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Comparing smash performance and technique between elite male and female international badminton players

Comparación del rendimiento y la técnica del remate entre jugadores hombres y mujeres internacionales de élite de bádminton

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Abstract

Performance of the badminton smash plays a crucial role in success during competition. Differences in performance and technique between genders is of interest to players/coaches with respect to appropriate training intensity and understanding performance expectations during competition. Three-dimensional position data were collected for 26 male and 26 female elite international badminton players (world ranking: male = 59 ± 36, female = 54 ± 24) performing the smash. Male players compared to female players performed smashes with greater shuttlecock speed (98.7 vs 78.5 m•s^{-1}; p < 0.001), racket head speed (63.3 vs. 51.0; p < 0.001), and shuttlecock angle below the horizontal (13.3° vs. 7.3°; p < 0.001) with the latter likely due to higher contact heights (2.90 vs 2.46 m; p < 0.001) and jump heights (53.6 vs 14.5 cm; p < 0.001). Female players typically used a 'kick-through' rather than a 'two-footed jump' movement. The majority of differences in technique, assessed via statistical parametric mapping, occurred during the backswing phase, where male players adopted a more flexed, less laterally flexed (to non-racket-arm side) and counter-rotated trunk positions. Male players held their racket arm further back during the backswing (negative shoulder plane of elevation angle), and the elbow joint was held in a more extended position at the start of the backswing and in a more flexed position just prior to contact. No differences were found at the wrist joint. This study provides normative performance and technique data for elite male and female international players, highlighting current differences between genders which may inform training and competition preparation.

Keywords: *racket, overhead, gender, kinematic.*

Resumen

El rendimiento en el remate de bádminton desempeña un papel crucial en el éxito durante la competencia. Las diferencias en el rendimiento y la técnica entre sexos son de interés para los jugadores y los entrenadores con respecto a la intensidad de entrenamiento adecuada y a la comprensión de las expectativas de rendimiento durante la competencia. Se recogieron datos de la posición tridimensional de 26 jugadores y 26 jugadoras internacionales de élite de bádminton (clasificación mundial: hombres = 59 ± 36, mujeres = 54 ± 24) al realizar el remate. Los hombres realizaron los remates con mayor velocidad del volante (98,7 vs 78,5 m•s^{-1}; *p* < 0.001), mayor velocidad de la cabeza de la raqueta (63,3 vs 51,0; *p* < 0,001) y mayor ángulo del volante por debajo de la horizontal (13,3º vs 7,3º; *p* < 0,001), este último probablemente debido a una mayor altura de contacto (2,90 vs 2,46 m; *p* < 0,001) y de salto (53,6 vs 14,5 cm; *p* < 0,001). Las mujeres solían saltar haciendo un movimiento de tijera en lugar de un movimiento con los dos pies. La mayoría de las diferencias en la técnica, evaluadas a través del mapeo paramétrico estadístico, se dieron durante la fase de backswing, en la que los hombres adoptaron una posición del tronco más flexionada,

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menos flexionada lateralmente (hacia el lado contrario al brazo de la raqueta) y contrarrotada. Los hombres mantuvieron el brazo de la raqueta más atrás durante el backswing (plano negativo del hombro del ángulo de elevación), y la articulación del codo se mantuvo en una posición más extendida al inicio del backswing y en una posición más flexionada justo antes del contacto. No se encontraron diferencias en la articulación de la muñeca. Este estudio proporciona datos normativos sobre el rendimiento y la técnica de jugadores hombres y mujeres internacionales de élite, y destaca las diferencias actuales entre los sexos que pueden servir de base para el entrenamiento y la preparación para la competencia.

Palabras clave: *raqueta, golpeo de mano alta, género, cinemática.*

INTRODUCTION

The badminton smash is a critical shot for successful performance and accounts for 54% of 'unconditional winner' and 'forced failure' shots in international competition (Tong & Hong, 2000), where successful performance is a function of both speed and direction (King et al., 2020). Of interest to researchers, biomechanists and coaches are the technique parameters that allow badminton players to perform faster smashes and/or more accurate smashes. The majority of research to date focused on biomechanics including elite players has focused exclusively on male badminton players (King et al., 2020; Ramasamy et al., 2021, Ramasamy et al., 2022), while very few have included female players (Ferreira et al., 2020).

Ferreira et al. (2020) studied 14 Polish national team players (seven male, seven female) focused primarily on upper extremity muscle strength and lower limb power, and their relationships with shuttlecock speed in the smash, both with and without a jump. Their analyses focused on performance outcomes, namely, the height of contact and shuttlecock speed. As expected on all upper extremity strength and lower limb power tests, males outperformed female players. Similarly, on all performance outcomes, the male players significantly (*large:* η^2 = 0.853) outperformed female players, on average producing shuttlecock speeds 15.7 m•s^{-1} and 14.4 m•s^{-1} faster during jump and no jump conditions, respectively, as well as contact points 44 cm higher when performing a jump smash (*large:* η^2 = 0.780). One limitation of comparing performance by post-impact speed in object-striking sports, such as badminton, is the effect of the impact mechanics where a poor impact results in a loss of performance despite a potentially large (but poorly timed) input from the athlete (McErlain-Naylor et al., 2020). Racket head speed could be considered a more appropriate measure of performance potential.

