CONSISTENCY IN THE BADMINTON JUMP SMASH

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Introduction

The game of badminton is dynamic and regarded as one of the fastest racket sports in the world. Players need to have good technical ability to make their game more effective. However, there have only been a few studies in the field of badminton which have primarily focused on the technique of different strokes. The majority of studies have concentrated on overhead shots, for example: comparing technique in the clear for players of different levels (Sorensen, 2010); comparing the kinematics of three different overhead strokes (Tsai et al., 2000); and comparing the arm movement between male and female players while performing a smash (Salim et al., 2010).

The smash is an important stroke in badminton with over 50% of winning shots coming from this stroke (Tong & Hong, 2000). A smash can be defined as an overhead shot where the shuttle is hit with speed and power so that the shuttlecock would go downward sharply (Ballou, 1992). There are two kinds of smash, the jump and standing smash. The performance of a badminton smash is usually assessed by measuring the velocity of the shuttlecock. Tsai et al. (1998) reported that the average shuttlecock velocity of elite players for a standing smash was 63 m/s and 54 m/s for college players. It was found that these velocities increased by 15-20% while performing jump smashes.

The ability to perform the smash consistently is crucial and may be a key performance indicator for the difference between high and low level players. Having low variability in the shuttlecock speed is important to perform the smash consistently. In addition to the speed of the shuttlecock, the direction of the shuttlecock is also an essential aspect of the smash. Badminton players usually direct the shuttlecock to the side line or to the body of the opponent. Both targets require high accuracy of the smash. If the player misses the court area, the smash would be out and the opponent would win the point. On the other hand, if the player misses a target on the body of the opponent, the opponent would be more likely to return the smash. Therefore, having a consistent smash, in terms of both the speed and direction of the shuttlecock is important.

The speed and the direction of the shuttlecock are the output of the smash (i.e. the performance outcome) and they need to be consistent. Therefore, it might be expected that the swing of the smash itself has to be consistent to produce a consistent output. The consistency of the swing could be divided into two parts, the temporal and spatial consistency. The temporal consistency is the consistency of the time-related variables, such as timings of the component parts of the action. The spatial consistency is the consistency in space-related variables such as the position of the parts of the body and the impact point of the shuttlecock on the racket. The consistency of the performance outcome from high-level players might be due to several possible reasons. Firstly, the player may use a technique which has a high level of robustness to variability. All human movement will contain some aspect of noise and therefore movement variability (Bartlett et al., 2007; Cohen & Sternad, 2009). It has been shown that some techniques are more robust to this phenomenon than others. For example, in men's artistic gymnastics, the scooped backward giant circle technique had a bigger margin for error than the traditional backward giant circle technique when releasing the high bar for dismounts (Hiley & Yeadon, 2003), due to the effect on the required accuracy of the timing at release. In addition, the consistency of the performance outcome of a high-level player might be due to the ability to adapt to the requirements of an individual shot. In other words the player is able to change their technique or their joint moment coordination to produce a similar performance from different conditions. In research on variability in human gait, Winter (1984) found a good adaptation of the motion system to correct a minor deviation which occurred over time. For example, the trunk might be leaning a few degrees too far forward on one stride. In that condition, the hip would extend more during the stance period to correct the deviation. However, in very rapid movements, there would be no time for the muscle to contract and change the movement before the movement itself finished. Therefore, the idea of correcting while doing a movement might not be applicable in a rapid movement such as the smash. Nevertheless, correcting the movement to adapt to different initial conditions early in the movement is still possible. The purpose of this study was to investigate the difference in strategy and technique adopted in the badminton jump smash between players of differing levels of performance outcome variability.

Methods

Nine elite subjects (age 22 ± 6 years, mass 73.5 ± 9.5 kg, height 1.753 ± 0.079 m) volunteered for the study. The subjects consisted of six males and 3 females with 6 right handed players and 3 left handed players. The data collection was in accordance with Loughborough University ethics procedure and informed consent was obtained from all subjects.

