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Original Article

Grip force and pressure distribution analysis of three badminton forehand overhead strokes of male and female players: A case study

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Abstract:
Badminton players rely on their hands to grip and control the racket face during play. This study aimed to explore how players use their fingers to manipulate the racket, an area with limited dynamic analysis in existing research. Specifically, we examined the distribution of grip force and pressure during three forehand strokes - drop, clear, and smash - between male and female university players. The grip distribution analysis focused on 18 regions of the dominant hand. A Phantom high-speed digital camera and palm pressure sensors were synchronized to capture 2-D kinematic data and record finger force and pressure signals from the preparation phase to the point of contact and follow-through. The results showed that male player performed higher smash velocity compared to female player. The greatest finger force and pressure of clear and smash strokes were appeared at distal phalanx of the middle finger in both genders. The finger force distribution at the point of contact for clears and smashes was similar between male and female participants, yet differed for the drop shots. As shuttlecock velocity increased, the upswing duration time decreased, and the maximum resultant finger force and pressure, the peak resultant finger force and pressure at the contact point increased. The results of the study found that the grip distribution during the forehand stroke. Grip strength training should be identified as crucial for enhancing shuttle velocity. This study provides valuable insights into badminton biomechanics and finger force dynamics, aiding badminton players and coaches in improving badminton technique performance.
Key Words: biomechanics, finger forces, smash, clear, drop shot

Introduction

Badminton is the fastest racket sport (Guinness World Records, 2024) and globally recognized as one of the most popular participating sports, second to soccer only (PledgeSports, 2024). There are four basic techniques of badminton: stance, grip (Prajongjai et al, 2023), strokes and footwork (Arnando et al 2023).

Regarding the badminton techniques, (Louie, 1990) examined the factor structure of the badminton skills for college students in the domain of human motor performance and selected 10 badminton skill tests and found that overhead strokes were one of the three common factors. The forehand stroke (Figure 1) is one of the most critical skills in badminton. It can be further divided into three primary techniques: drop shot, clear, and smash strokes (Figure 2).

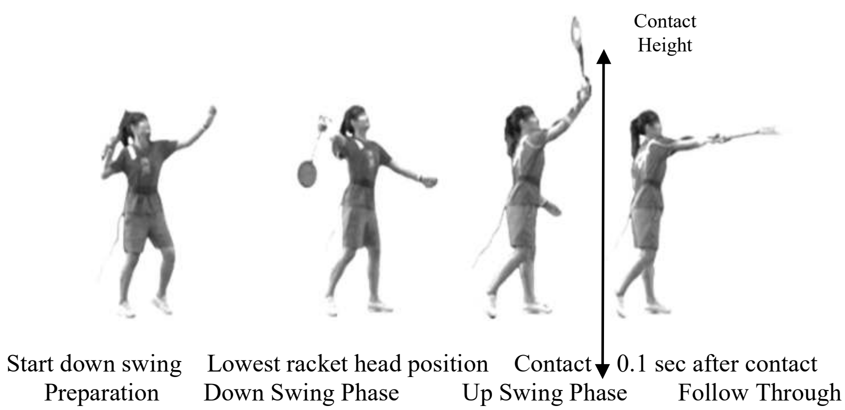

Figure 1. The Badminton Forehand Over Strokes

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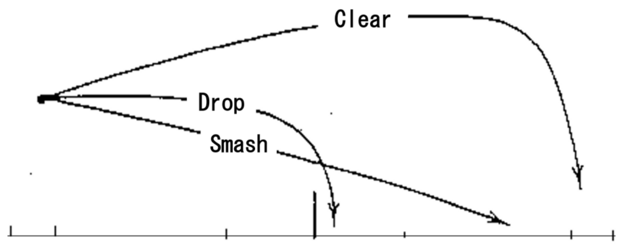

Figure 2 The Trajectory of 3 Strokes- Smash, Clear and Drop

Since the 1960s, there had been a significant amount of researches on badminton biomechanics. For instance, Broer & Houtz (1967) analyzed the specific patterns of muscle activity involved in executing various badminton strokes; Adrian & Enberg (1971) analyzed the sequences of the forehand throwing movements of badminton smash, volleyball spike, and tennis serve skills with a high-speed cinematographical camera. The result showed how athletes coordinated their muscle to execute the movements efficiently; Gowitzke & Waddell (1979) focused on the scientific theory of the badminton techniques, including the mechanics of movement, muscle activation, and coordination required for various badminton strokes to point out the strategies of badminton game for coaching and enhanced the performance of the badminton players, and reduced the risk of injury; Poole (1970) analyzed the forehand smash movement with a cinematographic camera (60Hz) and found that world-class players carried out the largest increasing velocity at 0.017 seconds before the contact point. In addition, the wrist seemed producing the most contribution in smash stroke. Xie, et al (2001) utilized six color video cameras (50Hz) to record the kinematics data of world-class players in the final round of competition and found that the top elite players' smash velocity were from 56.8 m/s to 64.9 m/s, with the maximum velocity was 68.7 m/s; Tsai et al, (1996), (1997), (1998), (2003), (2004), Pan, et al (2007), Hsueh, et al (2012), and Liao, et al (2014) recorded the different badminton techniques of the top-ranked players in the world and the elite badminton players to obtain kinematics data.

The dynamical variables included initial velocities, contact height, and upper arm angular data of different badminton techniques. They found that as the initial shuttle velocity increased, the contact height also increased; Tsai et al, (2003) analyzed the differences between the badminton standing smash and the jumping smash in different target setups and found that the jumping smash created a faster shuttle velocity, possibly because the degree of freedom of the jumping smash was greater than standing smash; Ferreira, et al (2020) investigated the relationships between initial shuttle velocity during a badminton forehand stand smash and jump smash with upper limb muscles, vertical jump height, and analyzed differences in these parameters for each gender. They found that the male participants had higher values than the female participants in all measured variables. Tang, et al (1995) and Tang & Toyoshima (1997) analyzed the rotation of the forearm and wrist during a badminton smash; Tsai, et al (2000) analyzed the inverse dynamics of the upper limbs in drop shots, clears, and smashes. They found that while the kinematic patterns of clears and smashes were similar, they differed from those of drop shots. Additionally, they noted that wrist extensor muscles undergo eccentric contraction before impact in smashes, during impact in clears, and after impact in drop shots; Tsai, Lin, Huang, Chang & Cheng (2001) analyzed the badminton forehand smash and found badminton players experienced wrist extensor muscle soreness after practice due to the eccentric contraction in strong forceful overhead strokes. Sakurai & Ohtsuki (2000) used the EMG approach to measure the upper limb muscles of skilled and unskilled badminton participants and found that the extensor carpi radialis and flexor carpi ulnaris were more unstable in the unskilled participants compared to the skilled ones after 6 days of practice, but the proximal muscles showed a similar pattern between the unskilled participants. It is important for achieving accurate performance of the smash in badminton to control the distal muscles. Tsai, Yang, Lin, & Huang (2005), Tsai, Huang, & Chang (2005), Tsai, Hsueh, Pan, Chang, and Yu (2008) and Tsai, Yang, Lin, Huang & Chang (2006), Hsueh, Tsai, Pan, & Chang (2010), conducted EMG analyses of the various badminton forehand and backhand strokes, presented the various EMG patterns in different strokes, and found that wrist extensor muscles engaged in eccentric contraction around the moment of impact during badminton smash.

