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Motion analysis of squash backhand drop shot – A kinematic analysis study

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Abstract. A hand-held sport characterises racket sports including squash, badminton, tennis, and table tennis. This study discusses squash and kinematics involved. There are varies shots can be played in squash including rail shot, boast shot, and backhand drop shot. Unlike other shots, the backhand drop shot requires control over the racket, control in swing speed and hitting angle, control in angular displacement of elbow, trunk and shoulder joints. With author's knowledge, there were not much research studies on squash kinematics. This study considered squash backhand drop shot and performed the kinematic analysis. Subjects (squash players) in the twenties participated, who had no injuries in the last six months. The players were separated into expert and novice groups. The kinematic analysis was performed through a 3D motion analysis system when the players are performing backhand drop shot. The results compare the displacement and velocities of trunk and racket, and the angular displacements and velocities of elbow and shoulder joints between the groups. Statistical analysis was performed using SPSS 20.0. The lap time required by the expert group was longer than that of the novice group. The expert group was used significantly ($p<0.001$) lower racket speed than that of the other group. Also, the expert group was maintained significantly ($p<0.001$) more extended elbow joint angle after the shot. Similarly, the expert group only used elbow extension just before the shot. However, the novice group played with the pre-extended elbow joint. These results conclude that the racket should move fast during the down-swing period and move slowly during the follow-through period, and the shoulder joint should extend before the elbow joint extension for the efficient backhand drop shot in squash game.

Keywords: Motion Analysis, Sports Biomechanics, Anterior-Posterior Displacement, Vertical and Lateral displacements

1. Introduction

The main skills of the squash game are a drive, drop, volley, boast, and lob, among these, the basic skill of the drive can be largely divided into a forehand drive and a backhand drive. In the match tactics analysis, among the basic skills, drive skill represents 60% of the total shots, leading the overall flow of the game, it is known that the drive skill account for 34% and the drop technique does 39% of the shots to decide the game.

In a study [1], the domestic male squash players playing skills were reported. The skills (rate in bracket) were: backhand drive (34.1%), forehand drive (16.8%), backhand volley (14%), forehand volley (6.8%), backhand drop (6.7%), forehand service (5.4%), forehand volley (4.6%), backhand lob (3.9%), backhand service (2.5%), backhand boast (2%), forehand lob (1.6%), and forehand boast (1.5%). In the same study, the rate of scoring in the whole game also reported. The scoring order (rate in brackets) were: backhand drive (20%), backhand volley (19.8%), backhand drop (12.3%), forehand drop (11%), forehand drive (8.8%), backhand lob (4.3%), forehand boast (2.2%), backhand boast (2.2%), forehand service (1.1%), forehand lob (1.1%), and backhand service (1.1%). In the whole games, out of 7059 times of total skills, backhand was 4456 times (63.1%), and forehand was 2603 (36.9%). Also, it appears to be the top three scoring skills were backhand drives, backhand volley, and backhand drop. Also, in the back-wall drive skill, the rate of the forehand drive was 41%, and the backhand drive was 59% [2]. Hence, a backhand drop shot seems to be an essential factor in the frequency of use and the score ratio.

Few studies in the past performed on squash game, kinematic analysis of squash stroke by Behm [3], Chapman [4] reported the factor affecting squash ball speed and stroke, Eliot et al. [5] studied the relationship between the rotary motion of upper extremity and speed of racket. Few Korean studies also performed on squash game. A kinematic analysis of forehand stroke [6, 7], backhand stroke and muscle activity [8], and upper limb segment [9]. Comparative kinematic analysis of close stance and open stance during forehand driving of elite squash player were studied [10]. Also, the accuracy of squash forehand swing timing according to age and speed conditions was studied [11]. However, very little research on the analysis of Squash drop shot was performed.

Meanwhile, in badminton, various researchers were studied main scoring skills and drop shot movement. In badminton, the technique that acts as the most significant obstacle to improvement is a drop shot, and analysis of drop shot movement is essential to improve the game [12]. Also, the badminton drop-shot shows that the ability to perform the swing motion the way as the smash by the moment of impact is an essential factor in the performance, and not exposing the attacking technique to the opponent is advantageous for scoring [13, 14]. Similarly, in squash game, the ability to keep the swing motion of the backhand drop shot until the impact, as with that of the backhand drive is advantageous for scoring and improved performance. However, it is recognised as the most robust shot to play, especially in squash game. Therefore, it is needed to research squash backhand drop shot to improve the performance of squash players.