The subjects performed jump smashes with their own racket. The shuttlecock was served by an experienced coach from the other side of the court (Figure 1). A life size target in a defence stance was used as a target and subjects were asked to aim for the same spot on the target for each smash while hitting their normal jump smash as hard and accurately as they could. The subjects were instructed to adjust the location of their body in order to be able to jump and perform the smash from the optimum position for each trial. The movement of the subject was important because it showed the ability of the player to adapt to variability in shuttlecock serve and produce a consistent performance. Before the data collection, the subject and the coach warmed up to ensure that the serve was in the appropriate location so that the subject could perform optimally with each smash.

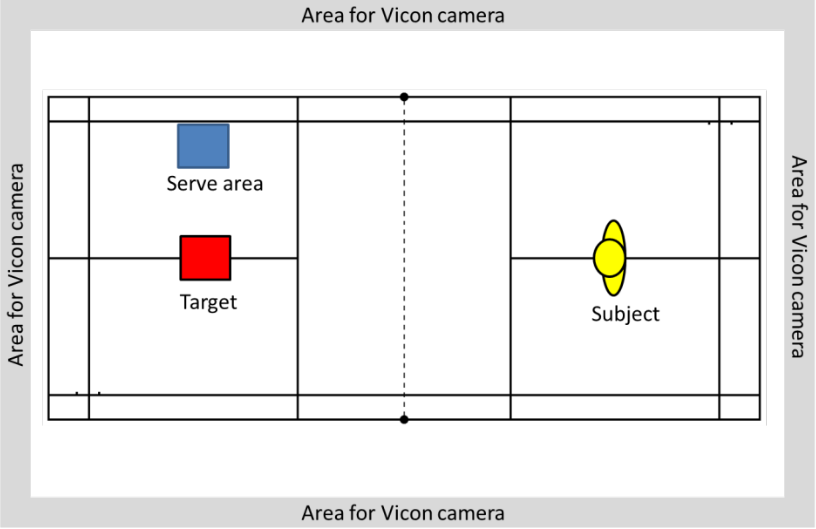

Figure 1. The data collection set-up.

The motion of the shuttlecock, racket, and subject performing the jump smash, from the start of the serve until the player landed after the jump were recorded at 400 Hz with an 18 camera motion analysis system (Vicon, Oxford, UK). The cameras were placed around the court and were configured to ensure the system captured the measurement volume (Figure 1). Forty-five reflective markers were attached to the subject (Figure 2). The racket was instrumented with a marker on the base of the racket and reflective tape on seven points around the head and shaft (Figure 3). In addition a thin strip of reflective tape was wrapped around the base of the shuttle (Figure 3).

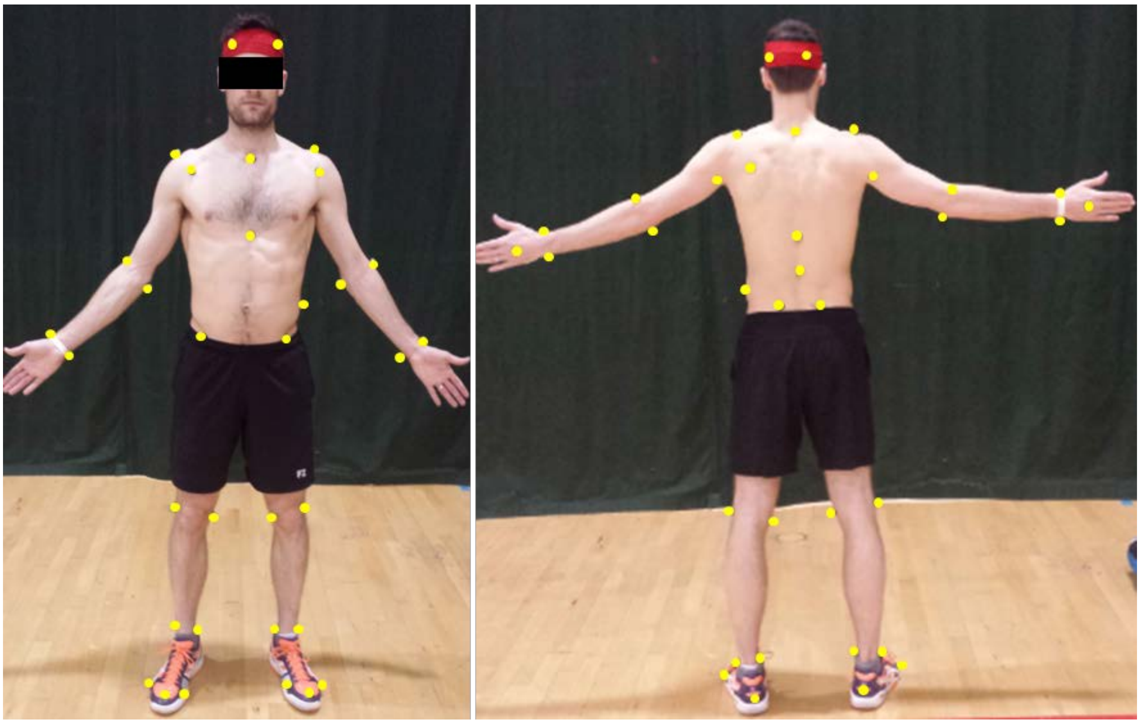
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Figure 2. The markers attached on a subject.

