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ORIGINAL ARTICLE

# A correlation study on the game of badminton and techniques on shuttlecock durability

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## ABSTRACT

Badminton shuttlecocks are often observed to break after several rallies in elite competitions. These change requests are frequent and considered disruptive to the game. The frequency of shuttlecock changes from 36 official matches from the Olympic Games and Super Series between 1997 and 2020 were observed. An Independent T-test and ANOVA were performed on the means of five relevant game characteristics including: format of play by structure (singles vs doubles) and categories (MS, WS, MD, WD and MD), scoring system (pre-2006 vs post-2006), the frequency of badminton shots (smash, attacking shots and rally) that resulted in shuttlecock changes and total time spent on changing shuttlecocks were analysed. The descriptive and frequency analyses found that singles matches resulted in almost 50% more change requests than doubles matches (18.52 ± 8.76 vs 10.73 ± 5.01) and that MS matches were found to have a disproportionately higher number of shuttlecock changes compared to all other categories of play (11.00 vs 3.57 – 4.80 per match). It was also observed that a considerable portion of game time was spent on changes shuttlecock (9.44% - 24.44%). It is believed that addressing shuttlecock durability will reduce disruption due to frequent shuttlecock changes and improve sustainability of the game.

**Keywords**: Performance analysis, Badminton, Notational analysis, Shuttlecock replacement, Game disruption, Game sustainability.

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## INTRODUCTION

The badminton shuttlecock is the sport projectile used in the game of badminton, which is constructed using 16 avian feathers (homogeneously from either geese or ducks) fixed into a polyester-wrapped natural cork base (Figure 1).

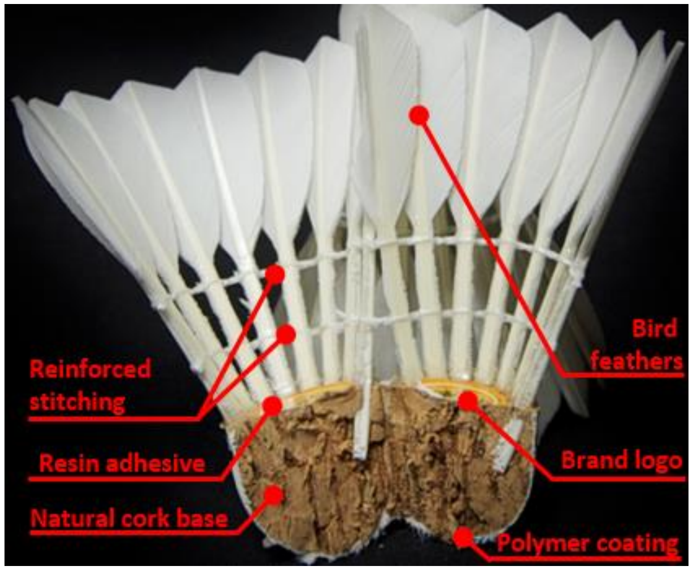



Figure 1. Components of a feather badminton shuttlecock (Woo, 2023).

The shuttlecock, despite being characterized as a high-drag projectile which rapidly decelerates after being launched (White, 2010; Woo and Alam, 2018), is the fastest racquet sport capable of reaching a speed of 565 km/h (Nag, 2023). In international tournaments, it is not uncommon to see players requesting for shuttlecock change after several rallies, or even after a single powerful smash, as a result of breakage. However, change requests at such frequency raises two major concerns including: disruption to the flow of the game and the sustainability of the shuttlecock for use in competitions due to a lack of durability.

This study quantified the frequency of shuttlecock changes in various official competition footages, determine the extent of disruption caused to the game in official matches.

## MATERIALS AND METHODS

### *Participants*

36 official international matches were observed including: 14 Olympic Games (2000 - 2016) and 22 official World Tour competitions over an extended period (1997 - 2019). Matches observed include: 14 men's singles (MS), seven women's singles (WS), four men's doubles (MD), five women's doubles (WD) and six mixed doubles (XD).

The match recordings were obtained from online streaming broadcast services. The quality of videos was appraised to ensure the resolution was appropriate for analysis. As a general criterion, the resolution of standard high definition (1280 x 720 pixels) or above for all post-2006 competition footage was deemed acceptable. Earlier footage (recordings prior to 2006) were exempted from this criterion as it was acknowledged that such video quality has not been implemented.

Figure 2 illustrates examples of gestures used by the different parties that signify a shuttlecock change including the umpire nodding then pointing towards the service judge (not in view) (a). Similarly, players with or without a shuttlecock in hand can also signal for a shuttlecock change (b) or express agreement to the request initiated by an opponent – e.g., making eye contact with the opposing player then waving one's racquet towards the service judge (c1 and c2). The umpire may also announce "*change*", which serves as an auditory cue to indicate approval.

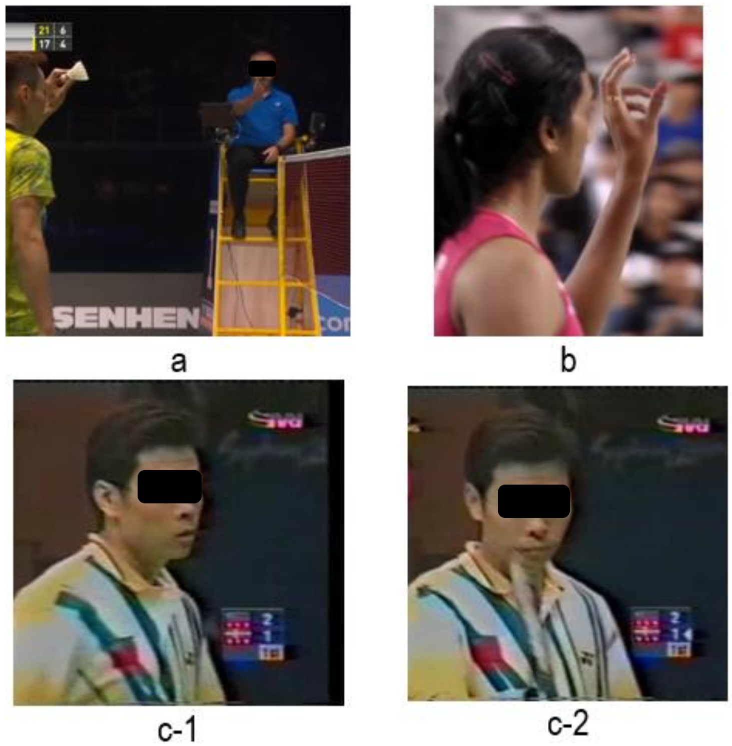



Figure 2. Examples of gestures used by players and umpires to indicate shuttlecock change in a game of badminton (Source: Lai, 2007).