Current grip strength research primarily relates to use in golf swing analysis. Komi, Roberts, and Rothberg (2008) used thin, flexible sensors placed in 31 locations on a golfer's glove or bare hand to measure the interactive forces between the hands and the golf club grip. Their study, focusing solely on driver swings, reported that grip pressures were different among the golfers while the swing trace patterns in each golfer were repeatable. Yang, et al (2021) investigated the distribution of grip pressure, force, and the peak pressure of different phases during the golf putting stroke. They found the grip pressure started to increase during the downswing and reached its peak, 0.02 ± 0.05s, before impact (4.70±1.97 Kpa). Results indicate that grip pressure does not remain the same throughout the stroke. Broker and Ramey (2007) presented grip force data from a professional golfer, confirming that grip force and pressure distribution vary during the swing. The professional's total grip force aroused immediately after the top of the swing, reached a local minimum near impact, and increased again after impact. Grip pressure research clarifies the critical interactions between a golfer's hands and the club. Early empirical evidence contradicts many opinions from elite professional golfers. However, research on this topic is rare, and several important issues remain unexplored. Notably, grip pressure profiles across different clubs for the same golfer have not been reported. The variability of grip pressure profiles within swing phases, among individual golfers, and between golfers has also not been fully described.

Despite extensive researches on badminton biomechanics and grip strength in other fields, detailed analysis using finger pressure studies in badminton remains limited. Rossi, et al (2010) measured the differences in total grip force among four basic badminton strokes: forehand, backhand, smash, and net roll, finding that grip force was greatest in the smash stroke. However, the study did not specify the palm's grip distribution; Pan & Tsai (2023) found that the pressure distribution at contact points during clear and smash of an elite male university player was similar but differed from that in drop shots. Since the hand, as the most distal part of the upper body, is responsible for holding and controlling the racket, the dynamic process of fingers involve in badminton strokes remains unclear. We aim to explore which region of the hand bears the greatest force during the racket swing and appear at what moment. Additionally, we seek to determine which finger parts experience the greatest force and pressure at the moment of impact. The purposes of the study were to measure the finger strength and pressure distribution across eighteen finger positions (Figure 3) during different phases of forehand overhead strokes (drop, clear and smash) for one male and one female college Level 1st badminton player. We were interested in analyze the dynamics changes in finger force from the preparation phase to contact point and follow-through. The variables in the study were shuttle velocity, contact height, contact duration time, grip force and grip pressure. We calculated the correlations between variables in each stroke phase. And the patterns of finger force distribution during strokes between male and female players.

Material & methods

One male (height: 172 cm, weight: 68 kg) and one female (height: 163 cm, weight: 49 kg) right-handed level-one college badminton players served as the participants in the study.

A Tekscan Grip 4256E finger pressure devices (Tekscan, South Boston, MA, USA; 500Hz) to collect finger force and pressure signals at 18 regions on the players' racket-holding palms (Figure 3). A PHANTOM VEO 710L-18GB-Mono high-speed camera (2000Hz) was synchronized to record the players' stroke actions. The finger force and pressure signals were calculated with the software of Tekscan. The badminton forehand overhead motion image data were captured and processed using Phantom CineViewer 3.4 software.

1. Distal phalanx of thumb
2. Proximal phalanx of thumb
3,4,5. Distal, Middle, Proximal
phalanx of index finger
6,7,8. Distal, Middle, Proximal
phalanx of middle finger
9,10,11. Distal, Middle, Proximalphalanx of the ring finger
12,13,14. Distal, Middle, Proximal
phalanx of little finger
15. Metacarpal of index finger
16. Third to fifth metacarpal
17. Thenar
18. Hypothenar

Figure 3. The Tekscan Palm pressure sensors

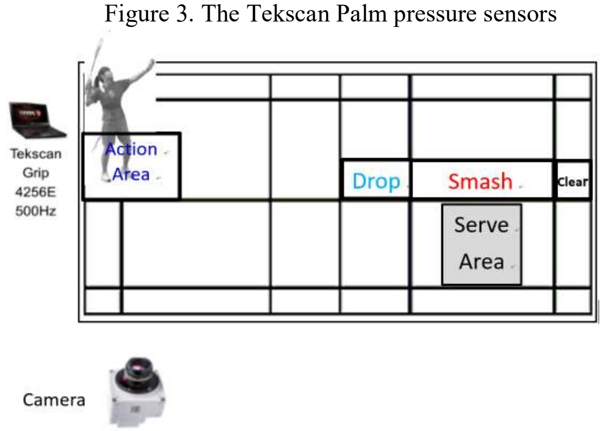

Figure 4. The Schematic of the Experimental Setup

Data Collection

The data collection focused on the time frame from 0.7 seconds before shuttle impact to 0.1 seconds after impact. The participants were standing at the rear of the court to prepare to hit the shuttle that was high-served over the net from the opposite court by a badminton player. The participants performed the drop, the clear and the smash strokes in the motion area on the badminton court as in the figure of the experimental setup. The action area, the serving area, and the landing areas of the drop, the clear and the smash strokes are shown in Figure 4. At least two successful trials of each movement of the participants were collected and chose the best trial of each participant for analysis. The stroke action was divided into several phases: The preparation phase, the down-wing phase, the up-swing phase, and the follow-through phase. The preparation phase was when the participants had moved to the action area to prepare to perform the forehand overhead strokes, the down-wing phase was from the racket head start to going downward and to the lowest racket head position, and the up-swing phase was from the lowest racket head position to the point of impact with the shuttlecock, and the follow through phase was from the contact point to the movement 0.1 seconds after contact. The finger dynamical force and pressure variables were analyzed throughout these phases. We measured kinematic parameters such as shuttlecock velocity, contact height, and shuttlecock flight angle post-impact, and dynamical force and pressure variables as the finger grip resultant force and pressure, specific finger grip force and pressure of each region. The experimental setup is schematically represented in Figure 4. Prior to the experiment, grip signals were calibrated by using a 4.55 kg dumbbell to fit one-point linear regression curves for each specific area with Tekscan software (Figure 5). Figure 6 outlines the framework of the study, emphasizing the collection and analysis of finger force variations during different stroke phases.