Figure 3. The marker and reflective tape attached to the racket and shuttlecock.

The data was labelled using Vicon Nexus software (Vicon, Oxford, UK) and Bodybuilder software (Vicon, Oxford, UK) was used to develop a skeletal model and calculate kinematic parameters. The level of consistency of a player was determined from the output (performance outcome) of the jump smash. The output included the velocity of the shuttlecock, both magnitude and the direction of the shuttlecock, and the impact point of the shuttlecock on the racket head. The velocity of the shuttlecock, which was used for comparison, was the instantaneous resultant velocity of the shuttlecock immediately after impact. The direction of the shuttlecock was defined by two angles. The first one was the vertical angle which was defined as the angle between the direction of the shuttlecock and the horizontal. The second one was the horizontal angle which was defined as the angle between the direction of the shuttlecock and the centre line of the court (Figure 4). The impact point of the shuttlecock on the racket head was the location of the shuttlecock at impact in the coordinate system of the racket head where the centre of the racket was the origin of the coordinate system.

The calculations of the speed and direction of the shuttlecock after impact, and the impact point of the shuttlecock on the racket were calculated from the time histories of the shuttle and the markers on the racket head using a curve fitting technique with custom written code (McErlain-Naylor et al., 2015). In addition to the methods of McErlain-Naylor et al. (2015), Fourier series models were fitted to the racket face markers during the swing prior to impact. Impact location was then calculated from the shuttle and racket face positions at the estimated impact time (calculated from the curve equations) using global to local coordinate system rotation matrices. This enabled the determination of the shuttle location relative to the local coordinate system of the racket.

