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RESEARCH

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Differences in backcourt forehand clear stroke between novice players and experienced badminton players: based on body segment acceleration data

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Abstract

Background Backcourt forehand clear stroke is a fundamental technique in badminton, but the biomechanical differences between novice and experienced players are not fully understood. This study aimed to compare the kinematic characteristics of body segment acceleration during the backcourt forehand clear stroke between these two groups.

Methods Forty-five participants (22 novice players with less than 2 years of experience and 23 experienced players with over 5 years of competitive experience) were placed with wireless accelerometers on key body segments (foot, calf, thigh, hip, shoulder, upper arm, forearm). Each participant performed 5 backcourt forehand clear strokes, and acceleration data were collected at 100 Hz. The mean values from the 5 repetitions were used for statistical analysis to ensure reliability and reduce variability.

Results The results revealed significant differences in movement patterns between the groups. Novices exhibited greater ranges of motion (ROMs) in most body segments, particularly at the hip, thigh, calf, and shoulder, across the x, y, and z axes ($p < 0.05$). Additionally, novices showed higher maximum and minimum accelerations ($p < 0.05$).

Conclusion These findings suggest that experienced players achieve more efficient movement patterns through refined motor control and reduced excessive motion. This research provides valuable insights for coaching interventions and technique refinement in badminton training programs, particularly for developing players.

Keywords Badminton biomechanics, Motion analysis, Clear stroke, Motor control, Sports performance

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Background

Badminton is one of the most popular racket sports worldwide, requiring players to demonstrate complex technical skills, tactical awareness, and physical capabilities [1]. Among various badminton techniques, the backcourt forehand clear stroke is considered a fundamental yet crucial skill that players must master, as it allows them to maintain defensive positions while creating opportunities for offensive play [2]. The execution of backcourt forehand clear strokes involves coordinated movements of multiple body segments, from the lower extremities through the trunk to the upper limbs [3, 4]. Research has shown that successful performance of this technique requires proper timing, appropriate force generation, and efficient energy transfer between body segments [4, 5].

Biomechanical studies of badminton strokes have highlighted differences in movement patterns between experienced and novice players [2, 6]. For example, professional players exhibit superior lower limb coordination and more efficient weight transfer during strokes [2]. Similar patterns are observed in other racket sports, such as tennis, where experts demonstrate distinct wrist kinematics compared with novices [7]. Understanding these differences is vital for several reasons: it enables coaches to design more effective training programs, helps in injury prevention by identifying improper techniques [3, 8], and supports evidence-based coaching methods that accelerate skill acquisition in novices [5]. However, while research has focused primarily on upper limb kinematics during strokes, the role of whole-body coordination and the contributions of different body segments remain understudied, particularly in the context of acceleration data from multiple body segments [9].

The rise of inertial measurement units (IMUs) has facilitated more detailed analysis of player movements. IMUs offer precise acceleration data from different body segments, enabling researchers to quantify movement patterns and identify skill-related differences between players [10–12]. In other sports, such as soccer and basketball, acceleration patterns have been linked to performance outcomes and injury risk [13, 14]. Similar studies in volleyball have revealed that experienced players exhibit more efficient landing kinematics and better control of body segments [15]. These findings suggest that experience enhances movement efficiency, leading to more controlled and optimized performance.

Table 1 Basic information of the participants

	Experienced group	Novice group	*p* value
Participants (n)	23	22	-
Age (years)	22.48 ± 2.69	21.88 ± 1.69	0.374
Height (cm)	179 ± 3.21	180 ± 2.17	0.226
Weight (kg)	74.89 ± 6.83	75.22 ± 6.78	0.872
Badminton training (h/week)	6.5 ± 2.0	2.0 ± 0.5	< 0.05
Badminton experience (years)	10 ± 2.5	1.5 ± 0.5	< 0.05

* *p* values were determined via independent t tests

In badminton, most research has focused on upper limb biomechanics during strokes, with limited attention given to the acceleration of whole-body segments. Although studies have explored aspects such as foot movement patterns and trunk acceleration [2, 3], there is a notable gap in understanding how body segment accelerations differ between novice players and experienced players during the backcourt forehand clear stroke. Given that experienced athletes often develop sport-specific movement adaptations [7, 15], similar changes are likely to occur in badminton players. Therefore, this study aims to investigate the differences in body segment acceleration during backcourt forehand clear strokes between novice and experienced badminton players. By using IMU technology to collect acceleration data from multiple body segments, we seek to identify key characteristics that differentiate skilled performance from novice execution. Specifically, we hypothesize that experienced players will demonstrate lower acceleration fluctuations and greater movement stability across body segments compared to novice players.

Methods

Study design

The study was an observational study design to compare the differences in backcourt forehand clear stroke between novice players and experienced badminton players. Ethical Committee approval was granted by the Beijing Sport University (Approval No. 2023073 H) and all methods were performed in accordance with the institution's set guidelines and regulations. Following this, participants from badminton club were invited to take part in the study. Based on previous studies investigating biomechanical differences between skill levels in badminton [16], we anticipated a large effect size (Cohen's d = 0.75–0.92). A priori power analysis using G*Power (v. 3.1), indicated a total sample size of 18 participants would yield acceptable power of (ANOVA: Fixed effects, omnibus, one-way, Effect size f = 0.75, α err prob = 0.05, Power = 0.80, number of groups = 2).