The purpose of this study was to identify the differences between squash players (elite vs novice) backhand drop shot technical skills, through kinematic analysis. The data from this study provide an essential data for the players, coaches, and the member of the clubs for improving their squash game and performance.

2. Method of study

2.1. Subjects of study

The study's subjects included a sample of eight men in their 20s who have not been injured in the past six months. The criteria for selection were that the experts who have more than six years of experience and have a prize of more than 3rd place in the national championships and the non-skilled, ordinary college students who do not have a title and have less than three years of experience. The participant's physical characteristics are presented in Table 1.

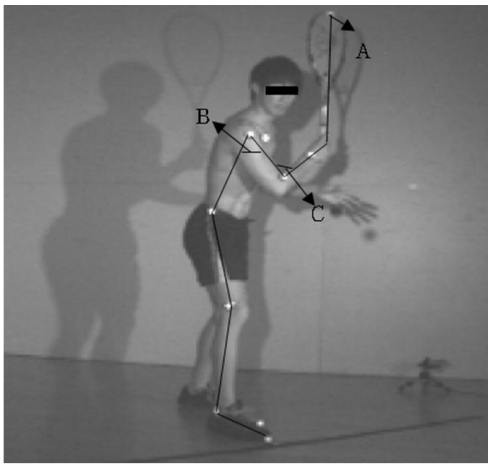
Table 1. Demographics details of participants.

Group	Age (years) AVG ± SD	Weight (kg) AVG ± SD	Height (cm) AVG ± SD	Experience (years) AVG ± SD
Novice	20.2±1.8	66.5±10.6	176.0±5.9	1.2±0.5
Expert	23.5±2.0	67.2±11.4	173.5±5.0	7.0±0.8

2.2 Experimental Procedure

The experiment was conducted on the squash court. The window was covered with a curtain for clear reflection of the marker, and the wall of the shooting place was covered with a black cloth to control the reflection of any light by other objects. The experiment was carried out with taking off the subject's top and wearing tight shorts.

In this study, the kinematic analysis of upper limb segment was performed by attaching 16 reflection markers to anatomical joints [9] and racket heads [15]. The measured anatomical movements of the upper extremities segments during squash backhand slice swings was: flexion/extension, adduction/abduction, internal rotation/external rotation of the upper arm, and flexion/extension, supination/pronation of the forearm and flexion/extension, adduction/abduction of the hand. Three high-speed cameras (Model: Basler 1394) was placed on the left side of the subject with 2 m spacing. The backhand drop shot was photographed more than ten times, and eight sets of data, satisfying both the researcher and the subject, were selected and stored. The shutter speed was 200 frames/second. The participants went sufficient practice and given 30 minutes rest before the test. With the watchword 'start', the assistant dropped the ball on the floor, and the subject was had swing the ball correctly, which was bouncing off the floor and passing the knee joint.



A - Racket Head. B - Shoulder Joint Angle
C - Elbow Joint Angle

Figure 1. Participants with markers attached backhand drop shot posture.

2.3. Analysis method

The variables calculated and analysed were time spent for each phase, racket displacement (X, Y, and Z axes), racket velocity, elbow joint displacement, elbow joint angular velocity, shoulder joint angular displacement, and shoulder joint angular velocity. The squash swing was divided into two phases downswing (Phase 1) and follow through (Phase 2) (Fig. 2). The event variables were analysed based on three periods: Top Swing (Event 1), Impact (Event 2) and Finish (Event 3).

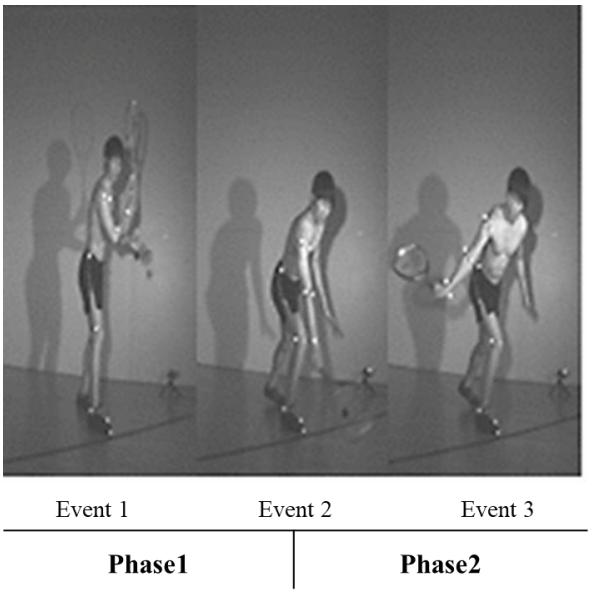


Figure 2. Definition of phases and events with backhand drop shot.