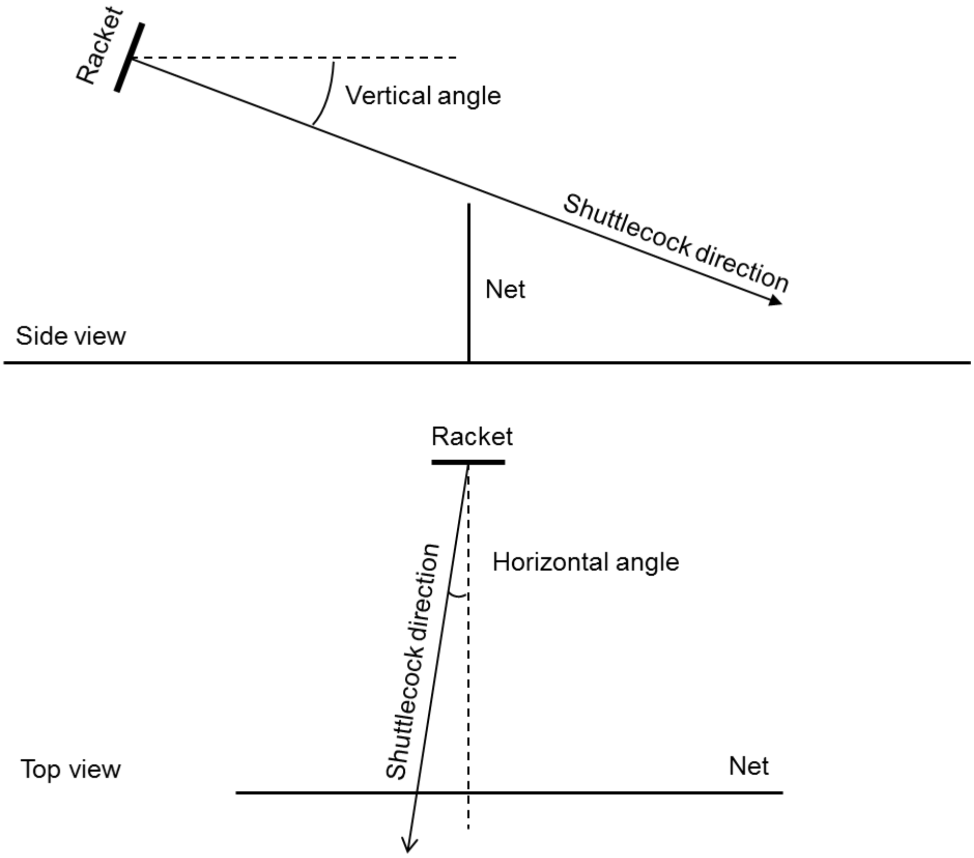

Figure 4. The definition of the vertical and horizontal angle.

One of the aims of this project was to compare the technique between a more and less consistent player. Out of nine subjects, two were chosen to be analysed in more detail. The more consistent subject was the subject who had a small standard deviation of the instantaneous velocity of the shuttlecock, the vertical and horizontal angles of the direction of the shuttlecock, and also a small standard deviation of the impact location of the shuttlecock on the racket. The less consistent subject was the one who had a high standard deviation of the output parameters. It was also desirable to have subjects who had a similar average instantaneous velocity of the shuttlecock to prevent choosing two subjects of different ability. Student's t-tests were used to compare the two subjects.

The toe and shoulder locations were compared with the shuttle location during the movement. The jump smash was divided into two movements - the jump and then the smash. The comparison between the more consistent subject and the less consistent subject started with a comparison of the jump. This was done to see whether the two subjects jumped differently and at what point in their jump the subjects hit the shuttlecock. The analysis of the movement started with maximum knee bend (mass centre at the lowest vertical height). The next instant was take-off (identified through visual inspection of the toe location time history). After that, the movement of the smash started with the start of the swing (identified by the start of knee extension) followed by maximum jump height and shuttle racket impact (Figure 5).

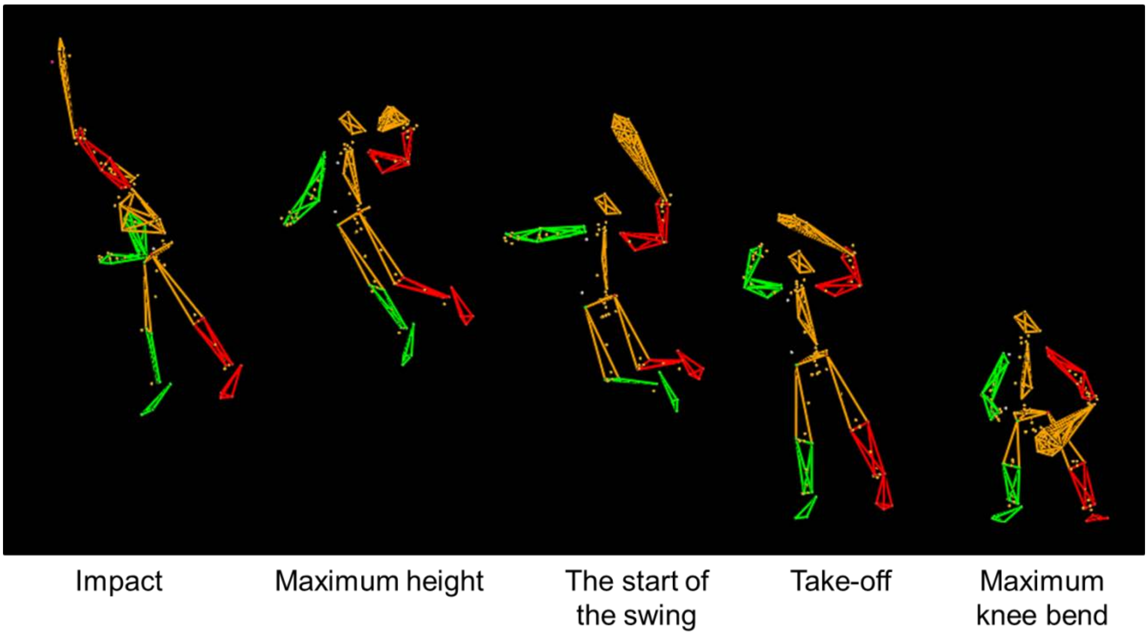

Figure 5. The sequence of the jump smash.