Participants

In this study, 45 male badminton players (22 novice and 23 experienced, Table 1) were recruited. The inclusion criteria for experienced players were to practice badminton at least twice a week and to have more than 5 years of competitive experience. The inclusion criterion for novice players was having learned badminton in less than 2 years. The participants in both groups had no history of musculoskeletal injuries, such as fractures, sprains, or tendon injuries, in the past six months, ensuring that the data collected accurately reflected their athletic performance without the influence of previous injuries. All participants provided informed consent prior to participation. Demographic information, including age, height, weight, and years of training experience, was recorded for analysis. The participants were screened to confirm eligibility.

Procedure

Each participant performed the forehand clear stroke in a badminton court. Prior to testing, all participants underwent a standardized warm-up routine consisting of 15 min of light aerobic activity followed by dynamic stretches specific to badminton movements. Following the warm-up, the participants were instructed to perform 5 repetitions of the badminton forehand clear stroke, aiming to replicate their usual stroke technique. The participants were instructed to execute the stroke with maximal effort, ensuring consistency in racket type, shuttle, and contact points across trials. The performance of each participant was recorded via IMUs and high-speed cameras (Canon, Tokyo, Japan, 120 fps), which were synchronized to provide comprehensive data for kinematic analysis. The mean values from the 5 repetitions of the forehand clear stroke were used for subsequent statistical analysis to ensure reliability and reduce variability.

Fig. 1 The placement of the IMUs

Data collection and instrument

Data were collected via the Perception Neuron® inertial measurement system (NOITOM, Beijing, China, 100 Hz), which utilizes 17 miniature IMUs. Each IMU (measuring 12.5 mm × 13.1 mm × 4.3 mm) integrates a 3-axis gyroscope, 3-axis magnetometer, and 3-axis accelerometer. These IMUs were managed via Axis Studio software, which generated a 3D model of the human body after a single static calibration. The placement of the IMUs is illustrated in Fig. 1. Prior to testing, a comprehensive calibration was performed according to the manufacturer's recommended procedure, which consists of the following sequence: A-Pose (standing in a neutral position with the shoulders relaxed and the arms hanging naturally by the sides), T-Pose (standing straight with arms extended horizontally, palms facing forward, ensuring that the arms were perpendicular to the ground), and W-Pose Walking (returning to the A-pose position and initiating a natural walking pattern while maintaining consistent direction with the initial A-pose). This standardized calibration ensured accurate spatial orientation of all sensors. Upon completion of the calibration, participants proceeded to perform the forehand clear stroke tests. Each participant executed 5 repetitions of the forehand clear stroke with maximal effort, the IMUs and high-speed cameras (Canon, Tokyo, Japan, 120 fps) simultaneously recorded the motion data, ensuring comprehensive and synchronized kinematic analysis. To ensure temporal alignment between the IMU system and high-speed cameras, a time-stamp synchronization protocol was implemented. Before each trial, participants performed a distinct trigger movement (rapid elevation of the right hand), which was identifiable in both the IMU acceleration data and high-speed camera footage. By identifying this common event in both data streams, we calculated the time offset and adjusted the data accordingly, ensuring precise synchronization between the two systems with an error margin of less than ± 10 ms. The high-speed cameras were setup to: (1) verify the accurate placement of IMUs on anatomical landmarks; (2) precisely identify the initiation and termination points of each stroke for proper temporal windowing of IMU data; (3) provide visual confirmation of correct technical execution across trials; and (4) assist in the identification and exclusion of anomalous data resulting from potential sensor displacement or interference.

Data analysis

The data collected by the IMU system were processed through Axis Studio software, where they first underwent Kalman filtering. The filtered data were then exported in BVH file format. These data were subsequently processed by the proprietary algorithm library built into the IMU system. Here, the system's fusion algorithm combines data from the accelerometer, gyroscope, and magnetometer to interpret and convert the raw data into information representing the acceleration of human motion. The processed data were saved in CSV format for further analysis. The IMU system collected data in parallel at a sampling rate of 100 Hz.

A linear trend refers to a steady increase or decrease in data values over time. In the IMU system, this is typically caused by a constant bias or drift in the accelerometer's measurements, resulting in a small error that accumulates over time, especially during double integration, leading to a systematic deviation. To mitigate this error, the linear trend can be removed from the data, allowing for a clearer focus on actual fluctuations. One simple method to remove the linear trend is by processing the acceleration data so that its mean value becomes zero. The formula for zero-mean processing is as follows:

$$a_{av} = \frac{\sum_{i=0}^{N} a_i}{N}$$

$$A_i = a_i - a_{av}(i = 0,1,2,3\ldots N)$$

In the IMU, the triaxial accelerometer registers gravitational acceleration (g) along the axis perpendicular to the ground when stationary. During movement, the vertical component of the accelerometer remains constant, influencing the output data of the triaxial accelerometer. To eliminate the effect of gravitational acceleration, the study uses angular velocity values collected from the gyroscope sensor, combined with trigonometric principles, to remove the influence of g on each axis. The formula for removing gravitational acceleration is as follows:

$$A(t) = a_{\text{out}}(t) - g * cos\theta(t)$$

The acceleration curves obtained from the IMU system were aligned at the point of the maximum knee flexion angle and trimmed to the same time range via Python software. The time for each trial was standardized to 100% of the movement cycle.

Statistical analysis

Data analysis was conducted via SPSS (version 25.0) and Python (version 3.9). Calculations were performed separately for each test action, body segment, and movement plane (sagittal, frontal, and transverse) on the dominant side. For each participant, the average of five test trials was computed, as well as the overall average for all participants. All parameters are reported as means ± standard deviations.