During the tennis serve, adolescent male players achieved greater maximum shoulder external rotation and front hip vertical velocity for both flat and kick serves (Connelly et al., 2019), however for Olympic-level players the only difference found was that male players produced greater maximal shoulder internal rotation angular velocities than females (2420 vs. 1370°•s^{-1}), achieving serve velocities approximately 22% faster (Fleisig et al., 2003). Therefore, with few significant differences in serve kinematics between male and female tennis players there would be no reason to coach different mechanics to males and females (Fleisig et al., 2003). Similar research within baseball pitching found that male players achieve greater upper torso/pelvis separation at stride foot contact and maximum elbow extension angular velocity during the arm acceleration phase, ultimately achieving ball velocities approximately 35% faster (Chu et al., 2009).

Previous research into kinematic differences during the golf swing between male and female golfers centred around pelvis and thorax rotations (Egret et al., 2006; Horan et al., 2010, 2011; Zheng et al., 2008). Interestingly these differences do not pertain to pelvis-thorax separation (Horan et al., 2010), which was correlated with greater shuttlecock speed in male badminton players (King et al., 2020). In cricket power hitting, McErlain-Naylor et al. (2021) found that male batters produced greater maximum bat speeds, ball launch speeds, and ball carry distances than similarly skilled female batters, and after controlling for the body mass and height, found that the male batters had greater pelvis-thorax separation in the transverse plane at the initiation of the downswing (similar to the start of the forward swing in the badminton smash), and extended their lead elbows more during the downswing.

From a dynamical systems theory perspective, the interaction of organismic, environmental, and task constraints determine individual movement patterns (Kelso, 1995; Newell, 1996). Any differences in performance and movement patterns between male and female badminton players may be due to differences in the above constraints which exist in all cases or on average (McErlain-Naylor et al., 2021). These constraints include anthropometry (Stuelcken et al., 2007), force-velocity relationships (Torrejón et al., 2019), and racket inertial properties (Creveaux et al., 2013). The aim of the present study was to identify the differences in performance and technique of the badminton smash between elite male and female badminton players only, without suggesting casual factors i.e., controlling for height and mass (McErlain-Naylor et al., 2021). It was hypothesised that male players would produce greater shuttlecock speeds, racket head speeds, and steeper trajectories. Additionally, it was hypothesised that male players would achieve a greater jump height and greater x-factor (pelvis-thorax separation).

MATERIAL AND METHODS

Participants

26 males (age 25.5 ± 4.6 years; height 1.82 ± 0.06 m; mass 75.9 ± 4.0 kg) and 26 females (age 23.0 ± 2.7 years; height 1.71 ± 0.07 m; mass 63.6 ± 8.9 kg) participated in this study. Participants were all international level competing at the BWF World Championships and/or Yonex All England Championships and/or members of the England/Great Britain national squad. The dataset included a mixture of singles and doubles players, where the average world ranking was 59 ± 36 and 54 ± 24 for male and female players, respectively (based on their highest ranking in all disciplines at the time of testing). All participants were free from any injuries that may affect their performance and participation in the study. Testing procedures were explained to participants in accordance with Loughborough University ethical guidelines, and subsequently, informed consent was obtained.

Data collection

All testing was conducted on a badminton (practice) court at two international events and a national training centre. These were the BWF World Championships, Glasgow, UK; Yonex All England Badminton Championships, Birmingham, UK; and National Badminton Centre, Badminton England.

Markers were attached to bony landmarks, racket, and shuttlecock consistent with King et al. (2020). Three-dimensional kinematic data were collected using a Vicon Motion Analysis System (OMG Plc, Oxford UK) operating at 400 Hz. All participants completed a self-selected warm-up and were given multiple trials to become familiar with the delivery of the incoming shuttlecock. Two methods of delivery were used: a racket-feed from an ex-international badminton player and a shuttlecock launcher (BKL, Badenko, France) launching every three seconds, both deemed representative of a lift stroke in competitive play by an international player. Given the high standard of the participants, the multiple methods used to deliver the shuttlecock was assumed not to affect subsequent performance. Participants were instructed to smash as fast as possible using their normal technique, completing approximately 25 trials (five sets of five), with variation due to loss of markers.

Data analysis

Racket and shuttlecock marker data for all trials were labelled within Vicon Nexus software (OMG Plc, Oxford, UK). The curve-fitting methodology of McErlain-Naylor et al. (2020) adapted from cricket (Peploe et al., 2014) was used to calculate racket and shuttlecock kinematic variables (maximum shuttlecock speed, racket head speed at contact, height at contact, shuttlecock angle at start of flight), where a precise time of impact was calculated for a more accurate determination of these variables. Note that the contact period was amended from 1 to 1.4 ms, in accordance with Towler et al. (2023). The best trial (i.e., greatest post-impact shuttlecock speed) was identified and used for further investigation.

Whole-body marker data for the best trial per participant were labelled within Vicon Nexus. To avoid problems with filtering through the racket-shuttlecock impact, the 'linear extrapolation' method was utilised by extrapolating pre-impact data through impact (Knudson & Bahamonde, 2001). Marker trajectories were then filtered using a recursive two-way Butterworth low-pass filter with a cut-off frequency of 30 Hz determined by residual analysis (Winter, 2009). Technique variables (joint angles) were calculated using Cardan/Euler sequences recommended for each joint (Wu et al., 2005, Smith et al., 2015; Table 1), where the x, y and z axes were unit vectors representing the mediolateral, anterior-posterior and longitudinal axes, respectively (Worthington et al., 2013). Left-handed players' global position data in the x-axis was multiplied by -1, such that they could be considered right-handed. An offset was applied to the wrist flexion angles based on the placement of the hand marker which protruded from the back of the hand.