The timings of each instant in the smash relative to maximum knee bend were observed to determine the variability in the timings of the jump smash. A student's t-test was carried out to compare the two subjects. The motion of the smash was concentrated on the motion of the arm. The main motions occurred at the shoulder, elbow, and wrist of the active arm. In this project, the analysis concentrated on the elbow flexion / extension and also the wrist flexion / extension. The area of interest was the motion between the start of the swing and impact. To observe the motion, the angles of the elbow and the wrist for each trial were calculated.

Results

The shuttlecock velocity was between 55-105 m/s (Table 1). Five of the subjects had an average shuttlecock velocity of around 80 m/s while there were two subjects with exceptionally high shuttlecock velocity. The vertical angle was between 10-20° and the horizontal angle was between 2-6° for all subjects (Table 1).

Table 1. Performance outcome measures (mean and standard deviation) for the jump smash

subject	number of trials	shuttlecock velocity (m/s)	vertical angle (degrees)	horizontal angle (degrees)
S1	14	92.7 (3.3)	13.5 (1.4)	3.4 (7.0)
S2	14	81.3 (3.6)	11.7 (1.6)	3.4 (1.6)
S3	18	88.6 (4.9)	13.0 (1.8)	3.8 (5.6)
S4	22	81.5 (6.0)	11.2 (1.8)	5.3 (3.5)
S5	19	84.4 (11.8)	16.7 (1.5)	2.3 (1.0)
S6	19	83.9 (4.6)	14.5 (1.8)	4.0 (2.9)
S7	13	77.3 (3.0)	11.4 (1.5)	3.0 (2.5)
S8	18	68.3 (5.3)	11.3 (1.8)	3.8 (2.6)
S9	18	93.7 (6.9)	17.9 (2.1)	2.9 (1.9)

The variability (standard deviation) of the shuttlecock velocity of subject S5 was considerably higher than the rest of the group (Table 1). The velocity of the shuttlecock of S6 had a similar average value as S5 but with lower variability. The variability of the vertical and horizontal angles was almost on par for all subjects except for the vertical angle of S9 and the horizontal angle of the S1 and S3.

The variability of the locations of the shuttlecock on the racket head at impact of S5 was the largest of all subjects (Table 2). Therefore, S5 was selected for further analysis as the least consistent player. Meanwhile, S6 had a similar average shuttlecock velocity and a relatively smaller variability of the impact point compared to S5 (Figure 6). Therefore, S6 was selected as the more consistent player. The student's t-test showed that there was no significant difference in the shuttlecock velocity between S5 and S6 ($t_{(36)}$=0.157, P=0.876), but there were significant differences in the vertical angle ($t_{(36)}$=4.066, P<0.005), the horizontal angle ($t_{(36)}$=-2.329, P=0.026), and the RMS distance of the impact point ($t_{(36)}$=3.690, P=0.001).

Table 2. RMS distance about the average of the impact point on the racket for all trials

	RMS distance from the average (mm)
S1	44.9
S2	31.0
S3	33.7
S4	37.4
S5	52.5
S6	31.6
S7	23.7
S8	26.7
S9	37.9