***Parameters***

The game characteristics to be correlated with the frequency of shuttlecock changes include:

- Format of play by structure (singles vs doubles);
- Format of play by category (men's singles (MS) and doubles (MD) matches vs women's singles (WS) and doubles (WD) matches vs mixed doubles (XD) matches);
- Scoring system (pre-2006 vs post-2006);
- Badminton shots (the final shot played that subsequently led to a change);
- Number of exchanges (the cumulative racquet contacts before a change was requested).

*Format of play by structure and category*

The frequency of shuttle changes was analysed based on the difference various game structures and categories as outlined above.

*Scoring system*

Prior to mid-2006, a 15-point and 11-point system were used in the men's and women's games, respectively. The defining feature was the 'server's point' rule, where points are not awarded unless the rally was won by the serving player, with the receiving player only able to win the service. Thus, an indefinite number of shuttlecocks can be expended without a single point being won. With the current 21-point scoring system which adopted the 'rally point' system, points are awarded to the winning player regardless of service, thus reducing shuttlecock use in each match.

*Badminton shots*

The various badminton shots were subcategorized into attacking and rally/defensive shots for further analysis (Figure 3). Shots hit at a flat or downward trajectory were considered attacking shots (e.g., drive/push, smash and net kill), while drop shot was classified as a defensive shot due to the force needed to play the shot was not deemed as destructive in nature as attacking shots. All other shots that launched the shuttlecock in a parabolic trajectory were considered to be defensive shots (i.e., net-drop, defensive deflect, clear and lift). These shots were also considered as 'rally' shots as they typically extend a rally-allowing the defending player to recover from an attack.

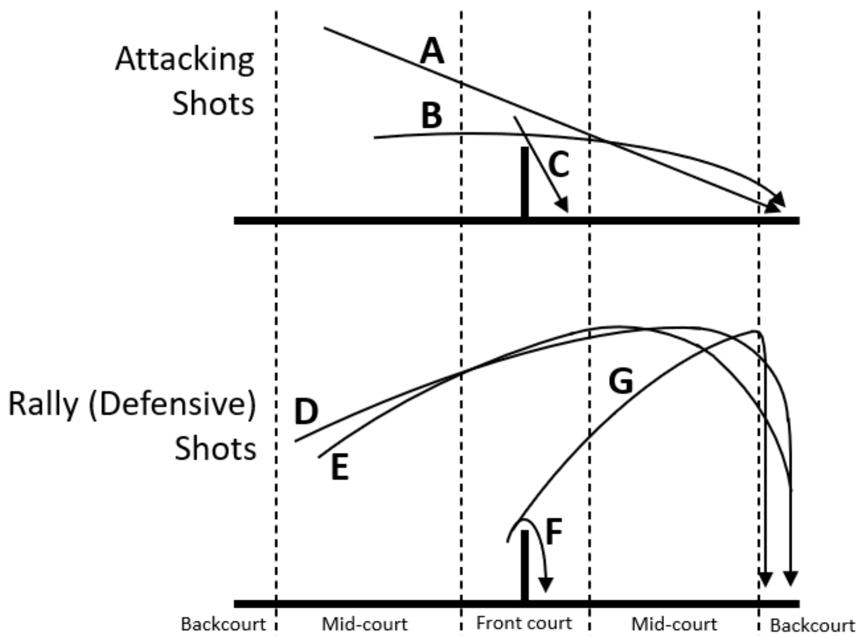



Figure 3. Schematic of the various badminton shots. Attacking shots, such as a: smash **(A)**, drive/push **(B)** or net kill **(C)**, do not consist of only a flat or sharp downward trajectory in a forceful manner and do not have an upward phase; defensive shots, including: defensive clear **(D)**, attacking clear **(E)**, net-drop shot **(F)** or lift shot **(G)**, display an initial upward trajectory before falling.

However, a mistimed frame shot (mishit or shank), may be categorized as attacking or defensive shots depending on the situation. For example, a smash that resulted from an attacking shot would be treated as such, and vice versa for defensive frame shots.

*Exchanges (Rally length)*

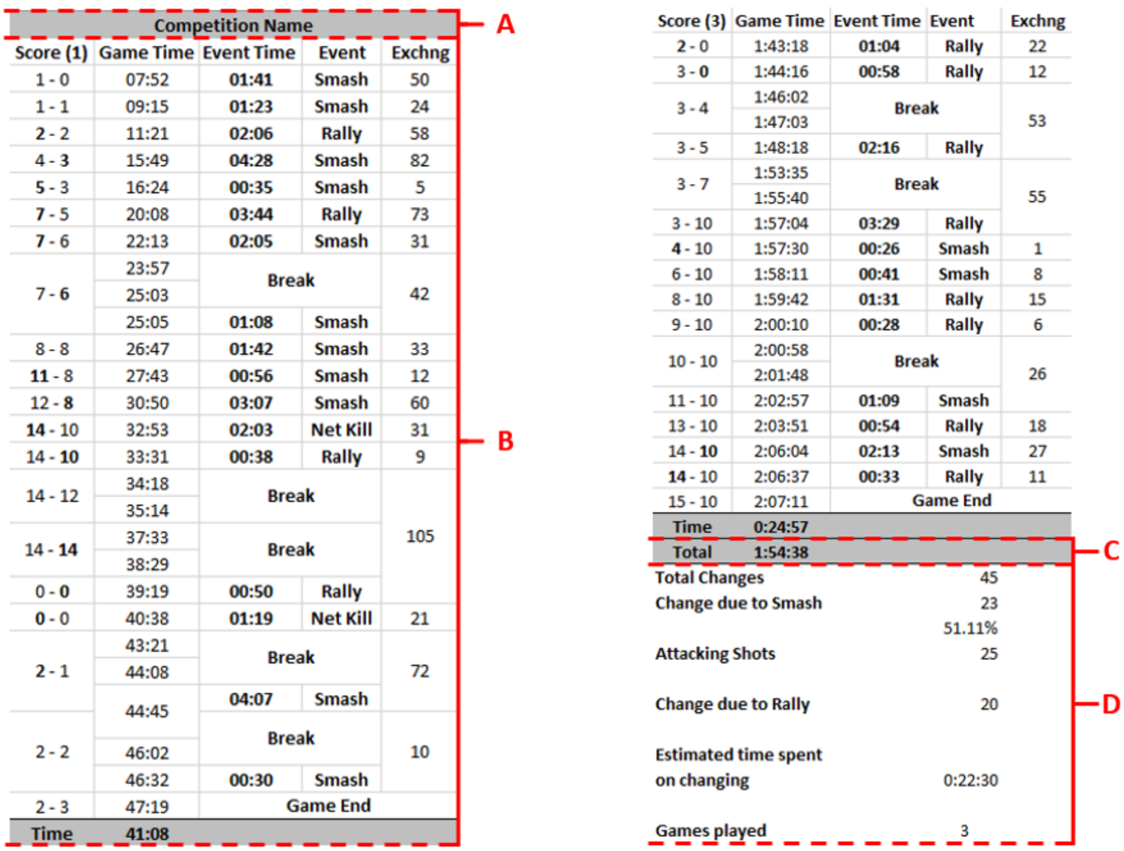
Exchange refers to accumulative count of every racquet-shuttlecock contact during a point-starting with the serve until play of the rally ends-until the shuttlecock is requested for change.