Table 1.
Euler/Cardan sequences used to calculate joint angles

joint	sequence	rotations
shoulder	z-y-z[1]	plane of elevation, elevation, internal rotation
elbow	x-y-z[1]	flexion, abduction, pronation (proximal)
wrist	x-y-z[1]	flexion, ulnar deviation, pronation (distal)
trunk	y-x-z[2]	lateral flexion, flexion, axial rotation (x-factor)

Recommendation by: [1] Wu et al. (2005), [2] Smith et al. (2015).

All joint angle data were normalised to represent the swing phase, the start of the swing was calculated as the frame in which the racket head centre speed exceeded 5 $m \cdot s^{-1}$ from which it did not decrease until impact, to exclude any random movement of the racket prior to the swing commencing. The end of the swing phase was defined as the last frame before impact, calculated using the curve-fitting methodology. The swing duration was also selected as a performance variable.

Whole body centre of mass was calculated using individual segment inertial values (Yeadon, 1990), where the body was modelled as 14 segments. Jump height was then calculated as the vertical distance between the maximum centre of mass height and the centre of mass height during a static standing trial. Height of contact was calculated as the vertical position of the shuttlecock at the last frame prior to impact.

Statistical analysis

All statistical analyses were performed in SPSS v.28.0. (IBM Corp., Armonk, NY, USA). Data were presented as mean ± standard deviation. Independent samples t-tests (t) were used to compare performance variables between genders, unless data were not normal, assessed by the Shapiro-Wilk test, in which case the Mann-Whitney U statistic (U) was used. A statistically significant threshold of $p < 0.05$ was used. Effect sizes were calculated using Cohen's *d* and interpreted as: *trivial* < 0.2; 0.2 ≤ *small* < 0.6; 0.6 ≤ *moderate* < 1.2; 1.2 ≤ *large* < 2.0; *very large* ≥ 2.0 (Hopkins et al., 2009). For Mann-Whtiney U test, the effect size was calculated as $r = \frac{|z|}{\sqrt{n}}$, and interpreted as: trivial < 0.1; 0.1 ≤ small < 0.3; 0.3 ≤ moderate < 0.5; 0.5 ≤ large < 0.7; very large ≥ 0.7 (Cohen, 1988; Hopkins et al., 2009).

SPM two-tailed independent sample t-tests ($p < 0.05$) were used to compare the joint angle time series between males and females (Pataky, 2010). SPM analyses were implemented using the open-source spm1d code on Matlab (v.M0.1, www.spm1d.org (accessed on 10 June 2023)).

RESULTS

Performance variables

Males generated significantly greater shuttlecock speeds, 98.7 ± 3.6 m•s^{-1} vs. 76.5 ± 8.2 m•s^{-1} (U = 0; $p < 0.001$; Table 2) and racket head speeds 63.3 ± 2.9 m•s^{-1} vs. 51.0 ± 4.7 m•s^{-1} (U = 0; p < 0.001). Note that a U statistic of 0 indicates that the ranks of all male values were higher than those of all the females. Male players also developed greater racket head speeds using shorter (duration) swings, on average 28 ms shorter (183 ± 15 ms vs. 211 ± 33 ms; $t_{(50)} = -3.98$; p < 0.001; Figure 1).

Males also generated significantly steeper smashes on average 6° further below the horizontal ($t_{(50)} = 9.04$; $p < 0.001$), presumably due to significantly higher contact heights, on average 0.44 m higher ($t_{(50)} = 11.39$; $p < 0.001$), as a result of greater jump heights, which were on average 39.1 cm higher (U = 5; $p < 0.001$).

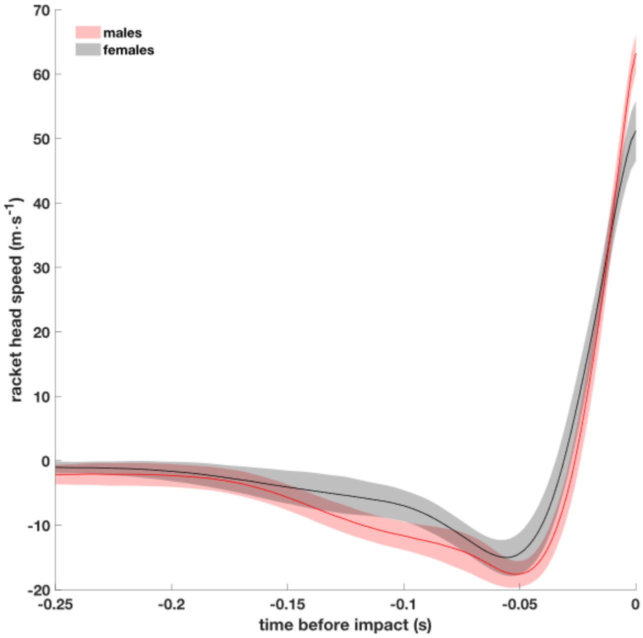

Figure 1. Differences in racket head speed development between males and females. Racket-shuttlecock contact occurs at t = 0 s. Racket head speed is the velocity of the racket head centre velocity acting normal to the racket stringbed.

