, as it was suitable for nature of research objectives. The sample was fitted with adhesive tags on the body using a whole-body model analysis template (18 anatomical points across all joints), with two additional template points added to the racket head and the ball. Basic and anthropometric measurements were performed on the player in the study sample, and the measurements for the study sample are listed below.

Table 1. Anthropometric measurements of the player in the study sample

No.	Anthropometric measurements	Right side	Left side
1	Arm length	44	43
2	Forearm length	29	29
3	Palm length	23	23
4	Arm length	67	66
5	Upper limb	90	91
6	Arm circumference	28	28
7	Thigh circumference	63	63
8	Lower limb length	98	98

Imaging and analysis procedures Capturing and Analysis Procedures

To refine the imaging procedures and three-dimensional biomechanical analysis of the two-handed backhand stroke skill in tennis, a preliminary study was conducted prior to the main study, aiming to refine this. The results of the preliminary study are as follows.

Exploratory study

The study was conducted on a tennis player on a regulation court using three high-speed GoPro Hero 6 cameras. The two-handed backhand stroke was performed six times, and the stroke was analyzed to ensure the objective acquisition of the variables under study. The aim was to determine the camera's field of view and dimensions. Determining the camera specifications and number. The most important finding is the necessity of using three cameras to film the backhand stroke in tennis using 3D technology. Two cameras are positioned to film the player's performance at a height of 1.10 meters and a distance of 5 meters from the player. The third

camera is placed on the opponent's court (0.25 meters high) to film the ball at the moment of impact. The cameras are set to a frequency of 120 frames per second to film the backhand stroke and the ball's impact with the ground.

Camera features Camera Specifications

3D motion capture was performed using two GoPro Hero 6 cameras , mounted at 45-degree angles to capture the player's movement while performing a two-handed backhand in tennis. The cameras were set to a frequency of 120 Hz. Frames per second .

Camera Setup

- Camera 1 is a front-facing, angled camera (45° angle from the front) on the player's right side .

- Camera 2 with a slanted rear angle (45° angle from the rear) on the same side .

- Camera 3 is positioned vertically on the opponent's field (0.25 meters high) to film the ball at the moment of impact with the ground.

- The cameras were installed at a height of 1.10 meters, and 5 meters away from the point of transmission.

Calibration Frame

A 3D drawing scale of $1 \times 1 \times 1$ meter dimensions was used, which was placed at the transmission performance site to determine spatial reference points and adjust video dimensions within the analysis software .

A three-dimensional scale was captured at the location where the player performed the backhand stroke, with a distance of 1 x 1 x 1 meter. The following figure shows the locations of the scale.

Camera 3   Camera 2   Camera 1

Figure (1) Locations of drawing scale

Sample Preparation

The study sample was prepared using adhesive labels on key anatomical points according to the Full Body Biomechanical Analysis model, where 18 [units/ points] were fixed . An anatomical point covering all the joints of the body, in addition to a point on the head of the racket and a point on the ball . Basic anthropometric measurements were also performed on the study sample.
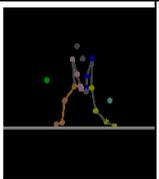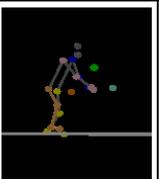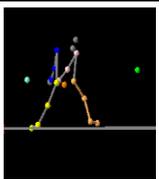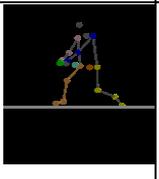
Motion Capture

Twelve attempts were recorded for the two-handed backhand stroke in tennis, where the player executed the stroke with both hands towards the opponent's court. The attempts were then processed for 3D biomechanical analysis, from which the best six were selected.

Analysis Procedures

The three-dimensional analysis was performed using the SkillSpector program , through which the key moments of the performance of the backhand stroke in tennis were analyzed during the preliminary, basic and final phases of the backhand stroke in tennis. Below is a table showing the performance analysis moments of the backhand stroke in tennis (stick figures).