*Notational analysis tool*

Figure 4 shows the notational tool developed to measure the various game parameters for subsequent analysis. The four main elements of the tool are: Competition Name (A): indicates where the specific data were aggregated from—i.e., which tournament and from which match; recording of key events (B), total game time (C) and total match time including the preliminary statistics of the match (D). The rows in between the two grey rows document the observation of events that led to the replacement of shuttlecocks. These observations include (from left to right): the score and number of games played in a match (in brackets, up to three games); starting time of a game in relation to the video footage (as matches rarely commence on 00:00:00); timestamp of the event (Game Time); time difference between the previous and current change of shuttlecock (Event Time); the cause of change (Event); number of racquet contacts made by the shuttlecock ('*exchng*').

The statistics in (D) include: total changes observed in the game; shuttlecock changes attributable to smashes, attacking shots and rally (or defensive shots); estimated time spent on shuttlecock changes (an average of 30s per change); and total number of games played.



Competition Name

| Score (1) | Game Time | Event Time | Event | Exchng |
|---|---|---|---|---|
| 1 - 0 | 07:52 | 01:41 | Smash | 50 |
| 1 - 1 | 09:15 | 01:23 | Smash | 24 |
| 2 - 2 | 11:21 | 02:06 | Rally | 58 |
| 4 - 3 | 15:49 | 04:28 | Smash | 82 |
| 5 - 3 | 16:24 | 00:35 | Smash | 5 |
| 7 - 5 | 20:08 | 03:44 | Rally | 73 |
| 7 - 6 | 22:13 | 02:05 | Smash | 31 |
| 7 - 6 | 23:57 | Break | | 42 |
| | 25:03 | | | |
| | 25:05 | 01:08 | Smash | |
| 8 - 8 | 26:47 | 01:42 | Smash | 33 |
| 11 - 8 | 27:43 | 00:56 | Smash | 12 |
| 12 - 8 | 30:50 | 03:07 | Smash | 60 |
| 14 - 10 | 32:53 | 02:03 | Net Kill | 31 |
| 14 - 10 | 33:31 | 00:38 | Rally | 9 |
| 14 - 12 | 34:18 | Break | | 105 |
| | 35:14 | | | |
| 14 - 14 | 37:33 | Break | | |
| | 38:29 | | | |
| 0 - 0 | 39:19 | 00:50 | Rally | |
| 0 - 0 | 40:38 | 01:19 | Net Kill | 21 |
| 2 - 1 | 43:21 | Break | | 72 |
| | 44:08 | | | |
| | 44:45 | 04:07 | Smash | |
| 2 - 2 | | Break | | 10 |
| | 46:02 | | | |
| | 46:32 | 00:30 | Smash | |
| 2 - 3 | 47:19 | Game End | | |
| Time | 41:08 | | | |

| Score (3) | Game Time | Event Time | Event | Exchng |
|---|---|---|---|---|
| 2 - 0 | 1:43:18 | 01:04 | Rally | 22 |
| 3 - 0 | 1:44:16 | 00:58 | Rally | 12 |
| 3 - 4 | 1:46:02 | Break | | 53 |
| | 1:47:03 | | | |
| 3 - 5 | 1:48:18 | 02:16 | Rally | |
| 3 - 7 | 1:53:35 | Break | | 55 |
| | 1:55:40 | | | |
| 3 - 10 | 1:57:04 | 03:29 | Rally | |
| 4 - 10 | 1:57:30 | 00:26 | Smash | 1 |
| 6 - 10 | 1:58:11 | 00:41 | Smash | 8 |
| 8 - 10 | 1:59:42 | 01:31 | Rally | 15 |
| 9 - 10 | 2:00:10 | 00:28 | Rally | 6 |
| 10 - 10 | 2:00:58 | Break | | 26 |
| | 2:01:48 | | | |
| 11 - 10 | 2:02:57 | 01:09 | Smash | |
| 13 - 10 | 2:03:51 | 00:54 | Rally | 18 |
| 14 - 10 | 2:06:04 | 02:13 | Smash | 27 |
| 14 - 10 | 2:06:37 | 00:33 | Rally | 11 |
| 15 - 10 | 2:07:11 | Game End | | |
| Time | 0:24:57 | | | |
| Total | 1:54:38 | | | |

| | |
|---|---|
| Total Changes | 45 |
| Change due to Smash | 23 |
| | 51.11% |
| Attacking Shots | 25 |
| Change due to Rally | 20 |
| Estimated time spent on changing | 0:22:30 |
| Games played | 3 |



Figure 4. Notational analysis tool devised to capture the critical events that led to shuttlecock replacement during a game of badminton. The layout of the tool consists of several parameters including: **A)** Name of the competition, **B)** Critical events, **C)** Total match time and **D)** Summary of observations.

### *Procedure*

The aforementioned tool described in Figure 4 was prepared prior to analysing each match. Once a request for shuttlecock change was observed, the key event data were recorded as described in the previous section.

In situations where a change was ambiguous, such as when the entire changing process was not broadcast and the visual or auditory cues were not immediately clear, the segment of the video was re-examined for other potential cues as described in Figure 2.

### *Statistical analysis*

SPSS Statistics (v27) was used to conduct a number of statistical analyses on the game characteristics namely: number of shuttlecock changes vs format of play sorted by structure, number of shuttlecock changes vs format of game play sorted by categories, number of shuttlecock changes vs duration of use of each shuttlecock and number of shuttlecock changes vs length of rally. The Independent T-test and one-way analysis of variance (ANOVA) were used on the observations with two and/or three or more groups, respectively. The Tukey-Kramer test was subsequently performed, which accounts for unequal sample sizes, when upon detecting statistical significance in the ANOVA. The effect size of the observations was also estimated.