2.4. Processing data

The captured data were synchronised using 3D motion analysis program (APAS, Ariel). The unwanted frames were trimmed, and noise removal and smoothing were performed using digital filtering (6 Hz, lowpass-filter). The filtered two-dimensional data were transformed into three-dimensional data using a direct linear transformation (DLT) technique (Abdel-Aziz & Kararah, 1971). The APAS system calculated the variables of the smoothed data. The instantaneous velocity was calculated using the finite difference method. The racket velocity and displacement, elbow and shoulder joint's displacement and velocity data were statistically analysed using the independent-test in a statistical program (SPSS 17.0). The statistical significance level considered was 5 %.

3. Results and Discussion

3.1. The time spent

The time spent or lap time referred as duration required by the players to complete a squash backhand drop shot. The timings were measured as phase 1, phase 2, and total time by the novice and expert groups and tabulated (Table 2). The average time spent by the novice and expert players was 0.37 ± 0.06 sec, and 0.45 ± 0.10 sec, respectively. In phase 1 and phase 2, the expert players took additional 0.02 sec and 0.06 sec, respectively to complete the squash drop shot than the novice players.

Table 2. Lap time for squash backhand drop shot.

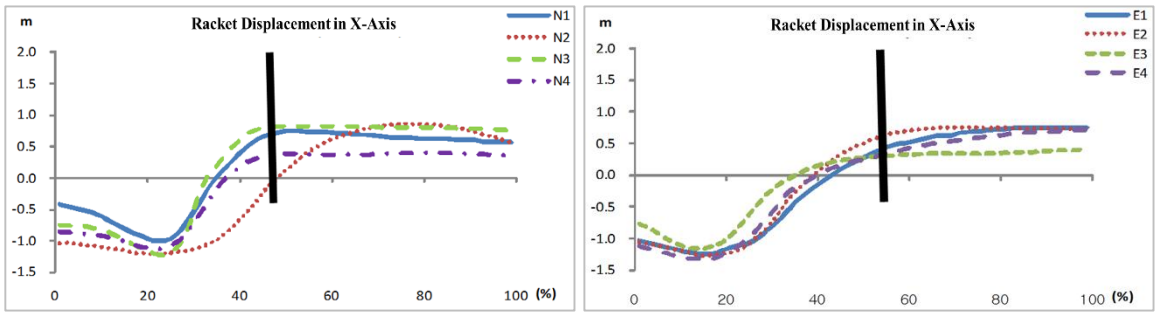
Group	Novice					Expert				
Phase	N1	N2	N3	N4	AVG ± SD	E1	E2	E3	E4	AVG ± SD
Phase 1	0.23	0.15	0.19	0.17	0.19 ± 0.03	0.23	0.15	0.18	0.26	0.21± 0.05
Phase 2	0.17	0.19	0.22	0.17	0.19 ± 0.02	0.26	0.28	0.17	0.28	0.25 ± 0.05
Total	0.40	0.34	0.41	0.34	0.37 ± 0.06	0.49	0.43	0.35	0.54	0.45 ± 0.10
N: Novice, E: Expert, AVG: Average, SD: Standard Deviation, Units: Second										

3.2 Racket displacement

The racket displacement data are essential data in the kinematic analysis. The racket displacement data was divided into X-axis (antero-posterior), Y-axis (vertical), and Z-axis (lateral). The descriptive data were graphically represented for all axes with Y-axis in the graph representing displacement data in metre, and in the X-axis time spent converted into a percentage (total time to complete the drop shot was 100%, and the impact point was mentioned as 50 % in the graph). The racket displacement data was statistically analysed and presented.