Table 2. Performance Analysis Moments for the Backhand Skill (Actual Player Performance and Stick Forms of the Same Performance)

No.	Moments of backhand strike	Real performance			Rod shape resulting from analysis of actual performance		
1	Moment of onset of basic acceleration						
2	Moment of striking						
3	Moment the ball is launched and goes out						
4	Follow-up moment after the strike						
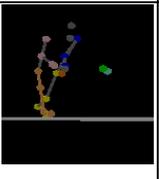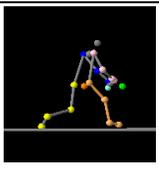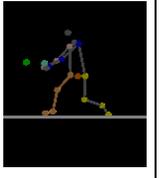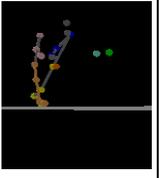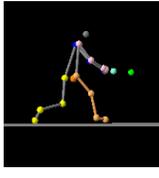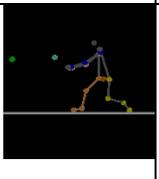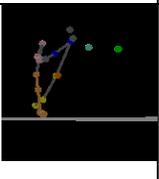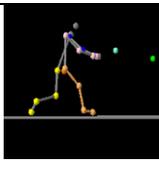
Study Variables

The study relied on a set of variables measured according to the research objectives, and these were classified as follows : Linear kinematic variable: variables of ball and bat launch and exit, displacements, speeds and body angles. Linear kinematic variables :Momentum quantities for all body joints.

Statistical Analyses

The statistical analyses were performed using the SPSS statistical analysis software.

Results

Table 3. Statistical description of kinematic variables (ball launch indicators - body center of gravity position - racket acceleration distance on levels)

No.	Kinematic variables	Measurement unit	Mean	St.d	Lowest value	Highest value
1	Speed of launch of the ball (VR ball)	M/s	27.45	7.14	19.41	33.07
2	Launch angle of the ball (RA ball)	Degree	6.33	5.13	2.00	12.00
3	Ball launch height (HR ball)	Meter	0.95	0.15	0.78	1.06
4	Position of the horizontal center of gravity of the body (lateral plane) relative to the fulcrum	Meter	-0.33	0.09	-0.39	-0.23
5	Position of the vertical body's center of gravity (transverse plane) relative to the fulcrum	Meter	0.65	0.11	0.55	0.76
6	Position of the body's transverse center of gravity (front plane) relative to the fulcrum	Meter	-0.02	0.12	-0.15	0.08
7	Horizontal acceleration distance of the bat during the basic striking phase	Meter	1.12	0.33	0.75	1.38
8	Vertical acceleration distance of the bat during the basic striking phase	Meter	0.13	0.17	-0.04	0.29
9	Lateral acceleration distance of bat during basic striking phase	Meter	-0.86	0.52	-1.44	-0.44

No.	Kinematic variables	Measurement unit	Mean	St.d	Lowest value	Highest value
10	Resulting acceleration distance of bat during basic striking phase	Meter	1.45	0.52	1.02	2.02

Table 4. Statistical description of angular kinematic variables at moment of start of basic acceleration of bat

No.	Angular kinematic variables	Measurement unit	Mean	St.d	Lowest value	Highest value
1	Right ankle joint angle	Degree	102	2	101	105
2	Right knee joint angle	Degree	139	7	133	146
3	Right hip joint angle	Degree	120	20	102	141
4	Right shoulder joint angle	Degree	50	2	48	52
5	Right elbow joint angle	Degree	170	4	166	174
6	Right wrist joint angle	Degree	167	12	155	178
7	Left ankle joint angle	Degree	96	11	85	106
8	Left knee joint angle	Degree	132	14	117	145
9	Left hip joint angle	Degree	152	3	150	155
10	Left shoulder joint angle	Degree	33	2	31	34
11	Left elbow joint angle	Degree	161	6	156	167
12	Left wrist joint angle	Degree	175	4	171	179

Table 5. Statistical description of angular kinematic variables of moment of impact

No.	Angular kinematic variables	Measurement unit	Mean	St.d	Lowest value	Highest value
1	Right ankle joint angle	Degree	115	4	111	118
2	Right knee joint angle	Degree	155	8	146	161