The standard a-level of $p < .05$ was implemented across all statistical tests.

## RESULTS

### *Format of play by structure*

The descriptive statistics and results of the independent-samples t-test between singles and doubles matches were presented in Table 1 and Table 2, respectively.

Table 1. Descriptive statistics of format of play compared by game structure.

| Observation (per match) | Format of play | *N* | Mean ± SD | SE |
|---|---|---|---|---|
| Change due to smash | Singles | 21 | 8.52 ± 5.56 | 1.21 |
| | Doubles | 15 | 4.60 ± 2.67 | 0.69 |
| Change due to rally | Singles | 21 | 8.24 ± 4.11 | 0.90 |
| | Doubles | 15 | 4.73 ± 3.43 | 0.89 |
| Change due to attacking shots | Singles | 21 | 10.29 ± 6.02 | 1.31 |
| | Doubles | 15 | 6.00 ± 3.34 | 0.86 |
| Total shuttlecock change | Singles | 21 | 18.52 ± 8.76 | 1.91 |
| | Doubles | 15 | 10.73 ± 5.01 | 1.29 |
| Time spent on shuttlecock change | Singles | 21 | 6:20 ± 2:57 | 0:38 |
| | Doubles | 15 | 3:16 ± 1:08 | 0:17 |

Five events were analysed, including: shuttlecock change due to smashes, shuttlecock change due to rally, shuttlecock change due to attacking shots, time spent on shuttlecock change per match and total shuttlecock change per match. The cumulative sample size for singles was inclusive of men's singles and women's singles, while doubles was inclusive of men's doubles, women's doubles, and mixed doubles; the sample size of singles and doubles were 21 and 15, respectively. The mean shuttlecock changes for singles and doubles due to smashes, rally/defensive shots, attacking shots were: 8.52 ± 5.56 and 4.60 ± 2.67; 8.24 ± 4.11 and 4.73 ± 3.43; 10.29 ± 6.02 and 6.00 ± 3.34, respectively. The mean total and time spent on shuttlecocks for singles and doubles were: 18.52 ± 8.76 and 10.73 ± 5.01; 6:20 ± 2:57 and 3:16 ± 1:08, respectively.

When comparing singles to doubles (Table 2), both shuttlecock changes due to rally shots, $t_{(34)} = 2.70$, $p = .011$; d = 0.91 and total shuttlecock change, $t_{(34)} = 3.10$, $p = .004$; d = 1.05, were found to be statistically significant. On the other hand, changes due to: smashes, $t_{(30.437)} = 2.81$, $p < .009$; d = 0.85 and attacking shots, $t_{(32.363)} = 2.73$, $p < .01$; d = 0.84, as well as time spent on changing shuttlecocks, $t_{(27.405)} = 4.32$, $p < .001$; d = 1.28 has also been found to be statistically significant.

Table 2. Independent T-Test on singles and doubles with respect to various causes of shuttlecock change.

| | | Levene*** | | Independent t-test (*p* < .05) | | | |
|---|---|---|---|---|---|---|---|
| | | F | Sig. | df | t | Sig. | Cohen's d |
| Change due to smash | nEV* | 5.447 | .026 | 30.437 | 2.811 | .009 | 0.85 |
| Change due to rally | EV** | .926 | .343 | 34 | 2.696 | .011 | 0.91 |
| Change due to attacking shots | nEV | 4.420 | .043 | 32.363 | 2.728 | .010 | 0.84 |
| Total shuttlecock change | EV | 1.843 | .184 | 34 | 3.075 | .004 | 1.05 |
| Time spent on change | nEV | 4.349 | .045 | 27.405 | 4.318 | .000 | 1.28 |

*Note. * Equal variances not assumed. ** Equal variances assumed. *** Levene's Test.*

***Format of play by category***

The resultant descriptive statistics, test for homogeneity of variances, ANOVA and Tukey test were presented in Table 3.

Table 3. Descriptive statistics for the format of play analysed by category.

| Observation | Sample (N) | | Mean ± SD | SE |
|---|---|---|---|---|
| Change due to smash | MS | 14 | 11.00 ± 4.98 | 1.33 |
| | WS | 4 | 3.57 ± 2.57 | 0.97 |
| | MD | 7 | 4.25 ± 1.89 | 0.95 |
| | WD | 5 | 4.80 ± 4.32 | 1.93 |
| | XD | 6 | 4.67 ± 1.63 | 0.67 |
| Change due to rally | MS | 14 | 8.21 ± 4.53 | 1.21 |
| | WS | 4 | 8.29 ± 3.45 | 1.30 |
| | MD | 7 | 3.75 ± 1.89 | 0.95 |
| | WD | 5 | 6.40 ± 5.03 | 2.25 |
| | XD | 6 | 4.00 ± 2.53 | 1.03 |
| Change due to attacking shots | MS | 14 | 13.07 ± 5.12 | 1.37 |
| | WS | 4 | 4.71 ± 3.09 | 1.17 |
| | MD | 7 | 4.75 ± 2.22 | 1.11 |
| | WD | 5 | 6.60 ± 4.83 | 2.16 |
| | XD | 6 | 6.33 ± 2.81 | 1.15 |
| Total shuttlecock change | MS | 14 | 21.29 ± 8.91 | 2.38 |
| | WS | 4 | 13.00 ± 5.48 | 2.07 |
| | MD | 7 | 8.50 ± 0.58 | 0.29 |
| | WD | 5 | 13.00 ± 7.65 | 3.42 |
| | XD | 6 | 10.33 ± 3.72 | 1.52 |
| Time spent on change | MS | 14 | 7:20 ± 2:57 | 0:47 |
| | WS | 4 | 4:20 ± 1:49 | 0:41 |
| | MD | 7 | 2:50 ± 0:11 | 0:05 |
| | WD | 5 | 3:48 ± 1:44 | 0:46 |
| | XD | 6 | 3:06 ± 0:50 | 0:20 |

The breakdown of the total sample of matches observed (*N* = 36) include (Table 3): 14 men's singles (MS), four women's singles (WS), seven men's doubles (MD), five women's doubles (WD) and six mixed doubles (XD). Regarding mean changes due to smashes (M ± SD), the highest frequency of change was observed in MS matches (11.00 ± 4.98), followed by WD (4.80 ± 4.32), XD (4.67 ± 1.63), MD (4.25 ± 1.89) and WS (3.57 ± 2.57). In contrast, shuttlecock change as a result of a rally point was observed to be more common in WS matches (8.29 ± 3.45), followed by MS (8.29 ± 3.45), WD (6.40 ± 5.03), XD (4.00 ± 2.53) and MD (3.75 ± 1.89).