Table 2
Performance variable comparison between males and females

parameter	male	female	*t [U]*	*d [r]*	interpretation	*p*
shuttlecock speed (m•s^{-1})	98.7 ± 3.6	78.5 ± 8.2	[0.00]	[0.86]	very large	<0.001
racket head speed (m•s^{-1})	63.3 ± 2.9	51.0 ± 4.7	[0.00]	[0.86]	very large	<0.001
swing duration (ms)	183 ± 15	211 ± 33	-3.98	-1.11	moderate	<0.001
shuttlecock vertical angle (°)	13.3 ± 2.2	7.3 ± 2.6	9.04	2.51	very large	<0.001
contact height (m)	2.90 ± 0.13	2.46 ± 0.15	11.39	3.16	very large	<0.001
jump height (cm)	53.6 ± 9.4	14.5 ± 11.0	[5.00]	[0.85]	very large	<0.001

t and d or U and r represent the statistics for an independent samples t-test or the Mann Whitney U test, respectively
†shuttle vertical angle refers to the angle below the horizontal

Technique variables

Male players had smaller trunk extension angles (more flexed) during 17-59% of the swing phase (Figure 1). Male players had smaller trunk lateral flexion angles (towards the left for a right-handed player) during 0-69% of the swing phase (Figure 2). Male players also adopted more counter-rotated (x-factor) positions during 0-73% of the swing phase and on average had marginally greater x-factor angles (Figure 3). Thus, male players used larger ranges of motions at the trunk, particularly x-factor, and lateral flexion, throughout the swing phase compared to females.

At the shoulder joint, the male players had a smaller plane of elevation angle between 0-56% of the swing phase i.e., the racket arm was held back further (Figure 4). There was no difference in the elevation angle or internal rotation angle throughout the swing phase between genders (Figures 5 and 6).

At the elbow joint, the elbow extension angle had two regions of interest, firstly from 0-37%, where male players adopted more extended positions. Secondly, leading up to racket-shuttlecock contact (97-100% of the swing phase), male players adopted more flexed positions (Figure 7). Therefore, throughout the swing phase, male players used a smaller range of motion of elbow extension. At the wrist joint, there were no differences in wrist flexion and wrist ulnar/radial deviation angles throughout the entirety of the swing phase (Figures 8 and 9).

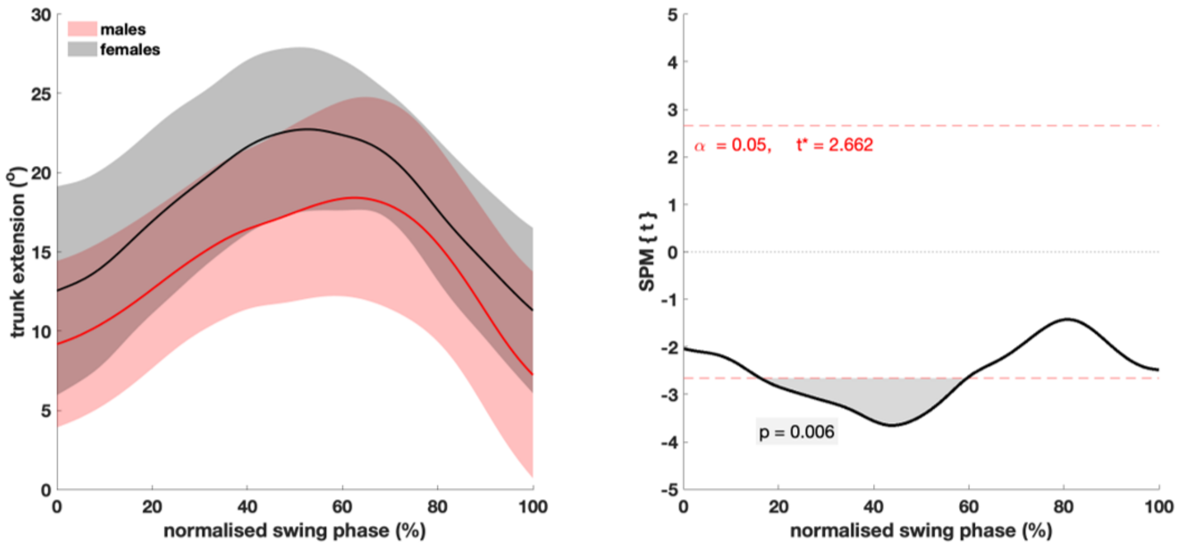

Figure 2. Trunk extension angles during the swing phase (left), statistical parametric mapping analysis comparing males and females (right)