3.2.1 Antero-posterior racket displacement (X-axis displacement)

The statistical results for the antero-posterior racket displacement in the downswing period given (Table 3) and descriptive data presented in Fig. 3. The novice players showed statistically significantly ($p < 0.01$) higher (difference = 0.19 m) displacement than the expert players. The negative values represent backward, and the positive represent forward movement. The players moved (novice: 1.74 ± 0.03 m & expert: 1.54 ± 0.03 m) forward from the top-swing to the impact, and the impact was made at about (novice: 0.53 ± 0.30 m & 0.34 ± 0.13 m) on average. After the impact, to complete the drop shot the racket was moved backwards by (novice: -0.56 ± 0.17 m & expert: -0.65 ± 0.16 m) on average.



(a) (b)

Figure 3. (a) Novice and (b) expert players' antero-posterior racket displacement (X-axis)

Table 3. T-test result comparing novice and expert players' antero-posterior racket displacement.

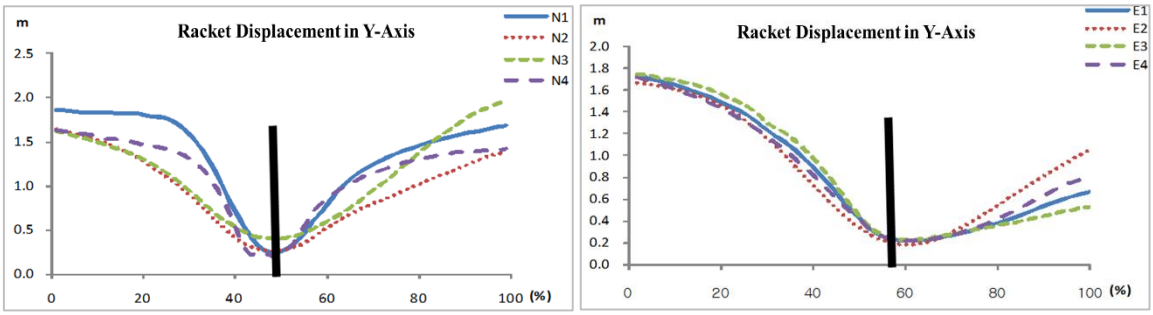
Group	Avg ± SD in cm	t
Novice	174.19 ± 3.10	t = 28.165 ***
Expert	154.23 ± 2.53	***$p < 0.001$
Difference	19.96 ± 0.71 (Novice > Expert)	

In the backhand drop shot movement, the expert group showed a high displacement in the follow-through period on the X-axis displacement, which is considered to be caused by the forward movement of the arm after the impact on the ball. In the follow-through period, the X-axis displacement of the expert racket was higher, and the time required by the experts for each period is longer than that of the novices.

3.2.2. Vertical (Y-axis) racket displacement

The statistical results of the vertical racket displacement in the downswing period given (Table 4) and descriptive data presented in Fig. 4. The novice players showed statistically significantly ($p < 0.01$) lower (difference = 0.15 m) displacement than the expert players. The negative values represent downward, and the positive represents the upward movement. The players moved (novice: -1.63 ± 0.11 m & expert: -1.48 ± 0.04 m) downward from the top-swing to the impact, and the impact was made at

about (novice: 0.28 ± 0.09 m & 0.34 ± 0.11 m) on average. After the impact, to complete the drop shot the racket was moved upward by (novice: 1.33 ± 0.20 m & expert: 0.48 ± 0.27 m) on average.



(a) (b)

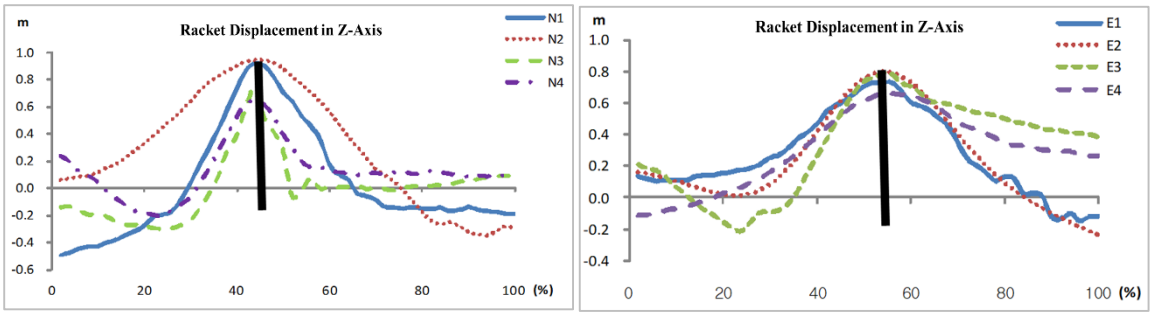
Figure 4. (a) Novice and (b) expert players' vertical racket displacement (Y-axis)

Table 4. T-test result comparing novice and expert players' vertical racket displacement.