Shuttlecock changes due to attacking shots observed a higher frequency in MS matches (13.07 ± 5.12), compared to WD (6.60 ± 4.83), XD (6.33 ± 2.81), MD (4.75 ± 2.22) and WS (4.71 ± 3.09). In terms of total changes, MS matches required shuttlecock change at a higher rate (21.29 ± 8.91); with shuttlecock usage in both WS (13.00 ± 5.48) and WD (13.00 ± 7.65) to be similar. This was followed by XD (10.33 ± 3.72) and MD (8.50 ± 0.58). Additionally, MS was also found to have spent the most time on shuttlecock changes per match (7:20 ± 2:57), which was almost two times that of WS matches (4:20 ± 1:49); followed by WD (3:48 ± 1:44), XD (3:06 ± 0:50) and MD (2:50 ± 0:11).

Statistical significance was detected for ($p < .01$): shuttlecock changes due to a smash, changes due to attacking shots, total shuttlecock changes and time spent on shuttlecock changes. The results on changes due to rallies were omitted as no statistical significance have been reported (Table 4).

Table 4. ANOVA performed on the format of play analysed by category.

| | | SS* | df | MS** | F | *p* |
|---|---|---|---|---|---|---|
| Change due to smash | Between groups | 392.958 | 4 | 98.239 | 6.612 | .001 |
| | Within groups | 460.598 | 31 | 14.858 | | |
| | Total | 853.556 | 35 | | | |
| Change due to attacking shots | Between groups | 495.360 | 4 | 123.840 | 7.036 | .001 |
| | Within groups | 545.640 | 31 | 17.601 | | |
| | Total | 1041.000 | 35 | | | |
| Total change | Between groups | 898.032 | 4 | 224.508 | 4.587 | .005 |
| | Within groups | 1517.190 | 31 | 48.942 | | |
| | Total | 2415.222 | 35 | | | |
| Time spent on change | Between groups | 455786.667 | 4 | 113946.667 | 6.563 | .001 |
| | Within groups | 538213.333 | 31 | 17361.720 | | |
| | Total | 994000.000 | 35 | | | |

*Note. *Sum of Squares. **Mean Square.*

A statistical difference for MS was identified for shuttlecock changes due to smashes with a moderate effect size (d = 0.46). Similarly, significance was also indicated for changes due to attacking shots in MS, with a similar effect size (d = 0.48). In contrast, neither of the other format of play were found to be statistically different from each other.

Regarding total shuttlecock changes, MS was found to be significantly different from MD ($p < .023$) and XD ($p < .024$), with a small effect size (d = 0.37). Similarly, in terms of time spent on shuttlecock change, statistical significance was identified for MS when compared to other categories with a moderately significant effect size (d = 0.46).

Table 5. Tukey-Kramer test performed on the ANOVA for format of play analysed by category with shuttlecock change due to smash, attacking shots, total shuttlecock changes and time spent on shuttlecock changes analysed as dependent variables.

| Observation | Format of play (I) | Format of lay (J) | Mean difference (I-J) | SE | *p* | Cohen's d |
|---|---|---|---|---|---|---|
| Change due to smash | MS | WS | 7.43 | 1.78 | .002 | **0.46** |
| | | MD | 6.75 | 2.19 | .009 | |
| | | XD | 6.33 | 1.88 | .005 | |
| Change due to attacking shots | MS | WS | 8.36 | 1.94 | .002 | **0.48** |
| | | MD | 8.32 | 2.38 | .004 | |
| | | XD | 6.74 | 2.05 | .015 | |
| Total changes | MS | MD | 12.79 | 3.97 | .023 | **0.37** |
| | | XD | 10.95 | 3.41 | .024 | |
| | | WS | 03:00 | 01:00 | .044 | |
| Time spent on change | MS | MD | 04:30 | 01:14 | .009 | **0.46** |
| | | WD | 03:32 | 01:08 | .032 | |
| | | XD | 04:13 | 01:04 | .004 | |

*Note. Mean difference of significance set at $\alpha$ = .05. Statistically significant values and their corresponding p-values were highlighted.*

***Scoring system (pre-2006 vs post-2006)***

The statistics and results of the Independent Samples T-Test between the service point (pre-2006) and rally point (post-2006) scoring systems were presented in Table 6 and Table 7, respectively.

Table 6. Descriptive statistics analysed by the change in scoring systems.

| Observation (per match) | Format of play | *N* | Mean ± SD | SE |
|---|---|---|---|---|
| Change due to smash | Pre-2006 (Service Point) | 5 | 8.40 ± 9.58 | 4.29 |
| | Post-2006 (Rally Point) | 31 | 6.65 ± 3.97 | 0.71 |
| Change due to rally | Pre-2006 (Service Point) | 5 | 7.60 ± 6.80 | 3.04 |
| | Post-2006 (Rally Point) | 31 | 6.65 ± 3.75 | 0.67 |
| Change due to attacking shots | Pre-2006 (Service Point) | 5 | 10.40 ± 9.89 | 4.42 |
| | Post-2006 (Rally Point) | 31 | 8.19 ± 4.58 | 0.82 |
| Total shuttlecock change | Pre-2006 (Service Point) | 5 | 18.00 ± 15.41 | 6.89 |
| | Post-2006 (Rally Point) | 31 | 14.84 ± 6.89 | 1.24 |
| Time spent on shuttlecock change | Pre-2006 (Service Point) | 5 | 5:44 ± 05:22 | 2:24 |
| | Post-2006 (Rally Point) | 31 | 4:56 ± 02:17 | 0:24 |

The size of the pre-2006 and the post-2006 groups were five and 31, respectively. The mean data (M ± SD) of shuttlecock change due to smashes for pre-2006 and post-2006 were 8.40 ± 9.58 and 6.65 ± 3.97, respectively. Similarly, shuttlecock change due to rally and attacking shots for pre-2006 and post-2006 were 7.60 ± 6.80 and 6.65 ± 3.75; 10.40 ± 9.89 and 8.19 ± 4.58, respectively. The total shuttlecock changes per match for pre-2006 and post-2006 were observed to be 18.00 ± 15.41 and 14.84 ± 6.89, respectively. The average time spent (mm:ss) on shuttlecock change during a given match in pre-2006 and post-2006 were 05:44 ± 05:22 and 04:56 ± 02:17, respectively.

From the result of Levene's Test for Equality of Variances (Table 7), all five observations reported to be of non-equal variances-i.e., $p < .05$-indicating that the sampled observations may not be treated as originating from the sample population. Given the above analysis, the adjusted degrees of freedom (df), t and *p*-value were therefore applied for subsequent interpretation of results.