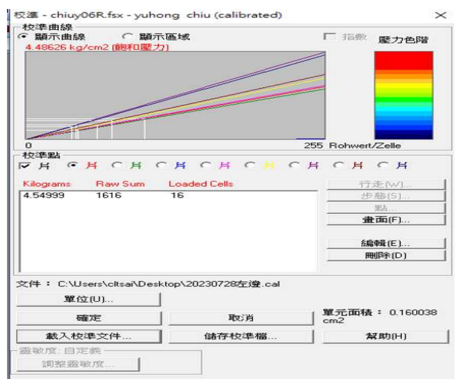

Figure 5. The Calibration of the Tekscan Grip System

Data Analysis

We aimed to calculate kinematics and grip force variables, including:

- Initial shuttlecock velocity: the initial velocity of the shuttlecock that the shuttle completely got away from the racket face after the contact point with the shuttlecock.
- Contact height: the height of the shuttlecock while the racket face contact with the shuttlecock cork base.
- Resultant grip force during movement: the sum force value of 18 grip region area force during movement.

$$\text{Force}_{\text{Resultant}} = \sum_{n=1}^{18} F\,n$$

- Resultant grip pressure during movement: the sum grip force value divided by the palm contact area between the palm and the grip of the racket.

$$\text{Pressure}_{\text{Resultant}} = \frac{\sum_{n=1}^{18} Fn}{\sum_{n=1}^{18} \text{Contact Area } n} = \frac{\text{Total Grip Force}}{\text{Total Contact Area}}$$

- Maximum resultant grip pressure during movement: the maximum pressure value calculated from each frame of the sum grip force value divided by the palm contact area during movement.
- Resultant grip force (pressure) during the preparation phase: the resultant grip force (pressure) value at the racket head began to downward movement.
- Resultant grip force (pressure) at the start of the upswing movement: the resultant grip force (pressure) value at the racket head began to upswing movement.
- Resultant grip force (pressure) at the contact point: the resultant grip force (pressure) value at the point that the shuttlecock cork base contacted with the racket face.
- Resultant grip force (pressure) of follow-through: Resultant grip force during the follow-through phase at 0.1 seconds post-contact.

- Top three regions of grip force (pressure) at the contact point: Top three regions of grip force (pressure) on the palm at the contact point during drop, clear, and smash strokes.
- A Spearman's Rank Correlation was used to calculate the correlation between the kinematics and the grip variables at .05 significant levels by using the SPSS 23.0 software.

Ethical Considerations

This study received approval from the Ethical Review Board of National Taiwan Normal University, and informed consent form was announced and obtained from all participants before testing.

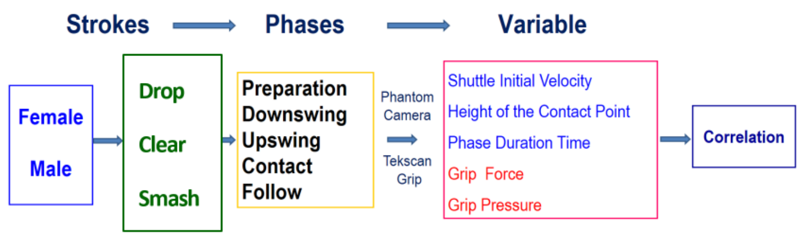

Figure 6. The framework of the study

Results

The participants' kinematic data was presented in table 1. We found that the velocities of forehand drop and clear were similar for both male and female players, likely due to the fixed court conditions. However, the smash velocity of the male player in this experiment was much faster than the female player. The height of the contact point with the shuttlecock was similar for both the male and the female players. However, after normalizing with the body height, the contact height of the male player was higher than the female player. After the preparation phase, the racket began to downward. The downward duration time of the female and male players was similar, and the downward duration time was decreasing for both the female and the male players by the order from the drop, clear, and smash. After the downward movement to the racket head was going down to the lowest position, the racket began to go upward.

The upward duration time of the female and male players presented a trend that the upward duration time was decreasing both of the female and the male players also by the order from the drop, clear, and smash. So, the total swing movement time was decreased by the order from the drop, clear, and smash both of the female and the male players. We observed that the male player performed higher finger grip forces from the upswing phase until the follow-through phase after the impact than female player. Compared with the smash and clear strokes, the drop shot grip force was much less.

The grip force patterns were similar between clear and smash strokes, but the drop shot was different. Figure 7 displays the finger grip force curves for executing three stroke actions. Figure 8 illustrates the maximum finger forces of three strokes, showing that the male player exerted greater resultant total finger forces than the female player. It was consistent for both male and female players that the maximum finger resultant force for clears occurred after impact, while for smashes, it occurred before impact. Figure 9 shows the distribution of the top three finger forces at the contact point for the three strokes. Male player performed greater finger forces than female players at the contact point for all three stroke. The greatest finger force region at the contact point of the male player occurred at the distal phalanx of the middle finger, followed by the proximal phalanx of the middle finger, and then the middle phalanx of the middle finger in all three strokes. However, the female player showed different grip force at the contact point, the greatest finger force region at the contact point of the female player occurred at the distal phalanx of the middle finger both in the clear and smash movements, followed by the Metacarpal of the index finger and proximal phalanx of the middle finger in the smash stroke. The greatest finger force region at the contact point of the female player occurred at the distal phalanx of the middle finger, then the proximal phalanx of the middle finger, and the Metacarpal of the index finger in clear stroke.

Table 1: The Kinematics Variables of 3 Strokes

Variables	ρ	Drop		Clear		Smash	
		Female	Male	Female	Male	Female	Male
Initial Shuttle Velocity (m/s)		25.11	25.11	52.69	51.08	47.53	97.2
Contact Point Height (m)		2.202	2.433	2.352	2.459	2.342	2.501
Contact Point Height/Body Height (BH)	*	1.351	1.415	1.443	1.430	1.437	1.454
Down Swing Duration Time (sec)	*	0.356	0.461	0.3075	0.445	0.176	0.383
Up Swing Duration Time (sec)		0.250	0.223	0.1435	0.148	0.120	0.106
Total Swing Movement Time (sec)		0.606	0.684	0.4510	0.633	0.296	0.489
Shuttle Flight Angle after Contact (deg)		18	11	15	29	0	-8
Contact Duration Time (sec)	*	0.0055	0.005	0.0025	0.0025	0.0025	0.0025