3	Right hip joint angle	Degree	132	18	111	145
4	Right shoulder joint angle	Degree	36	6	32	43
5	Right elbow joint angle	Degree	144	17	125	158
6	Right wrist joint angle	Degree	169	9	159	177
7	Left ankle joint angle	Degree	114	15	97	126
8	Left knee joint angle	Degree	123	4	118	126
9	Left hip joint angle	Degree	162	3	159	165
10	Left shoulder joint angle	Degree	48	8	42	57
11	Left elbow joint angle	Degree	148	9	137	154
12	Left wrist joint angle	Degree	166	12	154	177

Table 6. Statistical description of angular kinematic variables of moment of release and exit of ball from the racket

No.	Angular kinematic variables	Measurement unit	Mean	St.d	Lowest value	Highest value
1	Right ankle joint angle	Degree	117	3	114	120
2	Right knee joint angle	Degree	157	6	150	162
3	Right hip joint angle	Degree	136	15	119	146
4	Right shoulder joint angle	Degree	37	7	30	43
5	Right elbow joint angle	Degree	140	10	128	148
6	Right wrist joint angle	Degree	167	8	160	176
7	Left ankle joint angle	Degree	118	14	103	130
8	Left knee joint angle	Degree	123	3	120	126
9	Left hip joint angle	Degree	166	4	162	169
10	Left shoulder joint angle	Degree	52	9	45	62
11	Left elbow joint angle	Degree	150	4	145	153
12	Left wrist joint angle	Degree	160	2	158	161

Table 7. Statistical description of angular kinematic variables of follow-up moment after multiplication

No.	Angular kinematic variables	Measurement unit	Mean	St.d	Lowest value	Highest value
1	Right ankle joint angle	Degree	118	3	116	121
2	Right knee joint angle	Degree	157	5	151	160
3	Right hip joint angle	Degree	139	12	125	147
4	Right shoulder joint angle	Degree	41	7	33	46
5	Right elbow joint angle	Degree	143	2	142	145
6	Right wrist joint angle	Degree	169	5	163	173
7	Left ankle joint angle	Degree	120	13	106	132
8	Left knee joint angle	Degree	121	2	119	123
9	Left hip joint angle	Degree	168	5	164	173
10	Left shoulder joint angle	Degree	56	8	49	64
11	Left elbow joint angle	Degree	153	2	151	155
12	Left wrist joint angle	Degree	150	7	142	155

Table 8. Statistical description of kinetic variables of moment of start of basic acceleration of the bat

No.	Kinematic variables	Measurement unit	Mean	St.d	Lowest value	Highest value
1	Horizontal motion of the trunk	kg.m/s	20.33	0.86	19.34	20.91
2	Vertical momentum of the trunk	kg.m/s	3.75	1.62	1.88	4.79
3	Transverse motion of the trunk	kg.m/s	14.87	15.57	0.86	31.64
4	Net momentum of the trunk	kg.m/s	27.42	9.52	19.89	38.12
5	Horizontal movement of the arm	kg.m/s	3.79	1.07	3.06	5.01

6	Vertical motion of the arm	kg.m/s	0.23	0.33	0.03	0.61
7	Transverse motion of the arm	kg.m/s	2.21	1.39	0.98	3.72
8	Net mass of the arm	kg.m/s	4.54	1.12	3.27	5.38
9	Horizontal motion of the forearm	kg.m/s	3.54	0.92	2.61	4.46
10	Vertical motion of the forearm	kg.m/s	0.59	0.19	0.38	0.71
11	Transverse motion of the forearm	kg.m/s	1.31	0.66	0.70	2.00
12	Net motion of the forearm	kg.m/s	3.83	1.10	2.73	4.94
13	Horizontal hand movement quantity	kg.m/s	1.79	0.41	1.33	2.12
14	Vertical hand movement quantity	kg.m/s	0.40	0.16	0.22	0.53
15	The amount of lateral movement of the hand	kg.m/s	0.55	0.59	0.01	1.17
16	Total amount of hand movement	kg.m/s	1.96	0.57	1.35	2.48
17	Horizontal momentum of the body's center of gravity	kg.m/s	81.50	5.48	75.70	86.59
18	Vertical momentum of the body's center of gravity	kg.m/s	7.32	6.17	2.67	14.32
19	Lateral momentum of the body's center of gravity	kg.m/s	71.48	26.44	41.61	91.88
20	Net momentum of the body's center of gravity	kg.m/s	109.77	19.98	87.56	126.28