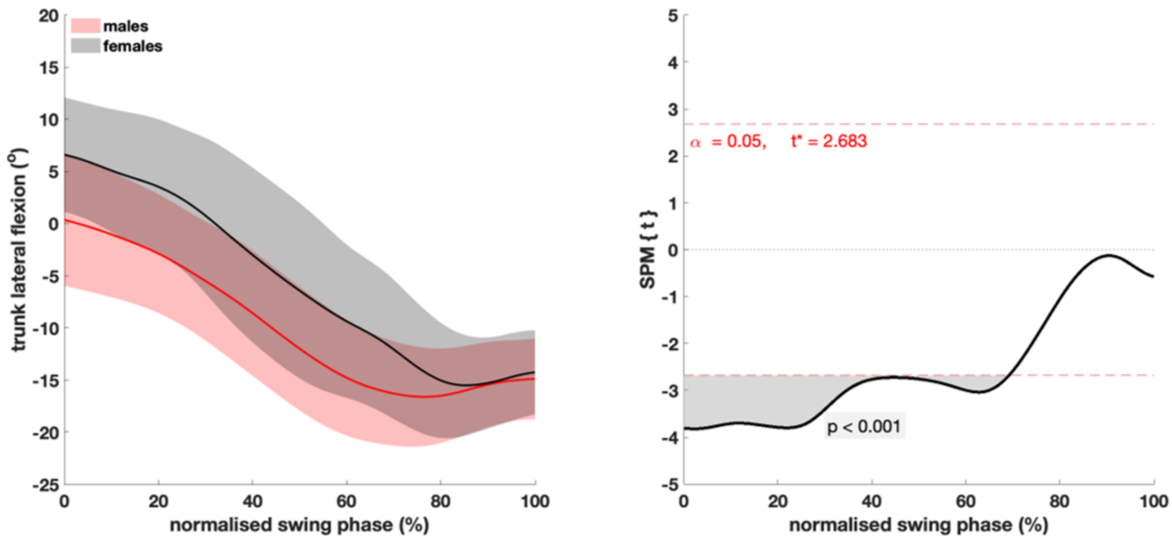

Figure 3. Trunk lateral flexion angles (towards the left for a right-handed player) during the swing phase (left), statistical parametric mapping analysis comparing males and females (right).

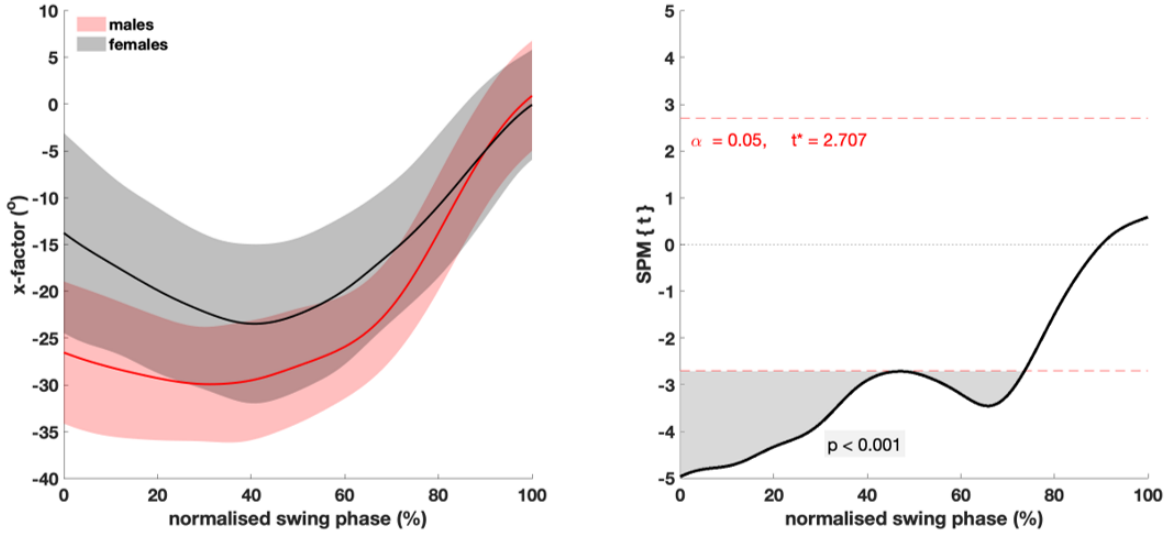

Figure 4. Trunk axial rotation (x-factor) angles during the swing phase (left), statistical parametric mapping analysis comparing males and females (right).

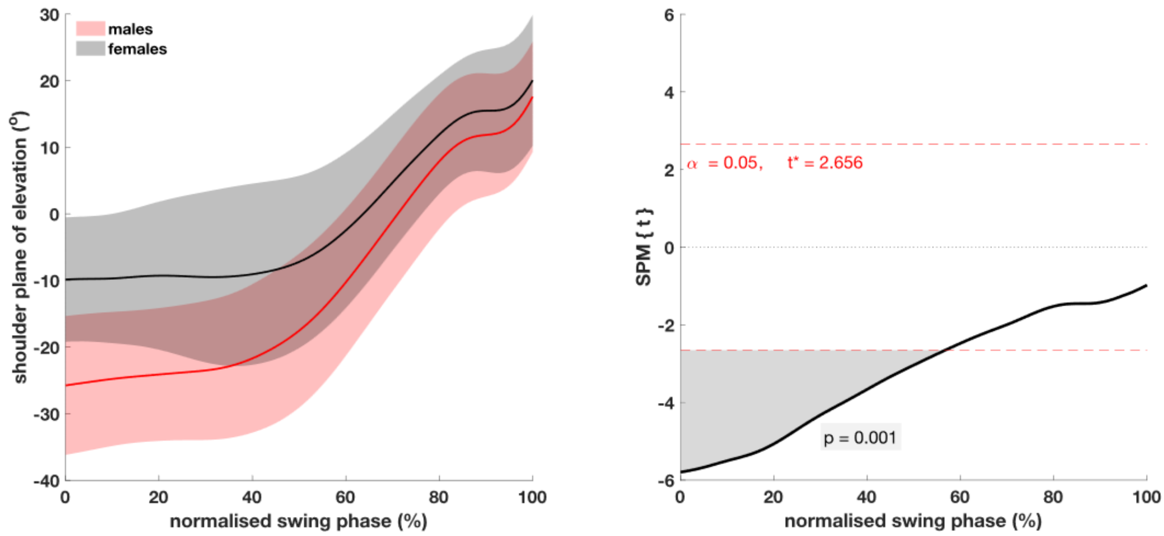

Figure 5. Shoulder plane of elevation angles during the swing phase (left), statistical parametric mapping analysis comparing males and females (right).