Prior to applying inferential statistics, we assessed the distribution of our data for normality using the Shapiro-Wilk test and examined homogeneity of variance using Levene's test. For variables where these assumptions were met ($p > 0.05$), one-way analysis of variance (ANOVA) was used to determine significant differences between groups, with degrees of freedom of 1 between groups and 43 within groups. For variables that violated assumptions of normality or homoscedasticity (Shapiro-Wilk test or Levene's test with $p < 0.05$), we employed the non-parametric Mann-Whitney U test as an alternative. The significance level for all statistical tests was set at $\alpha = 0.05$, and 95% confidence intervals (CI) were calculated for all mean differences to assess the precision of the estimated differences between groups.

The key variables analyzed included the maximum acceleration, minimum acceleration, and range of acceleration during the motion period. To analyze movement characteristics, we calculated the rate of change in total acceleration for each body segment. First, the total acceleration was computed as the magnitude of the three-dimensional acceleration vector for each sensor. Then, a Gaussian filter ($\sigma = 2$) was applied to smooth the acceleration data. Finally, we calculated the temporal derivative of the smoothed acceleration data to obtain the rate of change in acceleration, which reveals the dynamic changes in movement intensity. The data were normalized to 100 frames to facilitate comparison between trials. Positive values indicate increasing acceleration, while negative values represent deceleration phases of the movement.

Results

Range of motion (ROM) accelerations

The ROM in body segment acceleration significantly differed between novice players and experienced players, with novices consistently showing higher values across most body segments (see Table 2a, 2b). For the hip, novices demonstrated greater ROMs on the X-axis ($F_{(1, 43)} = 15.23$, $p < 0.05$, 95% CI [-0.69, -0.21]), Y-axis ($F_{(1, 43)} = 14.89$, $p < 0.05$, 95% CI [-1.22, -0.16]), and Z-axis ($F_{(1, 43)} = 13.67$, $p < 0.05$, 95% CI [-0.68, -0.06]). Similar trends were observed in the thigh, where novices had significantly greater ROMs on the X-axis ($F_{(1, 43)} = 16.78$, $p < 0.05$, 95% CI [-1.15, -0.19]), Y-axis ($F_{(1, 43)} = 17.23$, $p < 0.05$, 95% CI [-1.54, -0.62]), and Z-axis ($F_{(1, 43)} = 15.92$, $p < 0.05$, 95% CI [-1.19, -0.40]). In the calf, ROM differences were evident on the X-axis ($F_{(1, 43)} = 14.56$, $p < 0.05$, 95% CI [-1.80, -0.29]), Y-axis ($F_{(1, 43)} = 13.89$, $p < 0.05$, 95% CI [-1.40, -0.36]), and Z-axis ($F_{(1, 43)} = 16.34$, $p < 0.05$, 95% CI [-1.62, -0.78]). Novices also displayed greater shoulder ROM on the X-axis ($F_{(1, 43)} = 12.34$, $p < 0.05$, 95% CI [-1.06, -0.09]) and Y-axis ($F_{(1, 43)} = 13.56$, $p < 0.05$, 95% CI [-1.88, -0.32]). However, for the upper arm, experienced players had a greater ROM on the X-axis ($F_{(1, 43)} = 18.45$, $p < 0.05$, 95% CI [2.15, 4.37]), whereas novice players had a greater

Table 2 (**a**). Comparison of lower limb acceleration characteristics between novice and experienced badminton players. **b**. Comparison of upper limb acceleration characteristics between novice and experienced badminton players