*$p < .05$

Table 2: The Finger Force Variables of 3 Strokes

Variables	ρ	Drop Female	Drop Male	Clear Female	Clear Male	Smash Female	Smash Male
Resultant Force of Preparation (N)		34.62	100.86	76.75	87.86	134.29	82.62
Resultant Force of Start Swing Up (N)		53.18	98.88	43.24	125.00	66.44	387.10
Resultant Force at Contact Point (N)	*	106.79	179.67	255.68	371.27	237.43	630.43
Follow Through 0.1sec After Contact (N)	*	81.10	138.02	151.59	222.90	204.44	577.24
Max. Resultant Force (N)	*	109.62	192.94	337.02	579.79	342.20	774.00
Max. Resultant Force Time from Contact (sec)		-0.005	0.084	0.0235	0.056	-0.039	-0.032
Peak Finger Force of the Movement (N)	*	24.83	51.36	92.23	106.59	91.83	144.09
Peak Finger Force Time of the Movement (sec)		0.003	-0.020	-0.0305	-0.024	-0.031	-0.030
1st Large Finger Force at Contact (N)	*	21.88	45.89	70.05	91.60	61.04	112.22
2nd Large Finger Force at Contact (N)		17.69	38.75	33.54	54.60	31.40	107.57
3rd Large Finger Force at Contact (N)		14.91	28.42	20.11	45.41	21.93	94.15

*$p < .05$

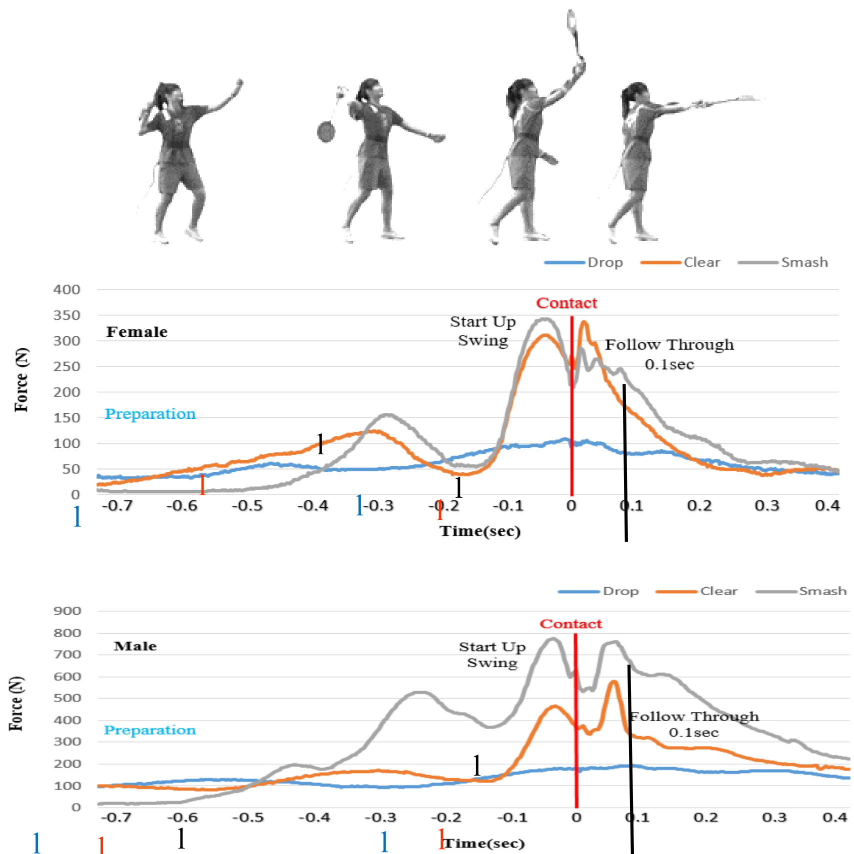

Figure 7: The resultant finger force curves of smash strokes of female and male badminton players

Table 3: The Finger Pressure Variables of 3 Strokes

Variables	ρ	Drop Female	Drop Male	Clear Female	Clear Male	Smash Female	Smash Male
Resultant Pressure of Preparation (N/cm²)		2.92	5.18	4.52	4.54	5.45	4.23
Resultant Pressure of Start Swing Up (N/cm²)		3.46	4.45	3.42	4.41	3.35	9.52
Resultant Pressure at Contact Point (N/cm²)	*	4.84	7.06	7.57	9.51	7.31	15.76
Follow Through 0.1sec After Contact (N/cm²)		3.93	6.90	5.96	6.80	6.08	14.15
Max. Resultant Pressure (N/cm²)	*	5.00	7.99	10.61	13.94	10.04	18.50
Max. Resultant Pressure Time from Contact (sec)		-0.005	0.009	-0.040	0.056	-0.038	0.055
Peak Finger Pressure of the Movement (N/cm²)	*	23.97	34.13	45.63	56.32	53.78	72.84
Peak Finger Pressure Time of the Movement (sec)		0.014	0.138	-0.032	-0.028	-0.006	-0.042
1st Large Finger Pressure at Contact (N/cm²)	*	21.70	22.02	40.20	35.78	37.57	56.02
2nd Large Finger Pressure at Contact (N/cm²)	*	17.54	19.74	34.29	28.43	30.23	49.03
3rd Large Finger Pressure at Contact (N/cm²)	*	15.24	19.12	33.10	23.65	21.03	43.83