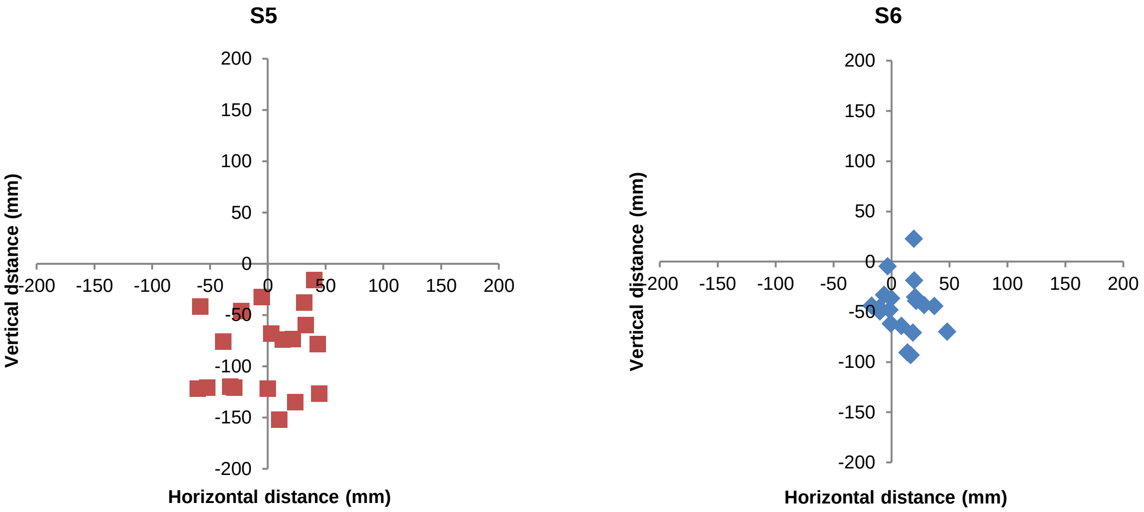

Figure 6. The impact points for S5 and S6 measured from the centre of the racket head.

The variability in the shuttle location (in the x and y directions) at 3 metres high prior to impact was low and similar for both subjects demonstrating the skill of the coach to serve the shuttle consistently for each trial (Figure 7). The student's t-test ($t_{(36)}$=1.988, P=0.054) showed that there was no significant difference between the shuttlecock serves for S5 and S6. Both subjects had a slightly different spread of the shuttlecock location relative to the toe at take-off (Figure 8). The RMS distance from the average for S6 (0.24 m) was larger than S5 (0.20 m). The different shape of the spread also occurred for the shuttlecock location relative to the shoulder at take-off (Figure 9) although this time the RMS distance from the average of S6 (0.18) was smaller than S5 (0.23 m). The spread of the shuttlecock location relative to the shoulder at impact was similar for both subjects although S6 was more shifted to positive X-axis (medio-lateral) than S5 (Figure 10). The RMS distance from the average for S5 (0.09 m) was larger than S6 (0.07 m).

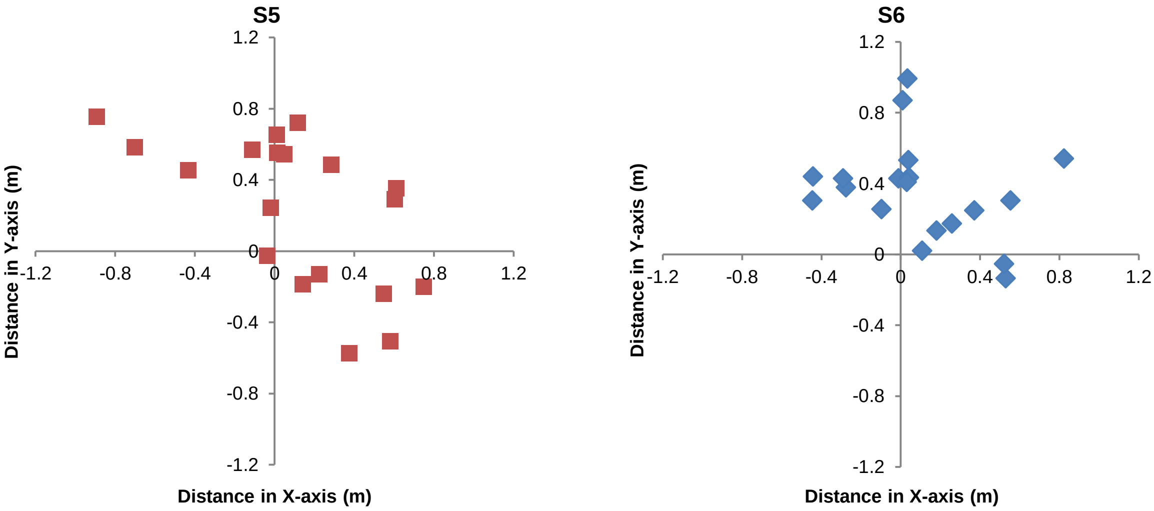

Figure 7. The shuttlecock location at three metres high prior to each smash.