Part		Novice			Experienced			Mean difference(95%CI)		
		ROM	Min	Max	ROM	Min	Max	ROM	Min	Max
a										
Hip	X	1.36 ± 0.53	-0.69 ± 0.28	0.66 ± 0.26	0.91 ± 0.24	-0.39 ± 0.05	0.52 ± 0.22	-0.44(-0.69, -0.21) *	0.31(0.19,0.43)*	-0.14(-0.29,0. 00)
	Y	2.08 ± 1.18	-1.16 ± 0.70	0.95 ± 0.45	1.43 ± 0.61	-0.66 ± 0.35	0.77 ± 0.28	-0.69(-1.22, -1.56) *	0.50(0.18,0.83)*	-0.18(-0.41, -0.04)
	Z	1.39 ± 0.49	-0.63 ± 0.19	0.75 ± 0.34	1.02 ± 1.51	-0.49 ± 0.27	0.53 ± 0.30	-0.37(-0.68, -0.06) *	0.14(0.01,0.28)	-0.22(-0.42, -0.03)*
Thigh	X	2.18 ± 0.80	-1.38 ± 0.68	0.80 ± 0.24	1.51 ± 0.84	-0.77 ± 0.35	0.74 ± 0.55	-0.67(-1.15, -0.19) *	0.62(0.30,0.94) *	-0.05(-0.30, -0.37)
	Y	2.19 ± 0.99	-1.03 ± 0.66	1.15 ± 0.47	1.11 ± 0.51	-0.54 ± 0.34	0.57 ± 0.18	-1.08(-1.54, -0.62) *	0.50(0.19,0.81) *	-0.58(-0.79,0.21)
	Z	2.12 ± 0.90	-0.93 ± 0.35	1.19 ± 0.62	1.32 ± 0.31	-0.70 ± 0.22	0.62 ± 0.18	-0.80(-1.19, -0.40) *	0.22(0.06,0.40) *	-0.57(-0.85, -0.29) *
Calf	X	2.80 ± 0.83	-1.44 ± 0.40	1.35 ± 0.53	1.76 ± 1.24	-0.75 ± 0.25	1.00 ± 0.54	-1.05(-1.80,0.29) *	0.70(0.50,0.89) *	-0.35(-1.03,0.34)
	Y	2.12 ± 1.11	-1.00 ± 0.64	1.12 ± 0.51	1.25 ± 0.56	-0.66 ± 0.54	0.58 ± 0.16	-0.88(-1.40, -0.36) *	0.34(-0.01,0.69)	-0.54-0.68, -0.31)
	Z	2.80 ± 0.88	-1.64 ± 0.65	1.16 ± 0.37	1.60 ± 0.49	-0.93 ± 0.30	0.66 ± 0.21	-1.20(-1.62, -0.78) *	-0.12(-2.22,1.98) *	-0.49(-0.68, -0.32)
Foot	X	4.05 ± 1.83	-1.84 ± 1.22	2.21 ± 0.76	4.17 ± 1.36	-1.85 ± 0.89	2.31 ± 1.10	0.12(--0.83,1.06)	-0.02(-0.65,0.61)	0.10(-0.47, -0.67
	Y	3.35 ± 0.97	-1.41 ± 0.46	1.93 ± 0.96	3.18 ± 0.91	-1.09 ± 0.44	2.09 ± 0.72	-0.17(-0.72,0.38)	0.33(0.06,0.59) *	0.15(-0.36,0.67)
	Z	5.82 ± 1.90	-2.93 ± 1.27	2.89 ± 1.17	2.60 ± 1.23	-1.50 ± 0.94	1.10 ± 0.46	-3.22(-4.16, -2.28)	1.44(0.78,2.09)	-1.78(-2.32, -1.24)
b										
Shoulder	X	2.08 ± 1.05	-0.92 ± 0.48	1.16 ± 0.58	1.51 ± 0.51	-0.81 ± 0.44	0.69 ± 0.22	-0.58(-1.06, -0.09)*	0.11(-0.16,0.38)	-0.46(-0.73,0.20)
	Y	2.99 ± 1.76	-2.10 ± 1.27	0.88 ± 0.54	1.89 ± 0.63	-1.03 ± 0.26	0.86 ± 0.39	-1.09(-1.88, -0.32) *	1.08(0.54,1.62) *	-0.02(-0.25, -0.18)
	Z	2.33 ± 0.51	-1.45 ± 0.32	0.87 ± 0.47	2.40 ± 0.66	-1.57 ± 0.66	0.84 ± 0.18	-0.07(-0.27, -0.42)	-0.11(-0.41,0.19)	-0.04(-1.8, -0.07) *
Upper arm	X	6.99 ± 2.04	-3.58 ± 1.82	3.40 ± 0.40	10.25 ± 1.74	-6.07 ± 1.79	4.18 ± 1.30	3.25(2.15,4.37) *	-2.49(-3.54-1.43)*	0.77(0.20,1.35) *
	Y	10.50 ± 2.63	-7.19 ± 2.54	3.30 ± 1.30	7.90 ± 2.66	-5.71 ± 2.16	2.19 ± 1.06	-2.60(-2.52, -0.59) *	1.48(0.10,2.86)*	-1.11(-1.83, -0.40) *
	Z	9.70 ± 2.19	-4.58 ± 1.46	5.11 ± 2.03	8.14 ± 0.79	-4.16 ± 0.97	3.97 ± 1.11	-1.55(-2.52,0.59) *	0.42(-0.30,1.15)	-1.13(-2.12, -0.14) *
Forearm	X	10.02 ± 2.30	-3.55 ± 0.59	6.46 ± 2.07	9.42 ± 2.81	-4.38 ± 1.26	5.03 ± 1.70	-0.60(-2.10,0.90)	-0.82(-1.39, -0.26) *	-1.43(-2.57, -0.28) *
	Y	11.62 ± 2.28	-7.49 ± 1.34	4.12 ± 1.28	12.70 ± 3.00	-8.58 ± 2.21	4.12 ± 1.29	-1.09(-0.47,2.64)	-1.09(-2.15, -0.03)	-0.01(-0.78, -0.77)
	Z	12.28 ± 4.23	-6.22 ± 1.68	4.60 ± 1.71	12.24 ± 1.67	-6.86 ± 1.50	5.40 ± 1.02	-0.03(-1.93,1.87)	-0.63(-1.56,0.30)	-0.79(-0.05, -1.65)*

Note: * There were significant differences, $p < 0.05$

ROM on the Y-axis ($F_{(1, 43)} = 13.67$, $p < 0.05$, 95% CI [-2.52, -0.59]).

Minimum acceleration

Significant differences were also observed in minimum accelerations, with novices demonstrating consistently higher values across most body segments (see Table 2a, 2b). In the hip segment, novices exhibited greater minimum accelerations on the X-axis ($F_{(1, 43)} = 13.78$, $p < 0.05$, 95% CI [0.19, 0.43]) and Y-axis ($F_{(1, 43)} = 14.23$, $p < 0.05$, 95% CI [0.18, 0.83]), whereas no significant difference was observed on the Z-axis ($F_{(1, 43)} = 2.45$, $p > 0.05$). In the thigh, the minimum accelerations on the X-axis ($F_{(1, 43)} = 16.92$, $p < 0.05$, 95% CI [0.30, 0.94]), Y-axis ($F_{(1, 43)} = 15.67$, $p < 0.05$, 95% CI [0.19, 0.81]), and Z-axis ($F_{(1, 43)} = 14.23$, $p < 0.05$, 95% CI [0.06, 0.40]) were significantly greater in novices. For the calf, novices presented higher minimum values on the X-axis ($F_{(1, 43)} = 15.34$, $p < 0.05$, 95% CI [0.50, 0.89]), whereas no significant difference was found on the Z-axis ($F_{(1, 43)} = 1.98$, $p > 0.05$). Similarly, for the shoulder Y-axis, novices had significantly greater minimum accelerations ($F_{(1, 43)} = 16.78$, $p < 0.05$, 95% CI [0.54, 1.62]).