Table 7. Independent Samples Test on the difference in scoring systems with respect to various causes of shuttlecock change.

| Observations | | Levene** | | t-test for Equality of Means | | | |
|---|---|---|---|---|---|---|---|
| | | F | Sig. | df | t | *p* | Cohen's d |
| Change due to smash | nEV* | 5.794 | .022 | 4.22 | 0.40 | .71 | 0.35 |
| Change due to rally | nEV | 5.331 | .027 | 4.40 | 0.31 | .77 | 0.23 |
| Change due to attacking shots | nEV | 4.203 | .048 | 4.28 | 0.49 | .65 | 0.40 |
| Total shuttlecock change | nEV | 4.994 | .032 | 4.26 | 0.45 | .67 | 0.38 |
| Time spent on change | nEV | 5.264 | .028 | 4.24 | 0.32 | .76 | 0.28 |

*Note. *Equal variances not assumed. **Levene's Test.*

The results from the Independent Samples Test between the two scoring systems found that shuttlecock changes due to smashes ($t_{(4.22)} = 0.40$, $p > .05$; d = 0.35), changes due to rally ($t_{(4.40)} = 0.31$, $p > .05$; d = 0.23), changes due to attacking shots ($t_{(4.28)} = 0.49$, $p > .05$; d = 0.40), total shuttlecock change ($t_{(4.26)} = 0.45$, $p > .05$; d = 0.38) and time spent on shuttlecock change ($t_{(4.24)} = 0.32$, $p > .05$; d = 0.28) were not statistically different to each other.

***Frequency analysis of badminton shots and duration between changes***

A total of 60 rallies of various rally lengths and the duration between shuttlecock changes from different international matches were selected at random for analysis (Table 8). In regard to the breakdown of the sample observations (*N* = 60), two net drops, one net kill, four lift shots, one drop shot, 34 smashes, six drives/pushes (Atk), three blocks/deflects (Def), six clears and three mishits were recorded as the final shot played prior to a change request.

Table 8. Descriptive statistics of badminton shot types and the corresponding duration of change.

| Observations | | | Mean ± SD | SE | Min | Max |
|---|---|---|---|---|---|---|
| Duration between changes | Net Drop | 2 | 1:59 ± 1:12 | 0:50 | 1:08 | 2:50 |
| | Net Kill | 1 | 2:30 | - | - | - |
| | Lift | 4 | 4:09 ± 2:03 | 1:01 | 2:17 | 6:11 |
| | Drop Shot | 1 | 7:36 | - | - | - |
| | Smash | 34 | 3:07 ± 2:55 | 0:30 | 0:10 | 13:47 |
| | Atk* | 6 | 4:39 ± 3:01 | 1:14 | 0:45 | 9:55 |
| | Def* | 3 | 8:32 ± 5:18 | 3:03 | 2:41 | 13:01 |
| | Clear | 6 | 3:40 ± 1:18 | 0:31 | 2:20 | 6:00 |
| | Mis-hit | 3 | 11:19 ± 6:39 | 3:50 | 3:48 | 16:30 |
| | Total | 60 | 4:06 ± 3:36 | 0:27 | 0:10 | 16:30 |

*Note. * 'Drive/push' and 'Block/deflect' categories were renamed to 'atk' and 'def', respectively; no standard deviation/error can be obtained for categories with only one observation.*

Regarding shuttlecock changes contributed by the various badminton shots (M ± SD), the highest frequency of change was observed in smash (34 out of 60 shots) but was not the shortest in duration (*n* = 34, 03:07 ± 02:55). Atk (*n* = 6, 4.39 ± 3.01) and clears (*n* = 6, 3:40 ± 1:18) were the next most frequent followed by lift shots (n = 4, 4:09 ± 2:03), Def (*n* = 3, 8:32 ± 5:18) and mishits (*n* = 3, 11:19 ± 6:39). Net drops (*n* = 2, 1:59 ± 1:12) were the shortest in use duration; net kills and backcourt drop shots were found to be the least frequent of all. The badminton shot with the largest range was found in smash (0:10 - 13:47) and the smallest range was found in net drop (1:08 - 2:50).

Table 9. Cumulative frequency of badminton shots played that led to shuttlecock change categorized with respect to use duration.

| **Duration of use (min)** | **Last shot played** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Net shot** | | **Lift** | **Drop** | **Smash** | **Atk*** | **Def*** | **Clear** | **Mis-hit** |
| | **Drop** | **Kill** | | | | | | | |
| 0 – 2 | 1 | - | - | - | 15 | 1 | - | - | - |
| 2 – 4 | 1 | 1 | 2 | - | 9 | 2 | 1 | 4 | 1 |
| 4 – 6 | - | - | 1 | - | 5 | 2 | - | 2 | - |
| 6 – 8 | - | - | 1 | 1 | 3 | - | - | - | - |
| 8 – 10 | - | - | - | - | 1 | 1 | 1 | - | - |
| 10 – 12 | - | - | - | - | - | - | - | - | - |
| 12 – 14 | - | - | - | - | 1 | - | 1 | - | 1 |
| >14 | - | - | - | - | - | - | - | - | 1 |
| **% (out of 60)** | **3.33** | **1.67** | **6.67** | **1.67** | **56.67** | **10** | **5** | **10** | **5** |

*Note. * 'Drive/push' and 'Block/deflect' categories were renamed to 'atk' and 'def', respectively; 0 values were replaced with ' - ' to improve readability.*

The cumulative frequency of each badminton shot that led to shuttlecock changes was further sorted into two-minute intervals up to 14 minutes and above (Table 9). It could be seen that majority (48 of 60) of shuttlecock changes occurred within the first six minutes of use. Overall, smashes accounted for 56.67% of all shuttlecock changes with 24 out of 34 (70.59%) of them occurring within the first four minutes. As the duration of use increased, the number of shuttlecock changes contributed by smash decreased. Meanwhile, between 2 - 4 minutes saw the greatest number of changes overall-both in count and variety of last shot played. Attacking shots, or drive/push type badminton shots, and clears were found to be the next largest contributor each accounting for 10% (6 out of 60) of all changes.