Table 9. Statistical description of kinetic variables of moment ball is struck

No.	Kinematic variables	Measurement unit	Mean	St.d	Lowest value	Highest value
1	Horizontal motion of the trunk	kg.m/s	16.48	7.94	7.81	23.38
2	Vertical momentum of the trunk	kg.m/s	6.61	7.17	0.72	14.59
3	Transverse motion of the trunk	kg.m/s	32.69	12.15	19.43	43.28
4	Net momentum of the trunk	kg.m/s	37.67	14.47	21.42	49.19

5	Horizontal movement of the arm	kg.m/s	1.12	1.68	0.15	3.05
6	Vertical motion of the arm	kg.m/s	0.96	0.98	0.05	1.99
7	Transverse motion of the arm	kg.m/s	7.66	2.01	5.76	9.76
8	Net mass of the arm	kg.m/s	8.00	1.76	6.58	9.96
9	Horizontal motion of the forearm	kg.m/s	4.95	1.58	3.31	6.46
10	Vertical motion of the forearm	kg.m/s	0.98	0.33	0.71	1.35
11	Transverse motion of the forearm	kg.m/s	4.67	0.97	3.57	5.41
12	Net motion of the forearm	kg.m/s	7.03	0.56	6.41	7.50
13	Horizontal hand movement quantity	kg.m/s	2.92	0.80	2.03	3.58
14	Vertical hand movement quantity	kg.m/s	0.67	0.22	0.49	0.92
15	The amount of lateral movement of the hand	kg.m/s	1.82	0.39	1.42	2.19
16	Total amount of hand movement	kg.m/s	3.55	0.65	2.79	3.96
17	Horizontal momentum of the body's center of gravity	kg.m/s	60.82	11.82	48.93	72.57
18	Vertical momentum of the body's center of gravity	kg.m/s	25.11	9.21	18.75	35.67
19	Lateral momentum of the body's center of gravity	kg.m/s	27.88	13.42	18.04	43.17
20	Net momentum of the body's center of gravity	kg.m/s	73.21	5.12	67.61	77.65

Table 10. Statistical description of kinetic variables of moment of release and exit of ball from the racket

No.	Angular kinematic variables	Measurement unit	Mean	St.d	Lowest value	Highest value
1	Horizontal motion of the trunk	kg.m/s	22.36	7.37	15.56	30.19
2	Vertical momentum of the trunk	kg.m/s	4.17	4.14	0.24	8.50
3	Transverse motion of the trunk	kg.m/s	31.87	2.04	29.60	33.55

No.	Angular kinematic variables	Measurement unit	Mean	St.d	Lowest value	Highest value
4	Net momentum of the trunk	kg.m/s	39.74	2.55	37.18	42.28
5	Horizontal movement of the arm	kg.m/s	1.33	0.41	1.06	1.80
6	Vertical motion of the arm	kg.m/s	0.94	0.57	0.31	1.41
7	Transverse motion of the arm	kg.m/s	6.33	1.25	5.25	7.69
8	Net mass of the arm	kg.m/s	6.57	1.18	5.54	7.85
9	Horizontal motion of the forearm	kg.m/s	3.19	1.73	2.05	5.18
10	Vertical motion of the forearm	kg.m/s	1.75	0.28	1.46	2.03
11	Transverse motion of the forearm	kg.m/s	4.82	1.19	3.51	5.85
12	Net motion of the forearm	kg.m/s	6.28	0.35	5.89	6.58
13	Horizontal hand movement quantity	kg.m/s	2.04	0.94	1.41	3.12
14	Vertical hand movement quantity	kg.m/s	1.11	0.15	0.95	1.20
15	The amount of lateral movement of the hand	kg.m/s	2.28	0.23	2.02	2.44
16	Total amount of hand movement	kg.m/s	3.33	0.51	2.97	3.91
17	Horizontal momentum of the body's center of gravity	kg.m/s	45.87	14.42	33.84	61.85
18	Vertical momentum of the body's center of gravity	kg.m/s	26.37	1.88	24.26	27.87
19	Lateral momentum of the body's center of gravity	kg.m/s	27.60	27.77	2.29	57.30
20	Net momentum of the body's center of gravity	kg.m/s	64.46	9.52	53.71	71.81