*$p < .05$

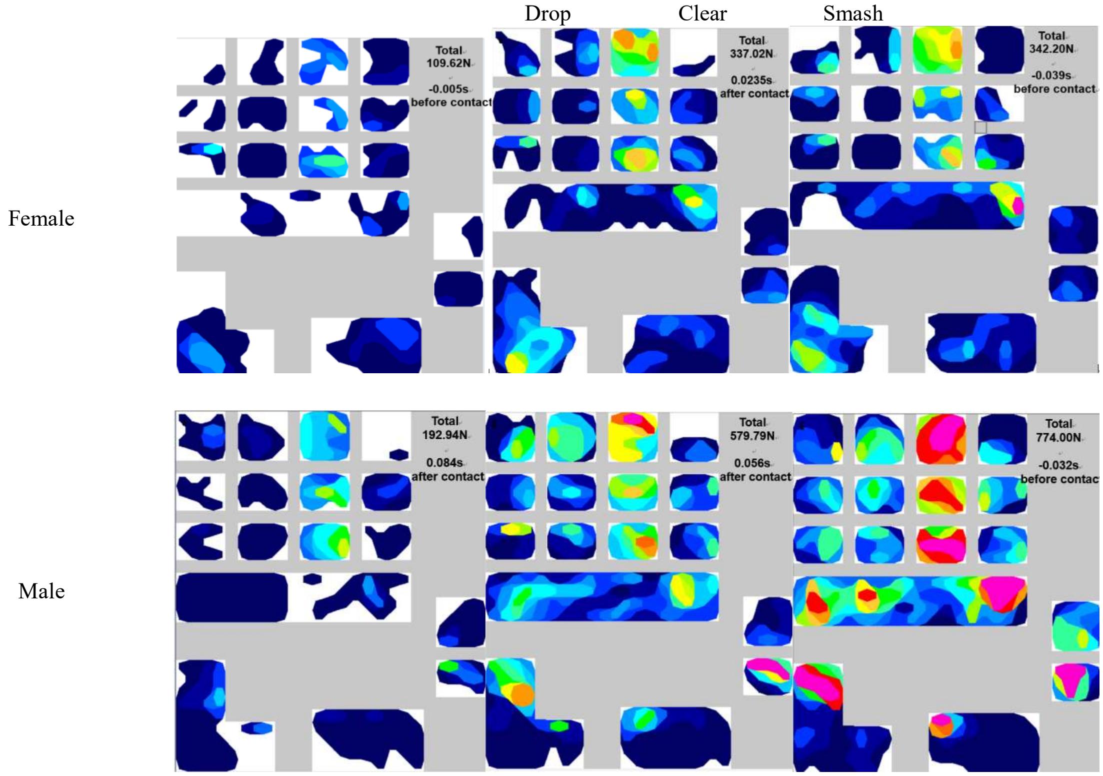

Figure 8: The Maximum resultant finger force of three forehand overhead strokes

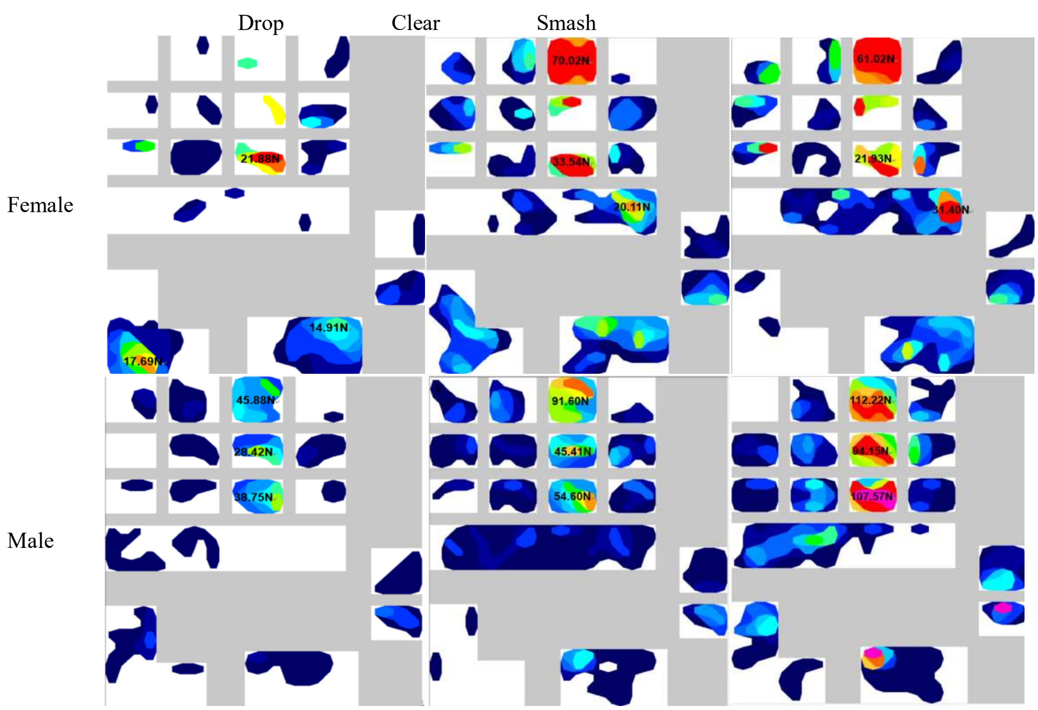

Figure 9: The top 3 finger force distribution of three strokes at contact

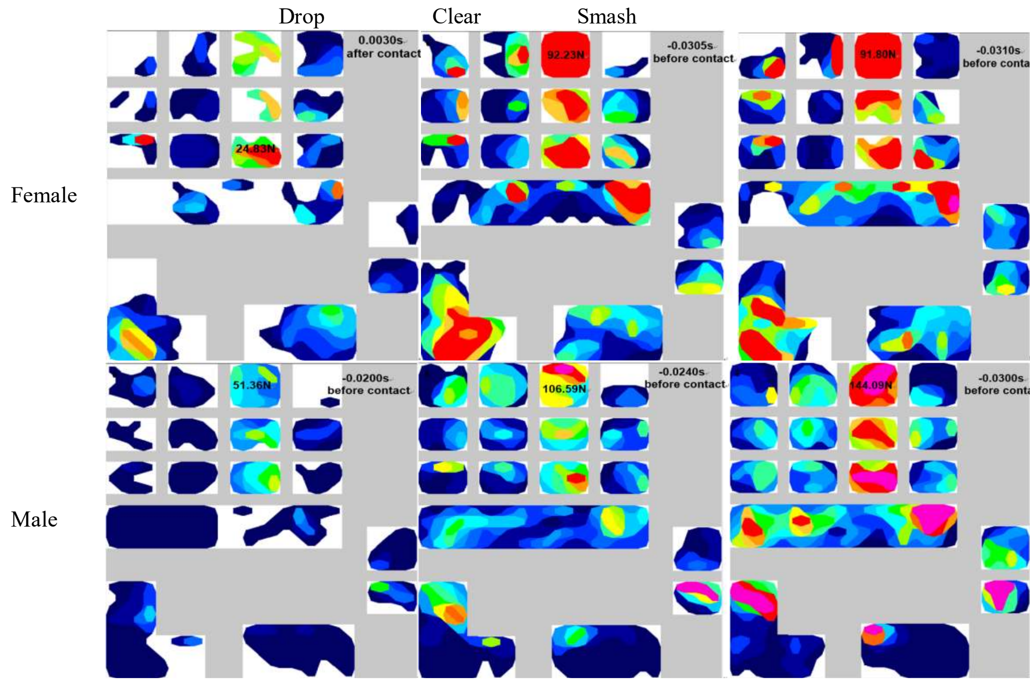