### *Frequency analysis of badminton shots and length of rallies*

Table 10. Cumulative frequency of badminton shots played that led to shuttlecock change categorized with respect to rally length.

| **Rally length** | **Last shot played** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Net** | | **Lift** | **Drop** | **Smash** | **Atk*** | **Def*** | **Clear** | **Mis-hit** |
| | **Drop** | **Kill** | | | | | | | |
| 1 - 19 Shots | 1 | - | - | - | 8 | 1 | - | - | - |
| 20 - 39 Shots | - | - | 1 | - | 8 | - | - | 1 | - |
| 40 - 59 Shots | 1 | - | 1 | - | 7 | - | 1 | - | - |
| 60 - 79 Shots | - | 1 | - | - | 5 | 2 | - | 1 | 1 |
| 80 - 99 Shots | - | - | 2 | - | 2 | 2 | - | 4 | - |
| 100+ Shots | - | - | - | 1 | 4 | 1 | 2 | - | 2 |
| % (out of 60) | **3.33** | **1.67** | **6.67** | **1.67** | **56.67** | **10** | **5** | **10** | **5** |

*Note. * 'Drive/push' and 'Block/deflect' categories were renamed to 'atk' and 'def', respectively; 0 values were replaced with ' - ' to improve readability.*

The aforementioned categories of badminton shots from the 60 observations were further reorganized by their respective number of racquet contacts (rally length), before a change request was observed. The groups were set to 19-shot intervals (e.g., 1 – 19, 20 – 39… up to 100+ contacts) (Table 10).

It could be seen that the shuttlecock changes were more evenly distributed across the number of racquet contacts compared to that of duration of use (Table 9). An increasing trend could be observed for smashes, where the majority (23 out of 34) of changes occurred within the initial 59 shots. As the rally lengths extend beyond 59 shots, the contribution of shuttlecock changes by shots other than smash was also saw an increase (7 vs 19 shots). Meanwhile, an evenly distributed amount of shuttlecock changes-i.e., 10 changes-per rally length group was observed. The largest variety of shuttlecock changes were seen in the '60 – 79 shots' and '100+ shots' group, respectively.

## DISCUSSION

The aim of this study was to identify correlations between the frequency of badminton shuttlecock changes and several game characteristics—including: the format of play, scoring system, badminton shots and the length of exchange, or rally. This, in turn, allowed an insight into the sustainability, or durability, of feather shuttlecocks, or lack thereof, to be gained; subsequently, enabling one to determine the extent of disruption of the game due to changing shuttlecocks.

### *Correlation between format of play and shuttlecock changes*

The descriptive and Independent T-test statistics on shuttlecock changes in relation to the match structure observed 50% more shuttlecock changes per match in singles than doubles (18.52 vs 10.73). Based on the recorded time spent on changing shuttlecocks for singles and doubles (6:20 vs 3:16), the average use duration of a single shuttlecock for singles and doubles were appropriately 2:55 and 3:39 minutes, respectively. Moreover, the large estimated effect sizes (0.84 – 0.91) observed between singles and doubles, in the changes due to the different badminton shots (smash, rally and attacking shots) differed by approximately one standard deviations on average, were also found to be statistically significant ($p < .05$). Most notable, time spent on change reported the largest effective size (1.28), suggesting both statistical and practical differences in the singles matches compared to doubles.

An in-depth examination of changes due to smash saw a 2- to 3-fold difference in the number of changes made in MS matches compared to the other categories (11.00 vs 3.57 – 4.80 per match) was observed. Regarding changes due to attacking shots, which compared all high-impact and/or high-speed badminton shots such as drives/pushes, net kills, and smashes, a marginal increase (13.07 vs 4.71 – 6.60) in changes per match was reported. This finding therefore supports that smash contributed to the vast majority of changes amongst all attacking shots; the same pattern was observed for total number of shuttlecock changes per match when MS is compared to the rest of categories (21.29 vs 8.50 – 13).

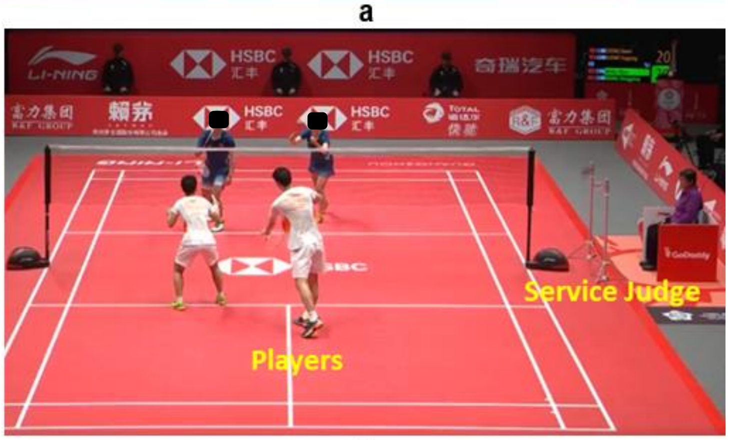
Additionally, a medium effect size was also identified for MS compared to the other format of play in the ANOVA and Tukey test with respect to shuttlecock changes due to smashes (0.46), and a minor increase in magnitude when attacking shots was compared (0.48). In contrary, no significant differences were found amongst MD, WS, WD and XD. This therefore may be suggestive of smashes in men's singles is a major factor to shuttlecock changes.

In regards to time spent on shuttlecock changes per match, MS matches (≈7:20 mins, 24.44%) was found to spend between two to three times more time in changing shuttles than all other categories-i.e., WS (≈4:20

mins, 14.44%), WD (≈3:48 mins, 12.67%), XD (≈3:06 mins, 10.33%) and MD (≈2:50 mins, 9.44%)-an equivalent of 9.44% - 24.44% of game time being spent on replacing shuttlecocks based on an average game time of 30 minutes (International Olympic Committee, 2013). The longer time as observed for a game of singles, compared to doubles, may be a direct reflection that players were required to travel the full distance to reach the service judge in order to receive a new shuttlecock (Figure 5a) rather than in the case of a doubles match (Figure 5b).


a




b

Figure 5. Comparison of the potential distance players need to travel to reach the service judge between singles (Source: HSBC BWF World Tour MS Finals 2019) and doubles (Source: HSBC BWF World Tour MD Finals 2019).

In the case of singles, players must walk the full distance themselves to reach the service judge to receive the new shuttlecock, whereas under most circumstances a shorter distance is travelled in a doubles situation. In the worst-case scenario, the distance travelled, and time spent in the doubles setting may be similar to that of a singles match-assuming that both players are standing in the same point on the court which is probabilistically low. The implication of the results highlights the excessive nature of shuttlecock changes that is currently occurring in singles matches and must be addressed with a viable solution-a shuttlecock alternative that offers greater durability and is not hampered in aerodynamic performance.