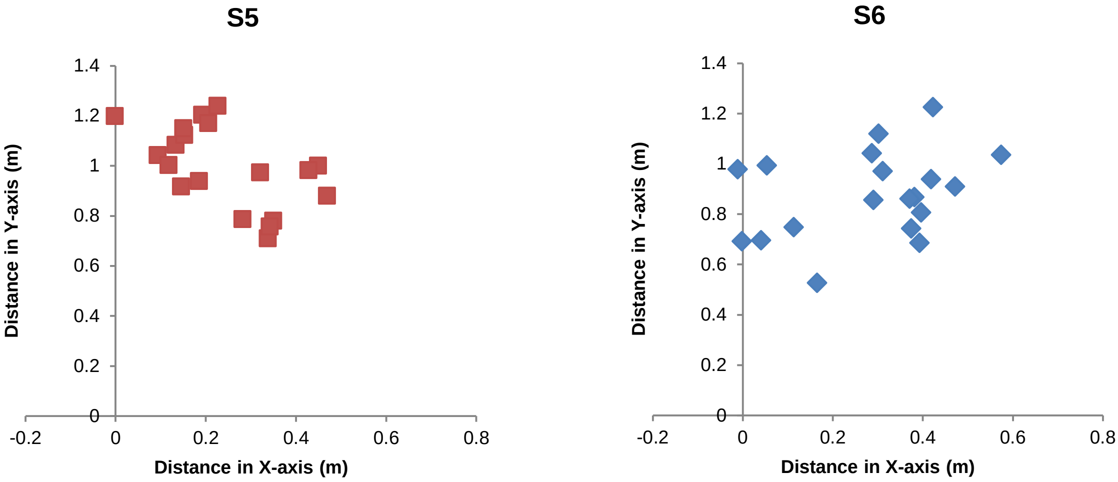

Figure 8. The location of the shuttlecock at impact relative to the location of the toe at take-off.

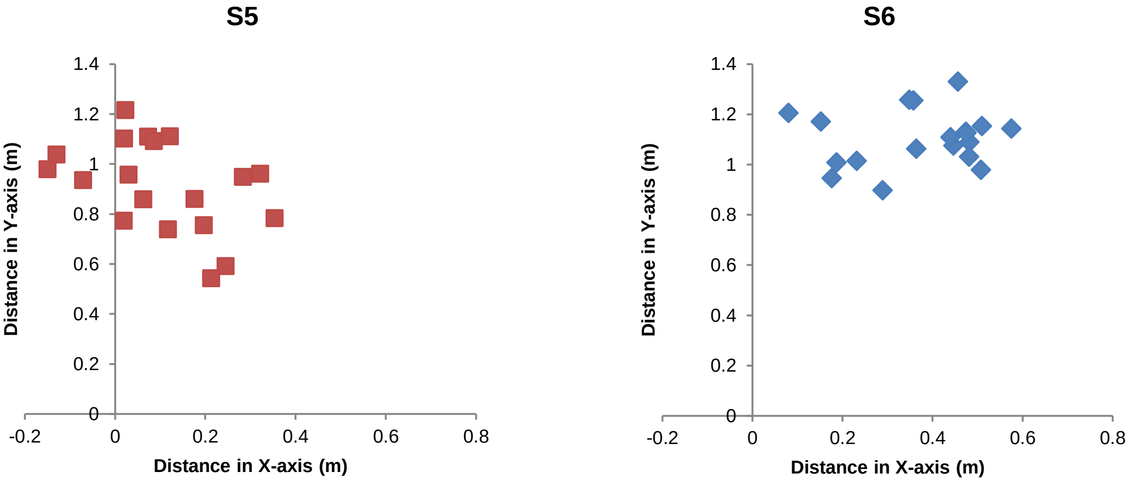

Figure 9. The shuttlecock location at impact relative to the shoulder location at take-off.