Table 11. Statistical description of kinetic variables of follow-up moment after multiplication

No.	Angular kinematic variables	Measurement unit	Mean	St.d	Lowest value	Highest value

No.	Angular kinematic variables	Measurement unit	Mean	St.d	Lowest value	Highest value
1	Horizontal motion of the trunk	kg.m/s	28.16	7.68	23.07	37.00
2	Vertical momentum of the trunk	kg.m/s	1.11	1.14	0.24	2.40
3	Transverse motion of the trunk	kg.m/s	26.89	7.25	21.66	35.17
4	Net momentum of the trunk	kg.m/s	39.60	6.03	32.73	44.01
5	Horizontal movement of the arm	kg.m/s	2.17	1.27	0.91	3.45
6	Vertical motion of the arm	kg.m/s	0.86	0.84	0.20	1.81
7	Transverse motion of the arm	kg.m/s	4.60	1.05	3.52	5.62
8	Net mass of the arm	kg.m/s	5.30	1.08	4.06	6.02
9	Horizontal motion of the forearm	kg.m/s	1.60	1.79	0.37	3.66
10	Vertical motion of the forearm	kg.m/s	2.63	0.52	2.05	3.03
11	Transverse motion of the forearm	kg.m/s	4.48	2.24	1.97	6.28
12	Net motion of the forearm	kg.m/s	5.91	0.75	5.14	6.65
13	Horizontal hand movement quantity	kg.m/s	1.11	1.25	0.04	2.49
14	Vertical hand movement quantity	kg.m/s	1.65	0.21	1.41	1.77
15	The amount of lateral movement of the hand	kg.m/s	2.23	1.01	1.09	3.02
16	Total amount of hand movement	kg.m/s	3.26	0.15	3.13	3.42
17	Horizontal momentum of the body's center of gravity	kg.m/s	32.13	19.70	18.76	54.75
18	Vertical momentum of the body's center of gravity	kg.m/s	23.51	5.82	18.27	29.78
19	Lateral momentum of the body's center of gravity	kg.m/s	36.36	30.81	13.65	71.43
20	Net momentum of the body's center of gravity	kg.m/s	60.46	15.76	44.56	76.08

Table 12. Matrix of correlation of kinematic variables (ball launch indicators - body center of gravity position - racket acceleration distance on levels) with launch and exit speed of ball from the racket.

Kinematic variables	Launch speed	Starting angle	High launch	horizontal center of gravity of the	vertical center of gravity of the	the transverse center of gravity of the	horizontal acceleration distance of	basic vertical acceleration distance of the racket	basic lateral acceleration distance of the racket	resultant acceleration distance of
Launch speed	1									
Starting angle	0.865	1								
High launch	.998*	0.835	1							
Position of the horizontal center of gravity of the body with the fulcrum	-0.346	0.170	-0.400	1						
Position of the vertical body's center of gravity with the fulcrum	0.713	0.266	0.752	-0.905	1					
Position of the body's transverse center of gravity with the fulcrum	0.758	0.329	0.794	-0.875	.998*	1				
Basic horizontal acceleration distance of the racket	1,000**	0.876	0.997	-0.327	0.698	0.744	1			
Basic vertical acceleration distance of the racket	0.897	.998*	0.870	0.104	0.330	0.391	0.906	1		
Basic lateral acceleration distance of the racket	0.476	0.853	0.425	0.660	-0.277	-0.213	0.494	0.816	1	
Basic resultant acceleration distance of the bat	0.854	1,000**	0.823	0.192	0.245	0.308	0.865	0.996	0.864	1

Table 13. Relationship between angular kinematic variables of body joints and variable of ball release and exit speed

No.	Angular kinematic variables	Measurement unit	Performance moments			
			Beginning of basic racket acceleration	Hit the ball	Ball is released and leaves the racket	Follow-up after hitting
1	Right ankle joint angle	Degree	.998*	0.293	0.956	0.807
2	Right knee joint angle	Degree	0.995	-0.007	1,000**	0.975