However, it should be noted that the observations of MS matches constitute 14 of all 36 observations. The abundance of MS videos is believed to be the result of the spectator community prefers viewing the high-speed nature of the male matches, which is often perceived one of the defining features of elite badminton games. For this reason, the fast-paced exchanges seen in the men's competitions-especially when played by top ranked players-are often considered the pinnacle of badminton in terms of athleticism (even though female players are no less impressive in their own right). Secondly, the "*entertainment aspect*" can be attributed to the occasional "*dive defence*" and trick/deceptive shots that are performed by male players at a seemingly higher frequency at international competitions compared to their female counterparts. However, as the spectatorship aspect of the sport is not within the scope of this study it cannot be verified.

***Shuttlecock changes with respect to the scoring system***

The main reason for the small samples for the pre-2006 group in this research activity was due to video footages of adequate resolution to be included for analysis prior to 2006 had been scarce-most of the video recordings were of the typical analogue tape cassette resolution of 480 pixels at best with most footages at even lower quality making any visual cues difficult to be determined. It was of a surprise that the Independent T-test on the change in scoring systems only reported a small-to-medium effective size (0.23 – 0.40)—with no statistical significance—in relation to shuttlecock changes, given the potential for unlimited use of shuttlecocks in the pre-2006 scoring system as described in Parameters section.

When compared to other sports, one study reported a 30% reduction in $C_D$ in cricket balls of significant wear-and-tear (40-50 overs) compared to new balls (0.4 vs 0.6) (Alam et al., 2010), through regular gameplay, a test cricket ball is said to be able to sustain 60 – 70 minutes of continuous play (Mukherjee, 2020). This is in stark contrast to the game of badminton, which, from the cumulative frequency of use duration (Table 9), found at least 24 shuttlecocks being replaced by smashes alone within the first four minutes of being it replaced. This finding poses a legitimate consideration regarding whether the sport's status quo is sustainable.

***Shuttlecock changes due to badminton shots and rally length***

While it was hypothesized that smashes could potentially possess the shortest duration of use (10s), it also possessed one of the longest use durations (13m 47s). However, it is believed that shorter rallies are better indicators of the true cause of shuttlecock change, as this implies fewer intermediate shots being played prior to the change. This conjecture is believed to be supported by the observation that the largest variety of shots leading to change was observed in the 2 - 4 mins category (Table 8). For longer duration of use, shuttlecocks that sustained various micro-damage from previous rallies may have been considered "*playable*" prior to the commencement of the point. Yet, play must continue until the point ends even if the shuttlecock breaks mid-rally; hence, the cause of change by the type of shot played becomes difficult to determine.

The inverse relationship also observed that the majority of the shuttlecock changes occurred within the first six minutes—coinciding with the period when most of the smashes (34/60 or ≈56.67%) and attacking shots (6/60 or ≈10% each) were recorded (Table 9). This finding suggests that shuttlecock replacements may be attributable to high-impact or high-speed shots (i.e., smashes and attacking shots). In many cases, players have had to request for another change immediately after performing/receiving a powerful smash.

In contrary, it may be argued that both high impact and speed may need to be considered collectively to better represent the cause of shuttlecock damage through a closer examination of lift shots and net kills. While a lift shot is typically high impact, as the shot is played with the intent of hitting the projectile as high and as far back as possible in order for the defending player to take a more favourable court position to defend the next attack. Regarding net kills, despite being an attacking shot, the trajectory is considered much more important as only a short distance (from the top of the net to the ground) needs to be travelled;

consequently, the execution does not entail a destructive swing. In both cases, neither has led to a high shuttlecock change count (four for lifts and one for net kill). This is likely due to the upward trajectory of lift shots provide sufficient time for the projectile to structurally and mechanically recover. Similarly, effective net kills travel in a steep downward trajectory—often described as a ‘tap’—which is unlikely to cause substantial damage. Tactically, players avoid giving the opposing side the chance to perform net kills given the high chance of losing the rally. Hence, these two shots rarely result as “*last shots*”. This, therefore, makes high velocity and high-power shots, such as smashes the prime candidate.

## CONCLUSIONS

The present study examined the frequency of shuttlecock changes in professional badminton with respect to various game characteristics. It was found that singles matches resulted in almost 50% more change requests than doubles matches and that men’s singles were observed to have a disproportionately higher number of shuttlecock changes compared to women’s singles. Up to 7 minutes (≈24.44%) may be spent on changing shuttlecocks in an average 30-minute match. In conclusion, a significant portion of the professional badminton game has spent on shuttlecock changes and may have hindered the flow of the game.

### *Implications*

This study established a high shuttlecock change count in badminton games not observed in any other sports where the change of sport projectiles is permitted. Coupled with the statistical significance and estimate effect sizes observed, it can be concluded that the current design of feather shuttlecocks is evidently not fit for its use. Evidently, the technology associated with shuttlecock design has not developed at the same pace as that of badminton racquets. This is reflected in the projectile’s inability to withstand structural damage inflicted by the current generation of racquets in conjunction with the improved training regimes.

To date, there are no quantitative studies that have investigated the wear-and-tear of badminton shuttlecocks to justify the need to develop synthetic shuttlecocks. On this front, this study is believed to have also demonstrated a need for a viable synthetic shuttlecock alternative to be developed in order to improve address the durability of feather shuttlecocks.

The rapid changes of shuttlecocks may also be an indication that the current feather shuttles cannot match the physical demand of repeated racquet strikes. Therefore, the development of a more durable synthetic design, but also has the capability to replicate the desired feather shuttlecock aerodynamics, would be beneficial to the game of badminton and its community.

### *Future research*

In this study, mixed doubles was analysed as a format of play (singles vs doubles). It would be interesting for future research efforts to explore the potential to incorporate this category into a gender analysis—i.e., male vs female—to further consolidating the finding of the cause of shuttlecock change. A multiple regression model study was conducted by Li et al. (2022) on table tennis to predict scoring contributions between male and female players, which may serve as an inspiration.

Additionally, it may also be beneficial for future studies to consider comparing the flow of games in local competitions of comparable grading that utilise both feather and synthetic shuttlecocks to compare the frequency of change. However, in this instance, the perceived quality of the games will also need to be considered as “*poor shuttlecock performance*” has commonly been cited as a reason for the rejection of the synthetic product.

## AUTHOR CONTRIBUTIONS

This study was conducted and designed by Dr Woo in collaboration with Dr Kootsookos and Prof Alam. Dr Woo and Dr Kootsookos were the main contributors to the administration of the project, method development, data collection and analysis, as well as manuscript preparation. Prof Alam provided supervision to the study and data validation.

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No potential conflict of interest was reported by the authors.

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