Figure 10: The peak finger force spot and appear time during the movements

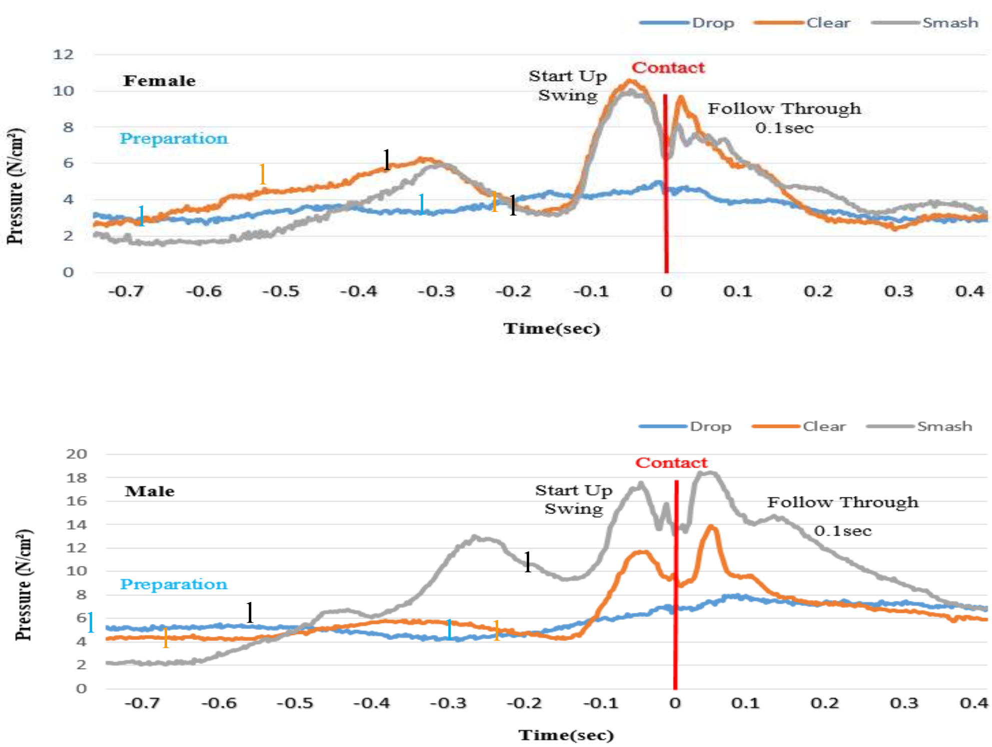

Figure 11: The resultant finger pressure curves of smash strokes of female and male badminton players

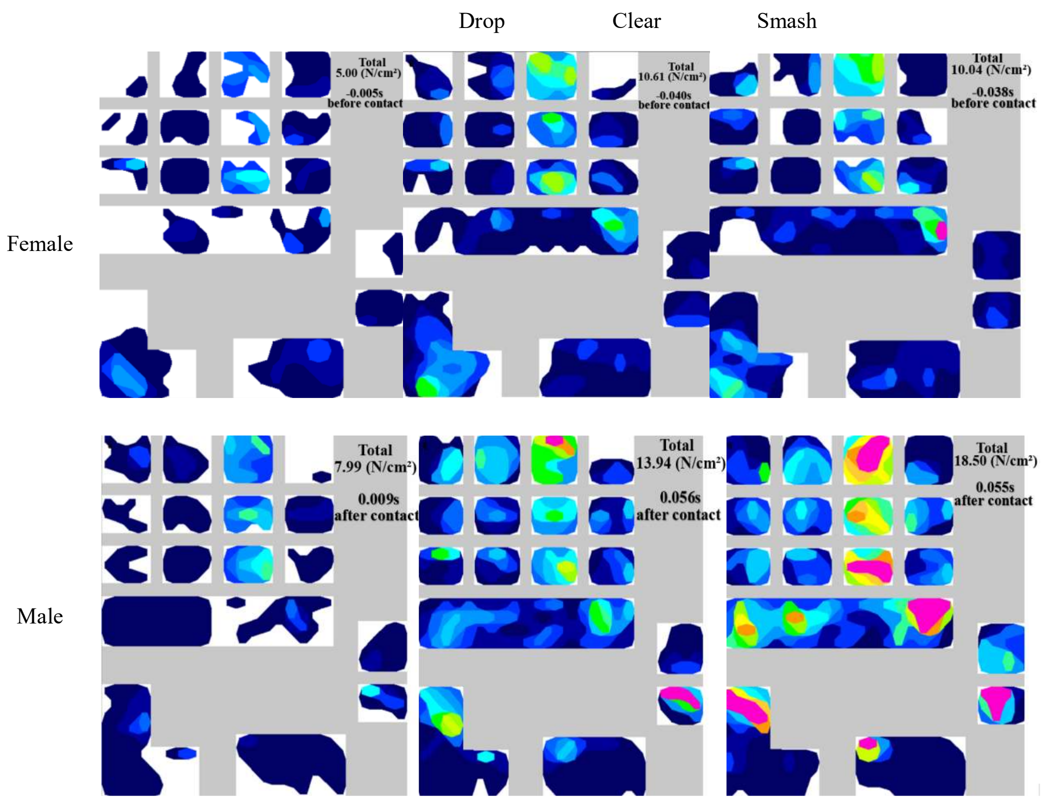

Figure 12: The Maximum resultant finger pressure of three forehand overhead strokes