Group	Avg ± SD in cm	t
Novice	-162.60 ± 11.17	t = -7.03 ***
Expert	-147.68 ± 4.38	***$p < 0.001$
Difference	-14.92 ± 2.12 (Novice > Expert)	

3.2.3. Lateral racket (Z-axis) displacement

The statistical results of the lateral racket displacement in the downswing period given (Table 5) and descriptive data presented in Fig. 5. The novice players showed statistically significantly ($p < 0.01$) higher (difference = 0.24 m) displacement than the expert players. The negative values represent left, and the positive represents the right side movement. The players moved (novice: 0.90 ± 0.08 m & expert: 0.65 ± 0.02 m) right direction from the top-swing to the impact, and the impact was made at about (novice: 0.57 ± 0.27 m & 0.70 ± 0.06 m) on average. After the impact, to complete the drop shot the racket was moved left direction by (novice: -0.64 ± 0.47 m & expert: 0.62 ± 0.33 m) on average.



(a) (b)

Figure 5. (a) Novice and (b) expert players' vertical racket displacement (Z-axis)

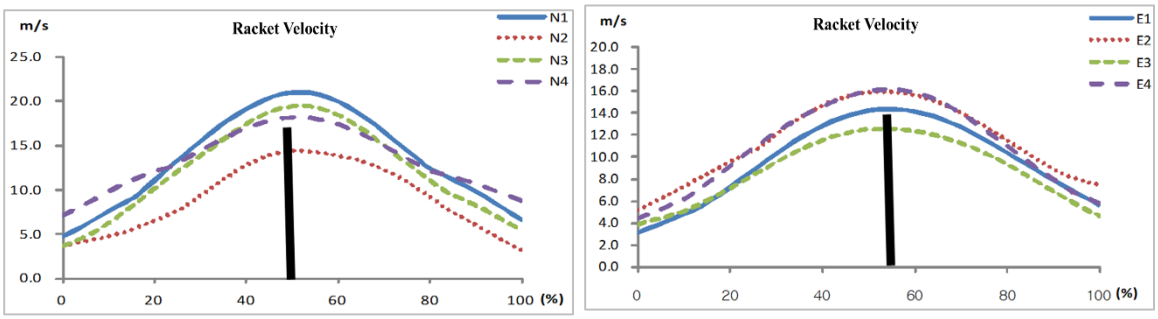
Table 5. T-test result comparing novice and expert players lateral racket displacement.

Group	Avg ± SD in cm	t
Novice	89.50 ± 7.99	t = -6.789 ***

Expert	65.30 ± 18.50	***$p < 0.001$
Difference	24.19 ± 3.56 (Novice > Expert)	

3.2.4. Racket velocity

The statistical results of the racket velocity given (Table 6) and descriptive data presented in Fig. 6. The novice players showed statistically significantly ($p < 0.01$) faster (difference = 3.37 m/s) racket velocity than the expert players. The racket velocity from the top-swing to the impact was (novice: 13.43 ± 2.96 m/s & expert: 10.64 ± 1.34 m/s), and the velocity during the impact was (novice: 17.93 ± 2.43 m/s & expert: 14.56 ± 1.43 m/s). After the impact, to complete the drop shot the racket was moved back with the velocity of (novice: -12.19 ± 2.38 m/s & expert: -8.89 ± 1.02 m/s).



(a) (b)

Figure 6. (a) Novice and (b) expert players' racket velocity

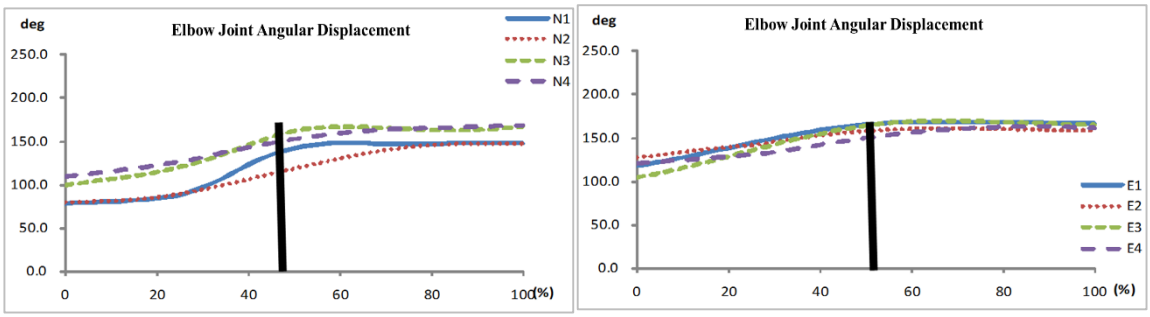
Table 6. T-test result comparing novice and expert players racket velocity.