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No.	Angular kinematic variables	Measurement unit	Performance moments			
			Beginning of basic racket acceleration	Hit the ball	Ball is released and leaves the racket	Follow-up after hitting
3	Right hip joint angle	Degree	0.924	0.658	0.947	0.953
4	Right shoulder joint angle	Degree	0.681	-0.892	0.180	-0.359
5	Right elbow joint angle	Degree	0.896	0.627	0.892	-0.975
6	Right wrist joint angle	Degree	-0.639	-0.344	-0.822	-0.001
7	Left ankle joint angle	Degree	0.879	0.977	0.869	0.789
8	Left knee joint angle	Degree	-0.761	-0.896	-0.224	-0.224
9	Left hip joint angle	Degree	-0.883	-0.111	-0.451	-0.036
10	Left shoulder joint angle	Degree	0.586	0.036	0.499	0.334
11	Left elbow joint angle	Degree	0.945	0.695	0.892	0.224
12	Left wrist joint angle	Degree	0.963	-0.361	-0.883	-0.359

Discussion

According to in-depth studies in biomechanics and kinematic analysis, it is clear that the indicators of success in racket sports are related to the player's ability to produce the best indicators of starting performance, whether they are indicators of speed, starting angle, or starting height (Badura, 2010; Brody, Cross, & Lindsey, 2002; BC Elliott, Marshall, & Noffal , 1995; BJBJSM Elliott, 2006; Leigh, Gross, Li, & Yu, 2008).

In tennis specifically, performance characteristics vary in terms of position and speed produced by the opposing player, as well as the player's position, distance from the ball, and ability to achieve speeds in reaching the ball and executing the skill. In this research, we controlled these factors by serving the ball from the other court at a specific, fixed location while the player performed a backhand stroke with both hands. The researcher observed that the ball's launch height had a positive impact on the stroke. The higher the ball's launch height at the moment of impact, the greater the player's ability to control and transfer the force exerted from the body to the hand to the racket and then to the ball. This launch height averaged 0.5 m, with a maximum value of 1.06 m and a minimum value of 0.78 m, according to Tables 3 and 12 of the study, which is consistent with the studies of Roetert, Kovacs, Knudson, Groppel , & Journal, 2009; and Walshe, Wilson, & Ettema , 1998 .

Analyzing biomechanical studies, it was found that the impact and transfer of forces are related to preliminary and preparatory processes, perhaps the player's attempt to increase the acceleration distance (the greater the acceleration distance of the tool, which is the racket, the greater its power, with time being constant or decreasing). Analyzing the player's performance and finding correlation relationships, it was observed that there is a direct correlation between the horizontal acceleration distance of the racket during the basic stroke phase and the speed of the ball's release and exit from the racket. This is important during training phases because acceleration is important and requires working at angles of greater range of motion and at a specific time rhythm. We note that the value of the horizontal acceleration of the racket was 1.12 m, with a maximum value of 1.38 m and a minimum value of 0.75 m, according to Table 3 and 12, which is consistent with the studies of (Bartlett, 1992; BC Elliott, Overheu, Marsh, & Sport, 1988; Frossard, 2012; Hubbard & Cheng, 2007; Rusdiana et al., 2022).

Perhaps the vertical acceleration distance plays a positive role during matches in order to increase or decrease the angle of departure of the ball, depending on the purpose of the strike. We note during the statistical analyses that the vertical acceleration distance is directly related to the launch and departure angle of the ball, according to what was explained by the full correlation matrix of the ten kinematic variables in Table 12, where it is clear that the average vertical acceleration distance of the bat is 0.13 m , with a maximum value of 0.29 m and a minimum value of -0.04 m, according to Table 3, which is consistent with the kinematic equations for extracting and determining the launch angle index of the projectile (Hamill & Knutzen, 2006; Schmidtbleicher , 1992; Stępień et al., 2011).

Theoretically, the net acceleration distance of the bat has a significant role and impact on the launch and exit angle of the ball. However, it must be known that the net acceleration is the result of the resultant horizontal, vertical, and transverse accelerations. The net acceleration distance of the bat is 1.45 m, with a maximum value of 2.02 m and a minimum value of 1.02 m. Table 13 shows that the vertical acceleration had the greatest role in affecting the angle (BJBJSM Elliott, 2006; D. Knudson, 2006).