Maximum acceleration.

The maximum accelerations followed a similar pattern, with novices exhibiting higher values in most body segments (see Table 2a, 2b). For the hip, novices presented significantly greater values on the Z-axis ($F_{(1, 43)} = 13.45$, $p < 0.05$, 95% CI [-0.42, -0.03]). In the thigh, the maximum acceleration on the Z-axis was greater in novices ($F_{(1, 43)} = 15.89$, $p < 0.05$, 95% CI [-0.85, -0.29]). Shoulder maximum accelerations did not differ significantly on the Z-axis ($F_{(1, 43)} = 2.34$, $p > 0.05$). For the upper arm, maximum accelerations were greater in experienced players on the X-axis ($F_{(1, 43)} = 14.23$, $p < 0.05$, 95% CI [0.20, 1.35]), whereas novices presented greater values on the Y-axis ($F_{(1, 43)} = 12.67$, $p < 0.05$, 95% CI [-1.83, -0.40]) and Z-axis ($F_{(1, 43)} = 13.56$, $p < 0.05$, 95% CI [-2.12, -0.14]). For the forearm, novices demonstrated significantly greater maximum accelerations on the X-axis ($F_{(1, 43)} = 18.45$, $p < 0.05$, 95% CI [-2.57, -0.28]).

Acceleration profiles

Figures 2 and 3 representative individual acceleration profiles of various body segments during the badminton clear stroke, normalized to 100% of the movement cycle. The complete acceleration profiles for all participants are available in the Supplementary Materials (Figure S1).

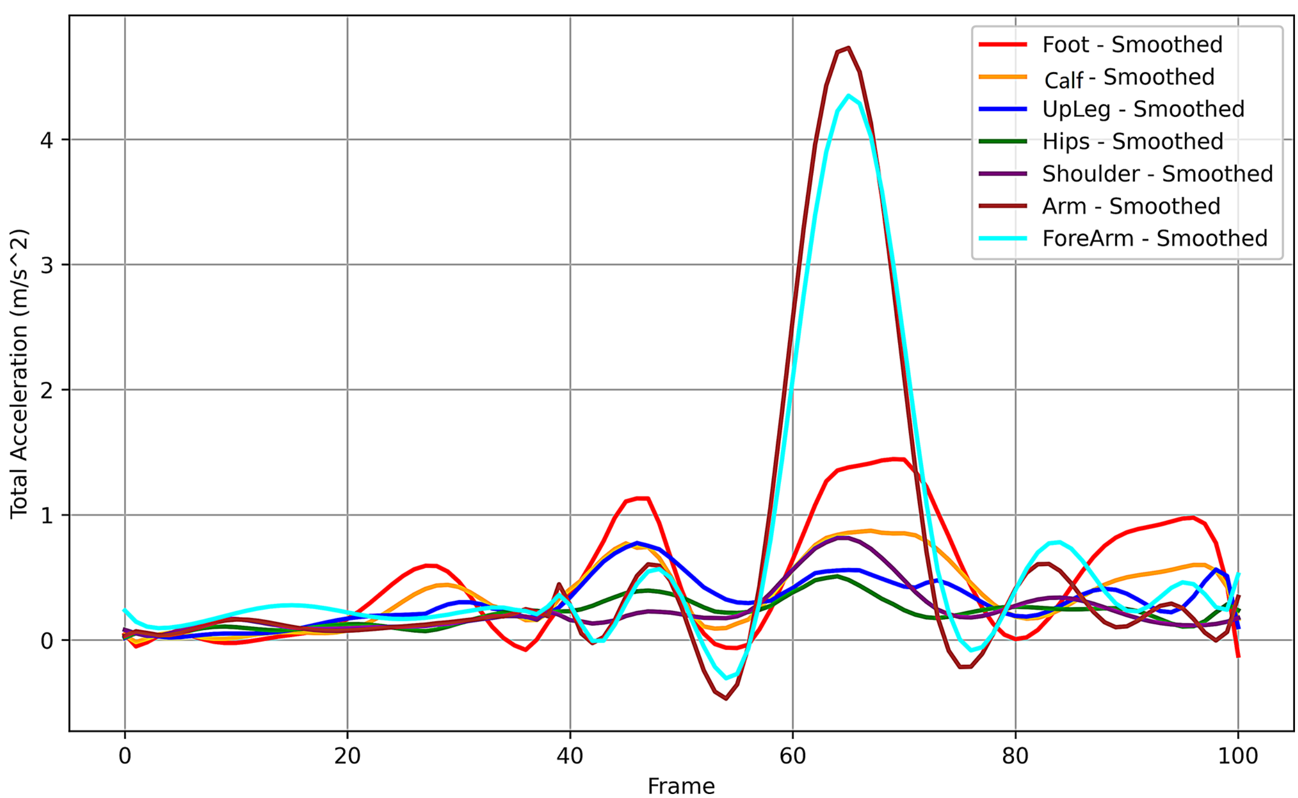

Fig. 2 Acceleration profiles of novice badminton players during the backcourt forehand clear stroke. The graph displays acceleration magnitudes (m/s²) of seven body segments across the normalized movement cycle (0-100%). Note the characteristic unstable pattern with greater fluctuations in the foot and leg segments (reaching 4–5 m/s²), indicating inefficient energy transfer and compensatory movements. The arm and forearm segments show lower peak accelerations (4 m/s² and 3.5 m/s² respectively) compared to experienced players, suggesting suboptimal force generation in the upper limbs. These patterns reflect less refined technique with excessive lower limb involvement and reduced coordination between body segments