Group	Avg ± SD in m/s	t
Novice	17.93 ± 2.43	t = 6.744 ***
Expert	14.56 ± 1.43	***$p < 0.001$
Difference	3.37 ± 0.49 (Novice > Expert)	

3.3. Elbow joint

3.3.1. Elbow joint angular displacement

The statistical results of the elbow joint angular displacement in the downswing period given (Table 7) and descriptive data presented in Fig. 7. The novice players showed statistically significantly ($p < 0.01$) higher (difference = 15.14 degrees) displacement than the expert players. During the backhand drop shot the players elbow joint angle was (novice: 61.93±2.74 degrees & expert: 46.78±3.99 degrees) at the downswing period, and the follow-through was (novice: 13.92±6.72 degrees & 3.74±3.91 degrees) on average. Concerning elbow angle alone, the player's elbow angle was (novice: 81.53±15.82 deg & expert: 111.88±3.30 deg) at the top-swing, at the impact (novice: 143.46±18.56 deg & expert: 158.66±7.29 deg). After the impact, to complete the drop shot the elbow angle was maintained by the players (novice: 157.38±11.84 deg & expert: 162.40±3.83 deg) on average.



(a) (b)

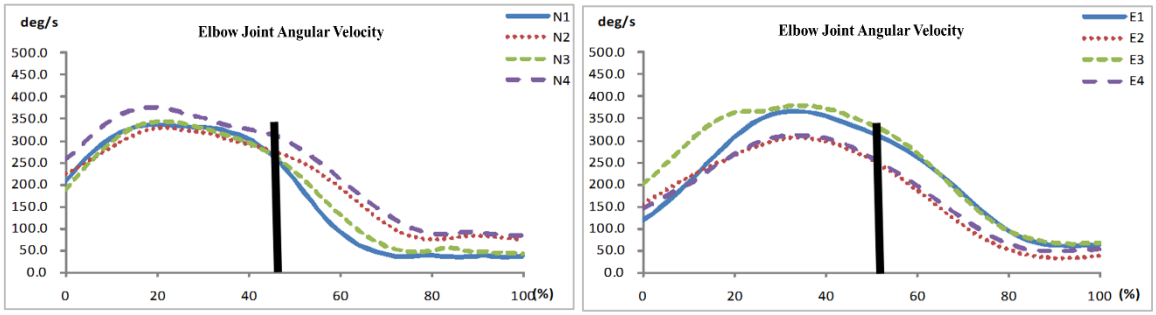
Figure 7. (a) Novice and (b) expert players' elbow joint angular displacement

Table 7. T-test result comparing novice and expert players elbow joint angular displacement.

Group	Avg ± SD in deg	t
Novice	61.93 ± 2.74	t = 41.029 ***
Expert	46.78 ± 3.99	***$p < 0.001$
Difference	15.14 ± 0.85 (Novice > Expert)	

3.3.2. Elbow joint angular velocity

The statistical results of the elbow joint angular velocity in the downswing period given (Table 8) and descriptive data presented in Fig. 8. The novice players showed statistically significantly ($p < 0.01$) faster (difference = 32.90 deg/s) angular velocity than the expert players. During the backhand drop shot, the players elbow joint angular velocity was (novice: 218.48±0.29 deg/s & expert: 153.89±0.34 deg/s) at the top-swing, at the impact (novice: 340.12±17.34 deg/s & expert: 307.21±28.43 deg/s). After the impact, to complete the drop shot the elbow joint angular velocity was maintained by the players (novice: 59.12±0.22 deg/s & expert: 54.29±0.13 deg/s) on average.