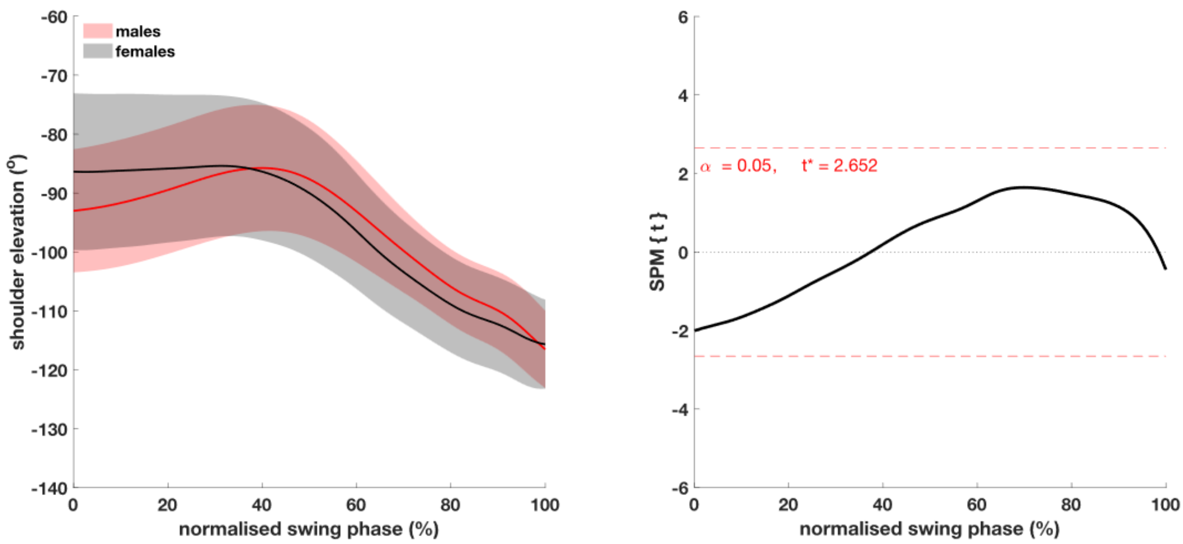

Figure 6. Shoulder elevation angles during the swing phase (left), statistical parametric mapping analysis comparing males and females (right)

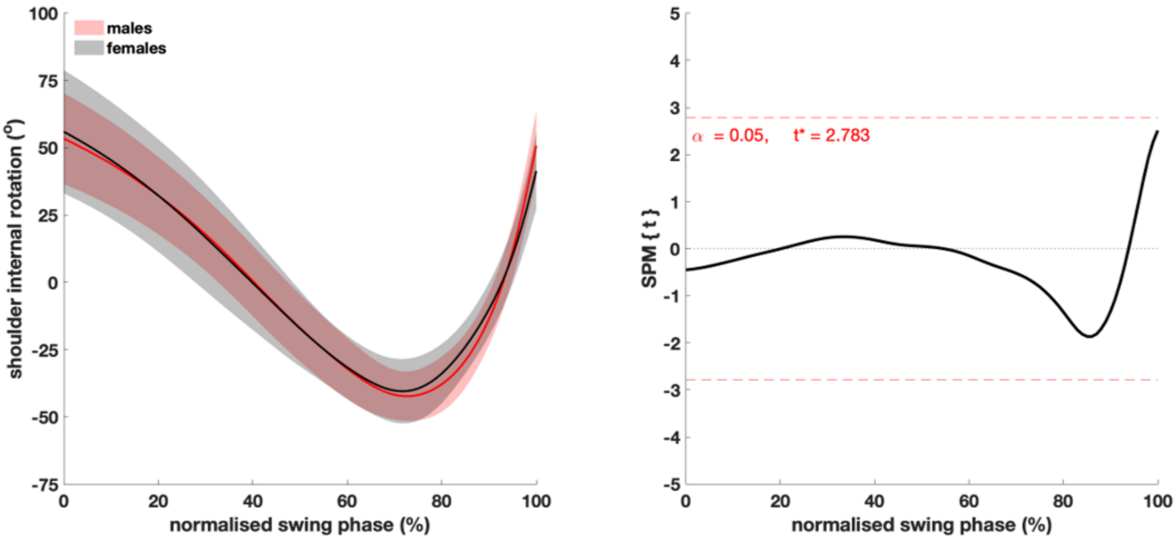

Figure 7. Shoulder internal rotation angles during the swing phase (left), statistical parametric mapping analysis comparing males and females (right)