It is known that the forces produced need an ideal torque and smooth force transfer through the body's joints. By analyzing the results, it becomes clear that increasing the range of motion of the joints, especially the right leg, during the moments of the beginning of the basic acceleration of the racket and the launch and exit of the ball from the racket has a major role in increasing the speed rates of the ball, specifically the angle of the right ankle during the beginning of the basic acceleration of the racket and the angle of the right knee during the launch and exit of the ball from the racket, which achieved an average of 102 degrees and 157 degrees respectively, Table 4 and 6, which is consistent with (Goldmann et al., 2015; DVJJ o. AB Knudson, 1990; Reid & Elliott, 2002).

Proposed specific exercises

The researcher designed specific drills according to the characteristics of biomechanical determinants and based on the variables most related to achieving the speed of launching the ball, falling, and achieving the goal of the strike, as the specific drills are shown in the following table:

Table 14. Specific Training Exercises

No.	Training	Training objective	Mechanical objective	Drawing
1	Exercises to increase acceleration distance using resistance bands	Improving the resulting power during the movement path of the backhand stroke	Increasing the horizontal distance for acceleration	
2	Sprint drills (3, 5, or 7 steps), catching a medicine ball of varying weights, throwing with a backhand technique in tennis, and throwing at hip level.	Improving running speed and increasing the power produced in the direction of the backhand stroke in tennis	Improving the height of the stroke, eliminating performance at the hip level.	
3	Standing in front of a wall while throwing medicine balls of varying weights at the wall using a backhand technique in tennis, with a slight extension of the knee of the pivot leg.	Improving the strength of the muscles involved in the backhand stroke in tennis	Improving the range of motion of the pivot leg joints during the backhand stroke in tennis	

The backhand stroke is a crucial skill in tennis, requiring a high level of technical and physical ability to execute effectively. Developing this skill also necessitates measuring and evaluating the ball's speed, as well as the player's ability to transfer power by increasing the racket's horizontal acceleration distance. This involves extending the knee joints as the ball leaves the racket and the ankle of the front foot at the start of the racket's initial acceleration. Furthermore, it's essential to achieve synchronization between the ball's height at the moment of impact and the contact with the racket during a two-handed backhand stroke. The foundation for developing specific backhand stroke training in tennis rests on the following points: Exercises to increase the

horizontal acceleration distance of the racket during the basic acceleration phase before hitting. Sprint running drills and executing the backhand stroke with both hands and the ball achieving a flight higher than the level of the pelvis. Follow-up exercises and swinging of the striking arm with extension of the knee joint of the pivoting leg.

Conclusions

Based on the nature and objectives of the study, the researcher was able to reach the following conclusions:

First: Conclusions related to the player's body it becomes clear to us that there are positions of body angles that help to achieve good kinetic transfer of force by bending and extending the knee joint of the pivoting leg, which in turn helps to achieve good force propulsion, especially during the part related to the propulsion, by increasing the magnitudes of the knee joint angle during the strike and follow-up.

Second: Conclusions specific to the racket it is evident that a large rear swing is necessary to help increase the acceleration distance and lead to achieving a high striking speed.

Third: Conclusions specific to football it becomes clear to the researcher that to increase the speed of launch and exit of the ball, the player must work on providing quantities of power from the body and transferring them to the racket through the appropriate movement path, with the necessity of hitting the ball while it is at the level of the pelvis.

Recommendations

After implementing the study procedures and discussing the study results, the researcher has several recommendations:

Recommendations for coaches and players the need to implement the suggested specific training exercises in order to improve the effectiveness of the backhand stroke using both hands in tennis. Performing specific drills to increase the acceleration distance before hitting improves the speed at which the ball leaves the racket. Performing specific training exercises to increase the extension of the knee joint of the pivot leg improves the effectiveness of achieving the backhand stroke in tennis. Performing specific training exercises for sprint speed over short distances while executing the backhand stroke with both hands and the ball at hip level improves the effectiveness of achieving the backhand stroke.

Recommendations for biomechanical specialists the need to analyze the backhand stroke in tennis using three-dimensional analysis. Using high-speed cameras to achieve accuracy and objectivity in the results obtained. Relying on biomechanics specialists to establish the most important points of the analysis model for the body, bat, and ball. Specialists in biomechanics and kinesiology are relied upon to identify the most critical and influential moments in performance.

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