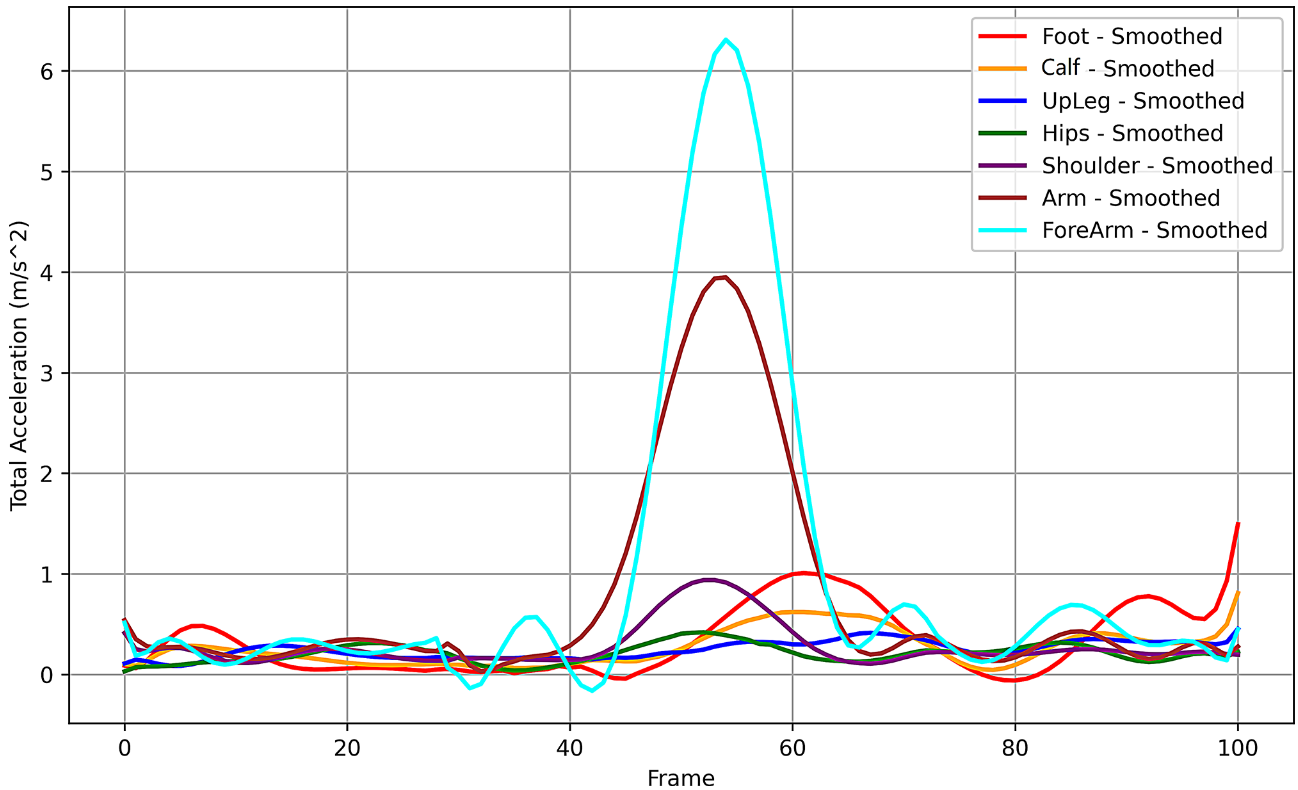

Fig. 3 Acceleration profiles of experienced badminton players during the backcourt forehand clear stroke. The graph illustrates acceleration magnitudes (m/s^2) of seven body segments across the normalized movement cycle (0-100%). Note the distinctive acceleration pattern featuring pronounced peaks in the forearm and arm segments (approximately 6 m/s^2 and 4 m/s^2 respectively), demonstrating efficient power generation in the upper limbs. The lower acceleration magnitudes in the shoulder, hip, and lower limbs indicate enhanced stability and controlled energy transfer from the lower to upper body. This characteristic pattern represents optimal technique with minimal extraneous movement and superior segmental coordination

These representative profiles were selected to demonstrate characteristic movement patterns observed in novice (Fig. 2) and experienced players (Fig. 3).

In Fig. 2 (Novice Players), the representative profile shows that although similar peaks are observed in the arm and forearm segments, the maximum acceleration is notably lower than that of experienced players, reaching approximately 4 m/s^2 and 3.5 m/s^2, respectively. The foot and leg segments show greater fluctuations, suggesting less efficient energy transfer and increased instability during movement. This pattern was consistently observed across the novice group (see Supplementary File 1), indicating a less refined technique with more pronounced involvement of lower limb acceleration, which may reflect compensatory actions due to suboptimal upper body coordination.