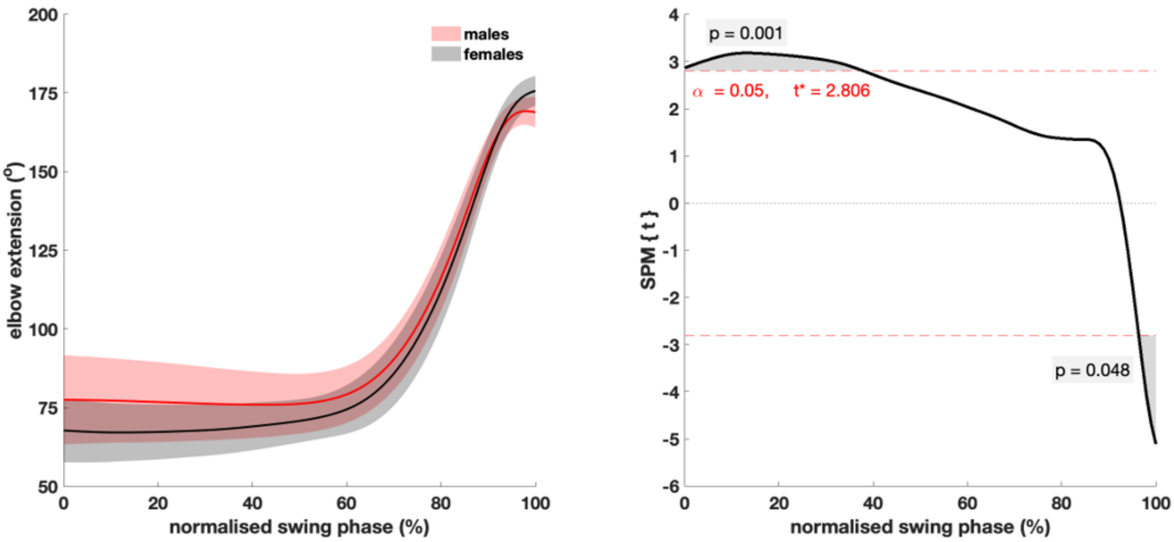

Figure 8. Elbow extension angles during the swing phase (left), statistical parametric mapping analysis comparing males and females (right).

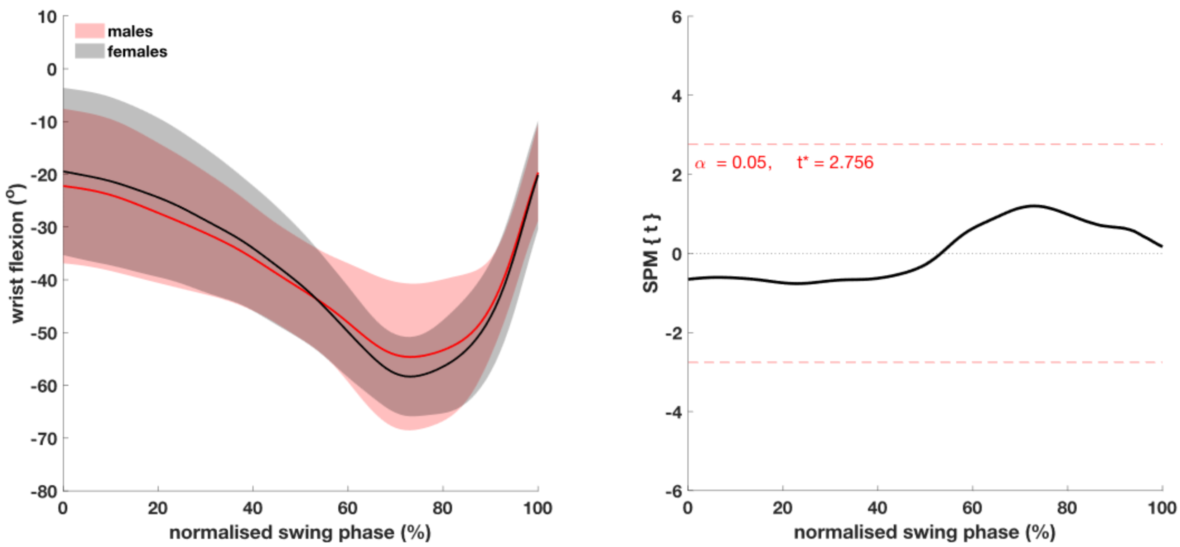

Figure 9. Wrist flexion angles during the swing phase (left), statistical parametric mapping analysis comparing males and females (right).

DISCUSSION

Males outperformed females for all performance variables. With respect to shuttlecock speed and racket head speed, males achieved 20.2 m•s^{-1} (25.7%) and 12.2 m•s^{-1} (23.9%) greater speeds than females. Similar performance differences have been observed in badminton (Ferreira et al., 2020) as well as other overhead sporting actions such as baseball pitching and the tennis serve (Chu et al., 2009; Fleisig et al., 2003). Differences were also evident relating to the shuttlecock trajectory (vertical angle) and the factors relating to the achievable vertical angle i.e., players that can achieve greater contact heights either through height or movement technique are able to achieve steeper vertical angles whilst still achieving a successful smash over the net. It is common in badminton for elite male players to perform a two-footed jump during their maximal smash technique, whereas female players tend to use a 'kick-through' movement which requires less elevation from the ground. Possible explanations for this difference include the physical capacity of males vs. females to perform the two-footed jump movement repeatedly through greater neuromuscular development and the ability to attenuate landing forces (Quatman et al., 2006). Secondly, as male players produce higher shuttlecock velocities, they use the smash more frequently to win points (Abian-Vicen et al., 2013).

By combining velocity, trajectory and contact point to describe a typical elite and female smash, it is possible to understand how the differences affect the difficulty for an opponent attempting to return the smash. Using the average speed and vertical angle, it was assumed that the male and female players made contact at the same location within the global transverse plane (*xy*), with only the *z* coordinate differing (males: 2.90 m, females: 2.46 m). The initial velocity was then modelled as 98.7 m•s^{-1} acting 13.3° below the horizontal for males and 78.5 m•s^{-1} acting 7.3° below the horizontal for females, based on the average performances from each cohort, with both having zero velocity in the mediolateral direction (Figures 10 and 11).