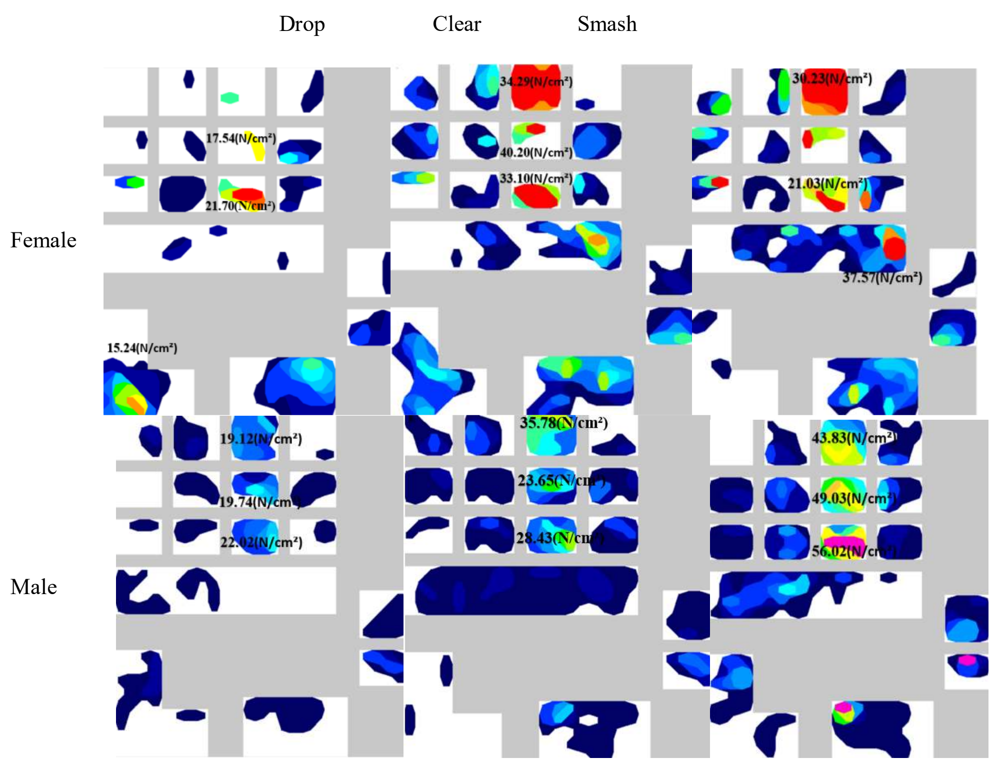

Figure 13: The top 3 finger pressure distribution of three strokes at contact

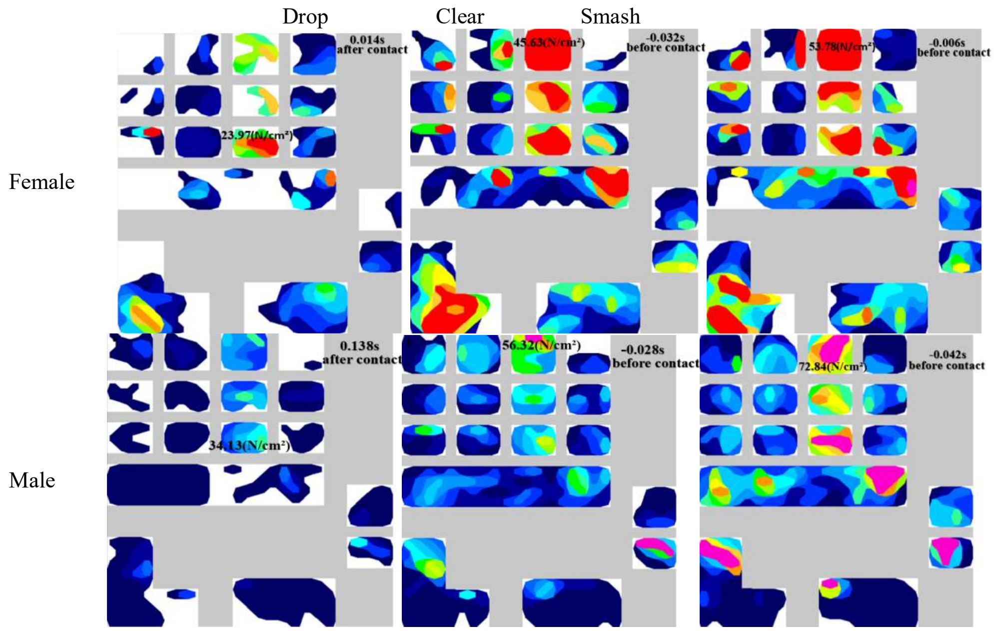

Figure 14: The peak finger pressure spot and appear time during the movements

The top three grip forces of the drop shot of the female player was Proximal phalanx of the middle finger the greatest, the Thenar was the second and the Hypothenar was the third large at the contact point. Figure 10 displays the distribution of finger forces and the timing of peak force in the movement occurrence for the different stroke actions. We found that the peak finger force of the male player occurred at the distal phalanx of the middle finger, and the timing occurrence of peak force was all before impact. The peak finger force at this location was greater for male player than for female player. The peak finger force of the drop shot occurred at the proximal phalanx of the middle finger for the female player, and the peak timing occurrence was after the contact point. The distal phalanx of the middle finger also exhibited the peak finger force for clear and smash of female player, occurring before impact, similar to male players. From the results, we found the female and male players with similar grip force patterns both in the clear and smash strokes, but different from the pattern of drop shot, even the actions among three forehand overhead strokes were similar.

The results also displayed the male player executed more grip force even though the shuttle velocity was similar to the female. Figure 11 shows the finger grip pressure curves for executing three stroke movements. We found that the male player performed greater finger grip pressures than the female player from the upswing phase until the follow-through phase all in the smash, clear and drop shots. Compared with the smash and clear strokes, the drop shot grip pressure pattern was different. The grip pressure patterns were similar between clear and smash strokes, but the grip pressure curves of the drop shot were different from the clear and smash strokes. Figure 12 illustrates the maximum finger pressures of the three strokes, showing that the male player exerted greater resultant finger pressures than the female player, similar to the grip force of the players. The different grip pressure timing of the female and male appeared on the peak resultant pressure. The maximum grip resultant pressure of the female player occurred before the contact point with the shuttle in all three strokes. However, the maximum grip resultant pressure of the male player appeared after the contact point with the shuttle in three strokes. Figure 13 shows the distribution of the top three finger pressures at the contact point of the female and male players for the three strokes. Male player performed greater finger forces than female players at the contact point in drop shot and smash stroke, but the female player showed greater grip pressure in clear stroke. The greatest finger force region at the contact point of the female player occurred at the proximal phalanx of the middle finger, followed by the middle phalanx of the middle finger, and then the Hypothenar in the drop shot.

The top three grip pressures at the contact point of the male player in the drop shot showed that the first large grip pressure appeared on the proximal phalanx of the middle finger, then the middle phalanx of the middle finger, and the distal phalanx of the middle finger was the third. In the clear stroke, the first large grip pressure appeared on the middle phalanx of the middle finger, then the distal phalanx of the middle finger, and the proximal phalanx of the middle finger was the third for the female player. The male player showed different grip pressure at the contact point in clear stroke, the greatest finger pressure region at contact occurred at the distal phalanx of the middle finger, then the proximal phalanx of the middle finger, and the middle phalanx of the middle finger was the third large. The greatest finger force region at the contact point of the female player occurred at the Metacarpal of the index finger, the second occurred at the distal phalanx of the middle finger, followed by the proximal phalanx of the middle finger in the smash stroke. The greatest finger force region at the contact point of the male player occurred at the proximal phalanx of the middle finger, then the middle phalanx of the middle finger, and the distal phalanx of the middle finger in the smash stroke. Figure 14 shows the distribution of finger pressure and the time of peak pressure occurrence for three different forehand overhead movements. We found that the peak finger pressure of female and male players both occurred at the proximal phalanx of the middle finger in the drop shot, and the peak grip force occurred after the shuttle contact. The peak finger pressure of clear and smash strokes occurred at the distal phalanx of the middle finger, and the peak grip force occurred before the shuttle contact both in female and male players. As in Table 2 and Table 3, the variables were calculated with Spearman's Rank Correlation by using SPSS 23.0 software to measure the correlation between the kinematic and grip dynamic variables. The results showed that as the initial shuttle velocity increased, the normalized contact height (contact point height/body height), resultant force at the contact point, follow-through force 0.1sec after contact, the peak maximum resultant force, peak finger force of the movement, the first large finger force at contact, resultant pressure at contact point, maximum resultant pressure, the first large finger pressure at contact, the second large finger pressure at contact, the third large finger pressure at contact were increased. The up-swing duration time and shuttle contact duration time with the racket were decreased while the initial shuttle velocity was increasing.