In Fig. 3 (experienced players), the representative acceleration pattern exhibits a noticeable peak in the forearm and arm segments, reaching maxima of approximately 6 m/s^2 and 4 m/s^2, respectively. This characteristic profile demonstrates a strong, coordinated effort involving these segments, emphasizing the use of arm and forearm acceleration in generating power for the clear stroke. The acceleration of the other segments (e.g., shoulder, hip, and lower limbs) remained relatively low, indicating stability and efficient transfer of energy from the lower to upper body. Similar movement patterns were observed across the experienced group (detailed in Supplementary File 2). The group-level summaries figures for the key segments of novices and experienced were detailed in Supplementary File 3.

Discussion

This study investigated the acceleration variations of seven body segments—foot, calf, thigh, hip, shoulder, upper arm, and forearm—along the coronal, sagittal, and horizontal axes, comparing the performance of experienced and novice badminton players during the backcourt forehand clear shot. By analyzing these differences, we aimed to elucidate their implications for overall badminton performance, including stroke effectiveness and potential injury risks. Compared with experienced players, the results show the following: (1) Novices exhibit a larger range of motion (ROM) at the hip, thigh, calf, and shoulder, with differences in the upper arm ROM requiring consideration of different body planes; (2) Novices display lower minimum acceleration at the hip, thigh, foot, and shoulder, and the differences in the upper arm also need to account for body planes; and (3) Novices demonstrate greater maximum acceleration at the hip, thigh, shoulder, and forearm, with the upper arm differences requiring analysis in relation to body planes. All these differences are statistically significant ($p < 0.05$). The acceleration patterns of novice players are highly variable, indicating that athletic experience plays a crucial role in the control and precision of movement patterns across different body segments.

The acceleration profiles in Figs. 2 and 3 further illustrate the technical disparities between novices and experienced players. Novices exhibit greater fluctuations in the lower limbs, with acceleration magnitudes in the foot and calf reaching 4–5 m/s^2, while their upper limbs show lower peak accelerations (4 m/s^2 in the upper arm and 3.5 m/s^2 in the forearm). In contrast, experienced players display pronounced acceleration peaks in the upper limbs (approximately 6 m/s^2 in the forearm and 4 m/s^2 in the upper arm), with lower and more stable accelerations in the lower limbs. These differences suggest that novices experience inefficient energy transfer due to excessive lower limb movement, which may compromise stroke effectiveness. The lower peak accelerations in the upper limbs further indicate suboptimal force generation, potentially reducing the power and accuracy of the stroke. Additionally, the pronounced fluctuations in the lower limbs may increase the risk of overuse injuries due to repetitive, uncontrolled stress on joints and muscles. Conversely, the acceleration profiles of experienced players reflect a more efficient technique, with controlled energy transfer from the lower to upper limbs, enabling greater force production in the upper limbs and thus enhancing stroke effectiveness. The stability in their lower limb movements also suggests a reduced injury risk, as refined motor control minimizes unnecessary joint excursions and mechanical loading.

In the lower limbs, the ROM in the hip, thigh, and calf of novices is greater than that of experienced players across all three axes (X-axis, Y-axis, Z-axis). This suggests that novices tend to exhibit larger movements in all directions when performing the backcourt forehand clear shot. As a result, they may require more acceleration and force output to complete the action, especially since their technical skills are still developing [2]. The minimum acceleration typically occurs during the preparation and initial force application phases of movement [17]. Along the X-axis, novices display lower minimum acceleration at the hip, thigh, and calf than experienced players do. Similarly, along the Y-axis, novices show reduced minimum acceleration at the hip, thigh, and foot, with a comparable decrease at the foot along the Z-axis. These findings suggest that novices experience delays in executing movements in the forward-backward, horizontal, and vertical directions, which leads to a longer initiation time. This delay, coupled with larger ROM, reflects a lack of motor coordination and neuromuscular control, hallmarks of novice athletes in the early stages of skill acquisition [17, 18]. Novices struggle with the timing and sequencing of multi-joint actions, resulting in inefficient force generation and reduced movement precision. In the context of badminton, this lack of coordination may lead to suboptimal racket positioning, diminishing the effectiveness of the backcourt forehand clear shot and overall stroke accuracy. During the preparation phase of the backcourt forehand, novices fail to fully engage the strength of their lower limbs, resulting in reduced acceleration, slower movements, and decreased precision. Consequently, their overall movement efficiency is impacted [2]. With respect to maximum acceleration, novices exhibit significantly greater acceleration than experienced players do only at the hip and thigh along the Z-axis. This finding indicates that novices tend to rely more on vertical force generation from their lower limbs [19]. This reliance on vertical motion likely stems from slower reactions in the horizontal and forward-backward directions, causing novices to compensate for these delays by focusing on vertical movements to maintain posture. As a result, they generate greater acceleration along the Z-axis.