The model showed that theoretically from contact to landing the male smash took 0.41 s to land, whilst the female smash required 0.61 s (+49%). The total flight time is of course linked to the trajectory, and the female smash landed 0.87 m further into court. For the female smash to reach the same anterior-posterior position on the court as the male smash at landing an additional 0.08 s (+20%) was required. For an opponent this means they have the option to either position themselves closer to the net to return the smash from a female, potentially allowing greater chances to play a counter-defensive stroke, or to remain in a similar position and give themselves more time to play an effective defensive stroke. Additionally, the contact point when returning the female smash would be higher, which would again give more options to the opponent for playing a more successful return.

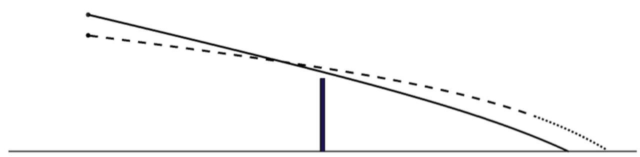

Figure 11. The solid lines represent t = 0-0.41 s, the time taken for the male smash to land. The dotted line indicates the female smash trajectory after the male smash has landed t = 0.41-0.61 s. The initial y position is equal (-6 m; net = 0) and the velocity in the x-direction was 0. The coefficient of air drag acceleration (α) was calculated as 0.2152 (Shen et al., 2020), where $\alpha = \frac{1}{2} C_D \frac{\pi d^2}{4} \rho v^2$, and C_D(coefficient of drag) = 0.59 (Alam et al., 2010), d (diameter of the shuttlecock) = 0.06 m, ρ (air density) = 1.29 kg•m^{-3} and v is the shuttlecock velocity.

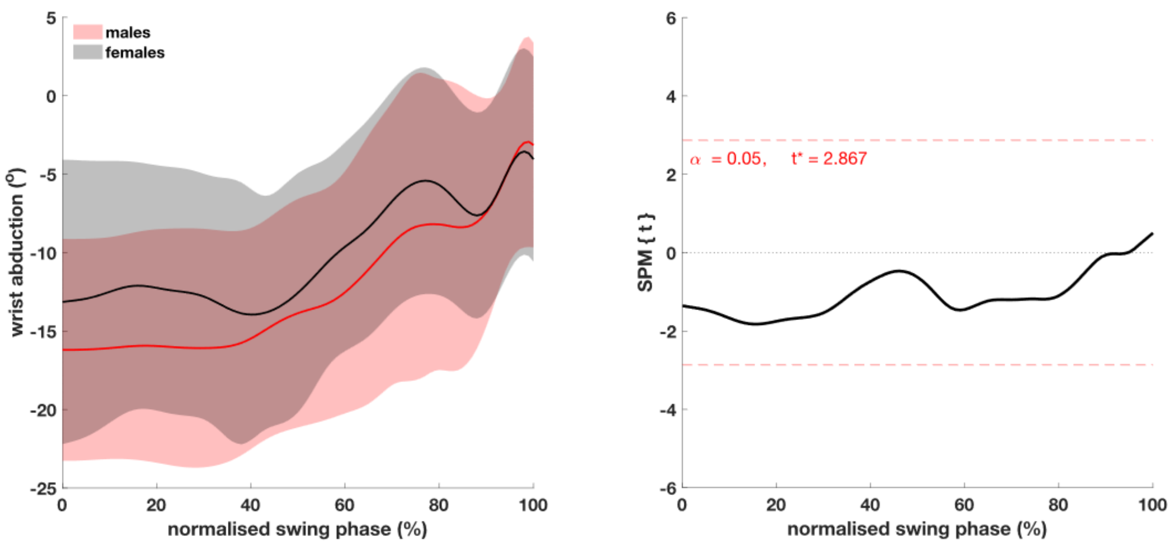

Figure 10. Wrist abduction angles during the swing phase (left), statistical parametric mapping analysis comparing males and females (right).

From a technique perspective, many of the differences between male and female players were during the backswing, approximately 0-80% of the swing phase for the majority of players. This supports previous research where players who achieve more counter-rotated positions for axial rotation of the trunk (x-factor) and pull the arm further back relative to the trunk (negative plane of elevation angle) achieve greater shuttlecock speeds (King et al., 2020; Towler, 2022). Whilst the present study did not include a specific analysis of angular velocities, given that the normalised time histories for many joint angles were similar and shorter swing duration for males (typically 28 ms shorter; 183 vs. 211 ms), it can be inferred that the average angular velocities were greater for male players.

CONCLUSIONS

This study quantifies differences in smash performance between elite male and female badminton players. On average, male players produced smash speeds 26% greater than their female counterparts and steeper trajectories, which has significant consequences for an opponent's chances and options for returning the stroke. These differences in shuttlecock speed and/or racket head speed are coupled with technique differences seen during the backswing phase, particularly in proximal joints (trunk and shoulder) which likely enhance the forward swing phase. Further research may look at intervention studies based on strength and technique improvements linked to these differences, as well as tactical strategies based on known differences in smash performance between males and females and the constraints placed upon the opponent.

AUTHOR CONTRIBUTIONS

Conceptualisation, methodology: H.T. and M.A.K.; data collection: H.T.; data processing: H.T.; formal analysis and writing—original draft preparation: H.T.; writing—review and editing: M.A.K.; supervision: M.A.K. All authors have read and agree to the published version of the manuscript.

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