Discussion

In Table 1, we observed that the sequence of initial shuttle velocities for male players was smash > clear > drop, consistent with previous research by Tsai, Huang, & Jyh, (1997), Tsai, Huang, Lin, & Chang, (2000) . The smash velocity of male players in this experiment was faster than that of previous participants. However, the initial velocity sequence of the shuttlecock for female players was clear > smash > drop, not the same as the previous findings Tsai, Hsueh, Pan, Chang, & Yu, (2008). The duration of the smash action for both male and female players was less than that of clears and drops. The contact duration time between the racket and the shuttlecock was 0.0055 seconds for the female drop shot and 0.005 seconds for the male drop shot. For both male and female players, the contact time between the racket and the shuttlecock during clears and smashes was 0.0025 seconds, slightly faster than in previous studies, likely due to the recording sampling rate of the camera. Figure 8 shows that the male player exerted greater finger resultant forces than the female player. The maximum finger resultant force for clears occurred after impact, while smashes occurred before impact in both male and female players. Figure 9 displays the distribution of the top three finger force areas at the moment of impact for different strokes. However, the female player with the 1st large force value occurred in clear and smashed at the distal phalanx of the middle finger, similar to male players. There were differences in the finger force distribution at the moment of impact between male and female players during the different strokes. Both male and female players showed the largest finger force in the distal phalanx of the middle finger for all three strokes at the point of contact.

For the female player, the peak finger force for clear and smash occurred in the distal phalanx of the middle finger, whereas for drop was occurred in the third phalanx of the middle finger, differing from clears and smashes. This observation was similar to the kinematic findings of Pan & Tsai (2023). The results showed the finger grip force curves for drop strokes were different from those for clears and smashes (Figure 7), with clears and smashes showing more similar patterns compared to drop shot. In Table 2, we found that the maximum resultant force and peak finger force for smash strokes were greater than those for clear and drop for both male and female participants. Additionally, we found that as initial shuttle velocity increased, the peak finger force and resultant finger force at impact also increased for both male and female participants, similar to the findings of Pan & Tsai (2023). The distribution of the top three finger force areas in three strokes was the same for male participants with the distal phalanx of the middle finger, followed by the third phalanx of the middle finger, and then the second phalanx of the middle finger. The strategies of the finger force differed between male and female participants in three stokes. In Table 2, we found that the maximum resultant force and peak finger force for forehand smash strokes occurred before impact for both male and female participants. Tsai, Huang, Lin, & Chang (2000) found that the wrist extensor muscles were executed eccentrically before impact during smash stroke, and this study might indirectly confirm that the resultant action of the wrist extensor and flexor muscles before contact point increases palm grip strength, leading to eccentric contraction of the wrist extensor muscles before impact. In Table 3, we found that the maximum resultant pressure and peak finger pressure for both male and female participants on smash strokes were greater than the maximum resultant pressure and peak finger pressure on clear strokes and drop shots.

This result was similar with the study of Rossi, et al (2010). Furthermore, we noticed that as the initial shuttlecock velocity increased, the peak finger force and pressure also increased in both male and female participants, which is similar to the findings of Pan and Tsai (2023). The distribution of the top three finger pressures at the contact point of the female and male players showed in Figure 13, the male player performed greater finger pressures than female players at the contact point in drop shot and smash stroke, but the female player showed greater grip pressure in clear stroke than the male player. That might be because the female player can do the clear stroke easier than she played the smash stroke. The greatest finger pressure at the contact point of the female player occurred at the proximal phalanx of the middle finger, followed by the middle phalanx of the middle finger, and then the Hypothenar in the drop shot. The male player's first large grip pressure at contact point appeared on the proximal phalanx of the middle finger, then the middle phalanx of the middle finger, and the distal phalanx of the middle finger was the third in drop shot movement. In the clear stroke, the female player's first large grip pressure appeared on the middle phalanx of the middle finger, then the distal phalanx of the middle finger, and the proximal phalanx of the middle finger was the third. The male player showed the greatest finger pressure region at contact occurred at the distal phalanx of the middle finger, then the proximal phalanx of the middle finger, and the middle phalanx of the middle finger was the third largest. Both of the female and male players relied on the middle finger to execute the clear stroke. The greatest finger pressure at the contact point of the female player occurred at the Metacarpal of the index finger, the second occurred at the distal phalanx of the middle finger, followed by the proximal phalanx of the middle finger when she performed a smash stroke.

The greatest finger pressure region occurred at the proximal phalanx of the middle finger, then the middle phalanx of the middle finger, and the distal phalanx of the middle finger in smash stroke for male player. In Table2 and table 3, we found that the peak finger force and pressure on forehand smash strokes occurred before the contact point for both male and female participants. A Spearman's rank correlation was used to measure the correlation between the initial shuttlecock velocities and the grip dynamic variables by using SPSS 23.0 software. The significant correlation (p<.05) showed that as the initial shuttle velocity increased, the normalized contact height, resultant force at the contact point, follow-through force 0.1sec after contact, the maximum resultant force, peak finger force, the first large finger force at contact, resultant pressure at the contact point, maximum resultant pressure, the first large finger pressure at contact, the second large finger pressure at contact, the third large finger pressure at contact were increased. The up-swing duration time and shuttle contact duration time with the racket were decreased while the initial shuttle velocity was increasing.

Conclusions

By using a high-speed cameras and a palm pressure sensors system, we collected the finger force of three different forehand strokes performed by a male and female college level 1st badminton players. The results displayed that the initial shuttle velocity of forehand drop and clear were similar between male and female player, but the smash velocity of the male player was much greater than that of the female player. During the strokes, the male player performed higher finger forces than female player for all three strokes, and the maximum finger grip force during the movements was also higher for male than female. The maximum resultant force and peak finger force for smash strokes occurred before impact for both male and female participants. Among the three forehand overhead strokes, the finger force and pressure curves for smashes and clears were more similar but differed from the drop shot.

We also found that the region of the maximum finger force was appeared at the middle finger, especially the distal phalanx both of the female and male players in smash and clear strokes. As shuttlecock velocity increased, the normalized contact height, resultant force at contact point, follow-through force 0.1sec after contact, the peak maximum resultant force, peak finger force, the first large finger force at contact, resultant pressure at contact point, maximum resultant pressure, the first large finger pressure at contact, the second large finger pressure at contact, the third large finger pressure at contact were increased. We recommend that grip strength training should be paid more attention by badminton players and coaches in order to improve their performance. From the results, we found that the grip dynamics strategies used by the male and female players were different. The strengthened finger force in badminton should contribute to increasing shuttle initial velocity. Since the influence of dynamic finger force variations on badminton performance remains unclear, future research should focus on collecting data from more badminton players to better understand how dynamic finger force affects their swing performance.

Conflicts of Interest: The authors declare no conflicts of interest.

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