Badminton backcourts for high-distance shots are executed primarily by generating force through the shoulders and arms [4]. This study examined the ROM and acceleration patterns in the upper limbs of novices and experienced players. This reveals several key differences between the two groups. For the shoulder, the ROM in the X-axis and Y-axis directions is greater in novices than in experienced players. Additionally, novices exhibit a lower minimum acceleration but higher maximum acceleration in the Z-axis. These findings suggest that novices rely on a larger range of motion when generating force through their shoulders [20, 21]. This reliance on excessive shoulder motion may compromise stroke effectiveness by reducing racket control and accuracy, while the higher maximum acceleration along the Z-axis could increase mechanical stress, potentially elevating the risk of shoulder injuries such as impingement. However, owing to less control over their movements, they experience more unstable changes in acceleration than experienced players do, who exhibit greater control and stability. The upper arm plays a crucial role in force generation during badminton shots [22]. In this study, the ROM of the upper arm in the Y-axis and Z-axis directions was greater in novices than in experienced players. However, novices demonstrated smaller minimum accelerations in the Y-axis and greater maximum accelerations in the Z-axis. These results indicate that novices experience greater instability in upper arm movements, which may lead to inconsistent racket trajectories and reduced stroke precisio. The increased maximum acceleration in the Z-axis likely serves as a compensatory mechanism for earlier delays, further highlighting movement inefficiencies. These results indicate that novices face greater instability and inaccuracy when force is applied to their upper arms, whereas experienced players exhibit more controlled and efficient movement patterns, leading to more precise and stable force application [23–25]. Interestingly, in the X-axis direction, novices had a smaller ROM in the upper arm than experienced players did. They also exhibited a larger minimum acceleration but a smaller maximum acceleration. This could be attributed to novices' limited range of motion in the X-axis, which results in unstable force output during the acceleration phase [26]. Owing to a lack of coordination, novices may initially generate larger accelerations but struggle to maintain high maximum accelerations, ultimately hindering the efficiency of their movements [26].

The increased instability in novices' acceleration patterns has significant biomechanical implications. Stable movement patterns are critical in badminton for effective force transfer and precise racket control. The larger ROM and higher maximum accelerations observed in novices suggest reliance on compensatory strategies, such as excessive joint motion, to generate force. This inefficiency not only reduces stroke effectiveness but also increases mechanical loading on joints and muscles, potentially heightening the risk of overuse injuries. For example, the exaggerated shoulder and upper arm movements may predispose novices to rotator cuff injuries due to repetitive, uncontrolled stress. In contrast, experienced players' refined motor control enables them to optimize force production while minimizing unnecessary joint excursions, reducing injury risk and enhancing performance. Overall, these differences highlight that novices experience significant instability in motion control. In contrast, experienced individuals, through years of training and accumulated experience, are better able to control their range of motion and acceleration, leading to improved force efficiency and greater stability. These disparities underscore the impact of athletic experience on stroke effectiveness and injury prevention. Understanding these disparities can provide valuable insights for coaches, enabling them to refine training methods and potentially reduce the risk of injury due to improper techniques.

However, this study also has certain limitations. Firstly, while IMU-derived acceleration data provided valuable insights into segmental dynamics, the study focused solely on linear acceleration metrics, such as maximum, minimum, and range of acceleration. This approach limits a comprehensive understanding of the movement, as it does not account for rotational aspects of motion. Joint angles and angular velocities are critical for assessing how different body segments coordinate during the stroke. For instance, the timing and sequence of joint rotations can significantly influence the efficiency and effectiveness of the stroke. Future research could incorporate IMUs capable of measuring both linear and angular motion or combine IMU data with optical motion capture systems to obtain detailed joint kinematics. Secondly, the study was conducted in a controlled laboratory setting, which, while allowing for precise measurement, may not fully replicate the complexities of competitive play. In real-game scenarios, players must adapt their strokes to unpredictable shuttle trajectories, tactical demands, and physical fatigue. These factors could influence movement patterns and acceleration profiles. Therefore, the ecological validity of the findings is somewhat constrained. Future studies could address this by employing wearable sensors during actual matches or simulated competitive environments. This would provide a more comprehensive understanding of how skill-level differences manifest in dynamic contexts and inform more applicable training recommendations. Lastly, the analysis emphasized segmental accelerations but did not explore temporal coordination between body segments, such as proximal-to-distal sequencing, or kinetic parameters like ground reaction forces. These factors are critical for understanding how experienced players optimize energy transfer from the lower limbs to the racket, a key aspect of skilled performance. Incorporating these elements in future research would enhance the understanding of inter-segmental coordination and force generation strategies.

Practical application

Acceleration data reveals distinct movement patterns between novice and experienced badminton players, guiding coaches to enhance stroke technique. Novices show inconsistent strokes with erratic lower limb acceleration (e.g., foot: 2–6 m/s^2) and weak upper limb force (e.g., hand: 3 m/s^2 vs. 5.5 m/s^2 in experienced players), indicating poor synchronization and power. Conversely, experienced players exhibit stability through tighter acceleration ranges and refined motor control, optimizing energy use. Coaches can use multi-shuttlecock drills, resistance exercises, and video analysis to improve these areas. Proprioceptive training, like balance drills, also can help novices develop similar stability.

Conclusions

These findings suggest that experienced players achieve more efficient movement patterns through refined motor control and reduced excessive motion. This research provides valuable insights for coaching interventions and technique refinement in badminton training programs, particularly for developing players.

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

Author contributions

Conceptualization, H.H. and Z.G.; methodology, M.L.; software, M.Z.; validation, Z.G. and M.Z.; formal analysis, M.Z.; investigation, H.H.; resources, Z.G.; data curation, M.L.; writing—original draft preparation, H.H. and Z.G.; writing—review and editing, M.L. and J.D.; visualization, M.Z.; supervision, J.D.; project administration, J.D.; funding acquisition, H.H. All authors have read and agreed to the published version of the manuscript.

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Data availability

The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The studies involving human participants were reviewed and approved by the Ethics Committee of Beijing Sport University (Approval number: 2023073 H). All participants provided written informed consent after receiving oral and printed explanations of the experimental procedures. The study was conducted in accordance with the ethical standards outlined in the Declaration of Helsinki.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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