(a) (b)

Figure 8. (a) Novice and (b) expert players' elbow joint angular velocity

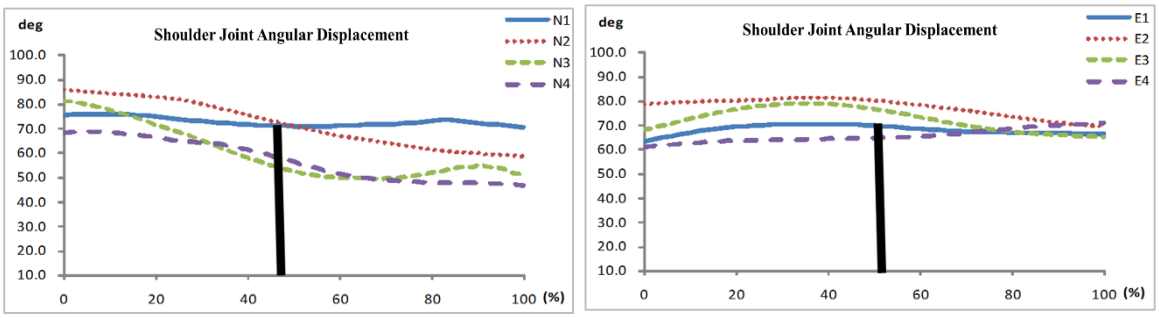
Table 8. T-test result comparing novice and expert players elbow joint angular velocity.

Group	Avg ± SD in deg/s	t
Novice	340.12±17.34	t = 5.589 ***
Expert	307.21±28.43	***$p < 0.001$
Difference	32.90 ± 5.88 (Novice > Expert)	

3.4. Shoulder joint

3.4.1. Shoulder joint angular displacement

The statistical results of the shoulder joint angular displacement in the downswing period given (Table 9) and descriptive data presented in Fig. 9. Concerning shoulder angle alone, the player's shoulder angle was (novice: 73.97±0.07 deg & expert: 64.74±0.01 deg) at the top-swing, at the impact (novice: 62.70±0.99 deg & expert: 72.76±0.08 deg). After the impact, to complete the drop shot the elbow angle was maintained by the players (novice: 56.65±0.11 deg & expert: 68.03±0.44 deg) on average. The novice players showed statistically significantly ($p < 0.01$) higher (difference = 3.24±0.32 degrees) displacement than the expert players. During the backhand drop shot the players shoulder joint angle was (novice: 11.27±1.69 degrees & expert: 8.02±0.07 degrees) at the downswing period, and the follow-through was (novice: 6.05±0.88 degrees & 4.73±0.04 degrees) on average.



(a) (b)

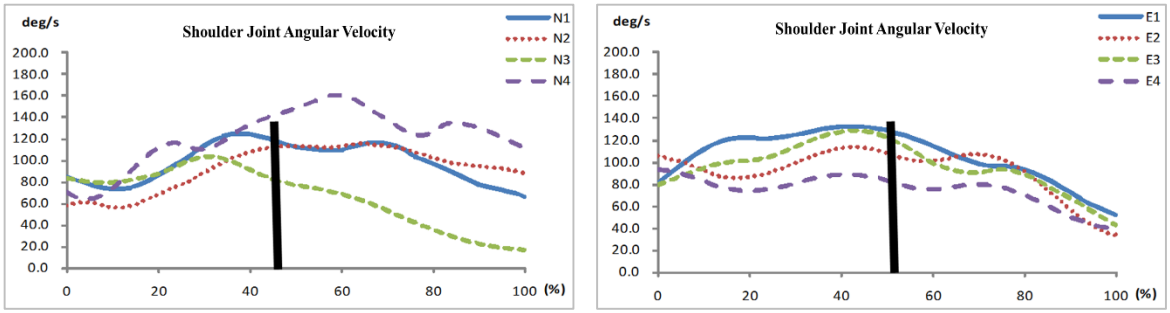
Figure 9. (a) Novice and (b) expert players' shoulder joint angular displacement

Table 9. T-test result comparing novice and expert players shoulder joint angular displacement.

Group	Avg ± SD in deg	t
Novice	11.27±1.69	t = 10.025 ***
Expert	8.02±0.07	***$p < 0.001$
Difference	3.24±0.32 (Novice > Expert)	

3.4.2. Shoulder joint angular velocity

The statistical results of the shoulder joint angular velocity in the downswing period given (Table 10) and descriptive data presented in Fig. 10. The novice players showed statistically significantly ($p < 0.01$) faster (difference = 8.36 deg/s) angular velocity than the expert players. During the backhand drop shot, the players shoulder joint angular velocity was (novice: 74.11±0.13 deg/s & expert: 89.86±0.13 deg/s) at the top-swing, and (novice: 119.97±9.56 deg/s & expert: 111.60±19.04 deg/s) at the impact. After the impact, to complete the drop shot the shoulder joint angular velocity was maintained by the players (novice: 70.42±0.40 deg/s & expert: 41.81±0.08 deg/s) on average.



(a) (b)

Figure 10. (a) Novice and (b) expert players' shoulder joint angular velocity

Table 10. T-test result comparing novice and expert players shoulder joint angular velocity

Group	Avg ± SD in deg/s	t
Novice	119.97±9.56	t = 2.534**
Expert	111.60±16.04	***$p < 0.05$
Difference	8.36±3.30 (Novice > Expert)	

4. Discussion

A hand-held sport characterises racket sports including squash, badminton, tennis, and table tennis. This study discusses squash and kinematics involved. Unlike other shots, the backhand drop shot requires control over the racket, control in swing speed and hitting angle, control in angular displacement of elbow, trunk and shoulder joints. With author's knowledge, there were not much research studies on squash kinematics. This study considered squash backhand drop shot and performed the kinematic analysis.

The expert group showed longer top-swing motion for impact than the novice group. Also little longer to finish movement after the impact than the novice group. This result conveys the expert players showed a relatively slower swing at each phase than the novice group. Overall backhand drop shot, the expert players took extra time to complete top swing, impact and down swing movement. These timing gave them the possibility for the accurate impact of the squash ball. Therefore, the novice players need to practice by considering this method.

During the backhand drop shot movement, the expert group showed a high displacement in the follow-through period on the racket displacement, which caused by the forward movement of the arm after the impact by the advancing direction of the ball. The time required by the experts for each period is longer than that of the novices, which is considered that the experts have sufficient time for ready poses before the impact and also has the long-timed follow-through after the impact.

The novice group maintained the faster racket velocity (13.43±2.96 m/s) than the expert group (10.64±1.34 m/s) in the down-swing. The expert group was used significantly ($p<0.001$) lower racket speed than that of the other group. Also, the novice group maintained faster racket velocity (12.19±2.38 m/s) at the follow-through than the expert group (8.89±1.02 m/s). These reduced velocity confirm the inexperience of novice groups and also this result stresses the necessity of more practice for the novice group.

The novice group maintained higher elbow joints angular displacement than that of the expert group in both down-swing and follow-through period. The novice group kept the higher shoulder joint angular displacement than that of the expert group in the down-swing period. However, the expert group kept the higher shoulder joint angular displacement than that of the follow-through period. The reason could be the experts' moves the shoulder joint little forward after impact, according to the direction of the ball. Also, the expert group extended their shoulder just before the impact. Also, the expert group was

maintained significantly ($p<0.001$) more extended elbow joint angle after the shot. Similarly, the expert group only used elbow extension just before the shot. However, the novice group played with the pre-extended elbow joint.

These results conclude that the racket should move fast during the down-swing period and move slowly during the follow-through period, and the shoulder joint should extend before the elbow joint extension for the efficient backhand drop shot in squash game. However, it is difficult to generalise the result of this study to the whole population, since, the sample size is small. Future research should consider statistically significant sample size. However, the result presented in this study helps to improve the technique of the novice squash players, especially for the backhand drop shot.

5. Conclusion

This study discussed the kinematics involved in squash backhand drop shot with a group of novice and expert players. The kinematic analysis was performed through a 3D motion analysis system. The results compared the displacement and velocities of elbow and shoulder joints and also racket velocity and displacement between the groups. The lap time required by the expert group was longer than that of the novice group. The expert group was used significantly ($p<0.001$) lower racket speed than that of the other group. Also, the expert group was maintained significantly ($p<0.001$) more extended elbow joint angle after the shot. Similarly, the expert group only used elbow extension just before the shot. However, the novice group played with the pre-extended elbow joint. It is concluded that while playing a backhand drop shot in squash game, it is needed to maintain fast racket movement during the down-swing and relatively slower flow in the follow-through periods. Also, the shoulder should extend before the extension of the elbow joint for an efficient shot. These result could also be the primary data for the squash players and coaches for the improvement of the play technique and development of the game.

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