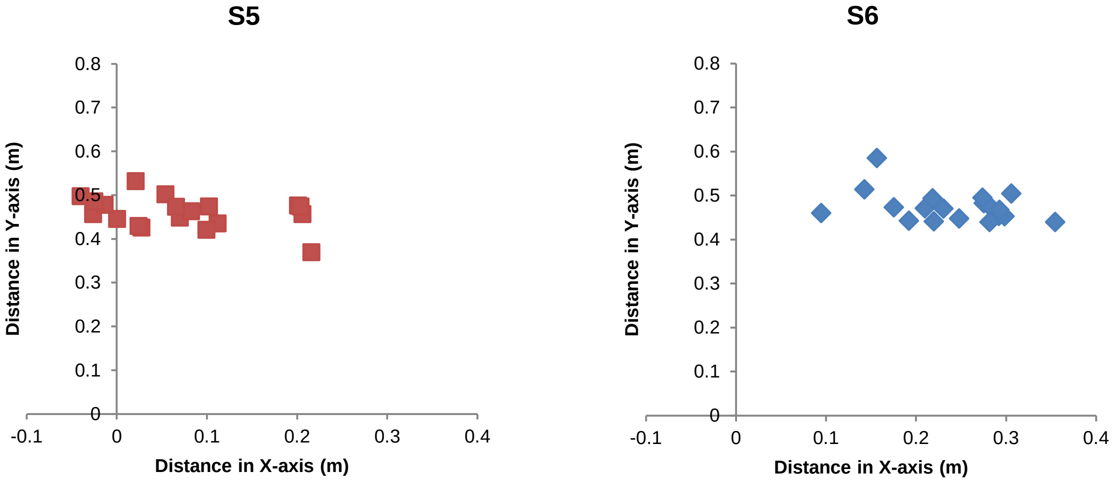

Figure 10. The shuttlecock location at impact relative to the shoulder location at impact.

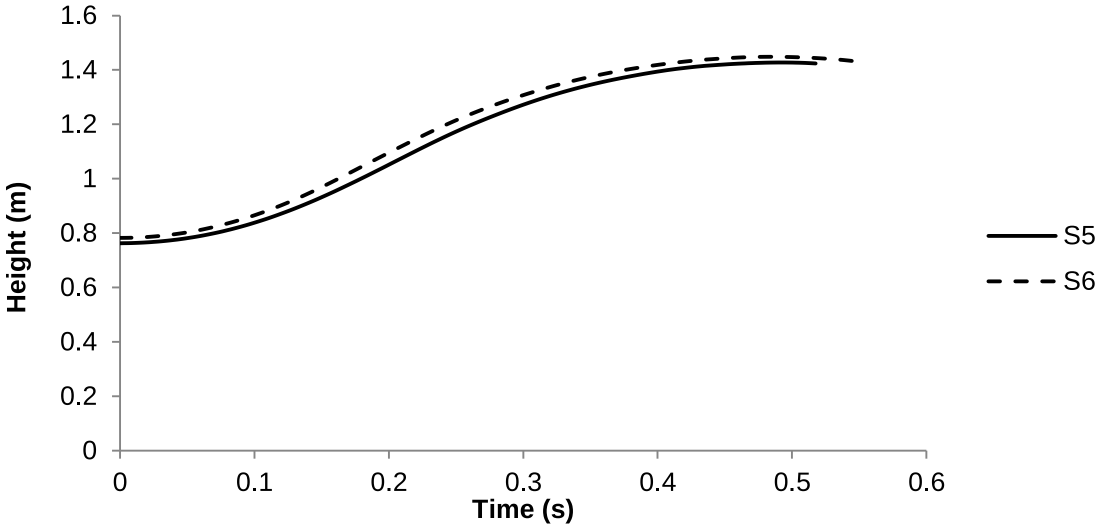

Figure 11. The vertical position of the centre of mass between maximum knee bend and impact.

The average path of the mass centre for each subject was similar in maximum height and pattern (Figure 11). However, S6 tended to hit the shuttlecock later than S5. Similarly at the start of the swing S6 initiated the motion of the swing later than S5 (Table 3). The student's t-test showed that there was no significant difference in the timing of take-off ($t_{(36)}$=0.805, P=0.426) and maximum height ($t_{(36)}$=0.830, P=0.412) while there was a significant difference in the timing of the start of swing ($t_{(36)}$=-3.306, P=0.002) and the impact ($t_{(36)}$=-3.018, P=0.005). The pattern of elbow flexion / extension was similar between S5 and S6 although S6 extended a little bit more than S5 and the variability was low in both subjects (Figure 12).

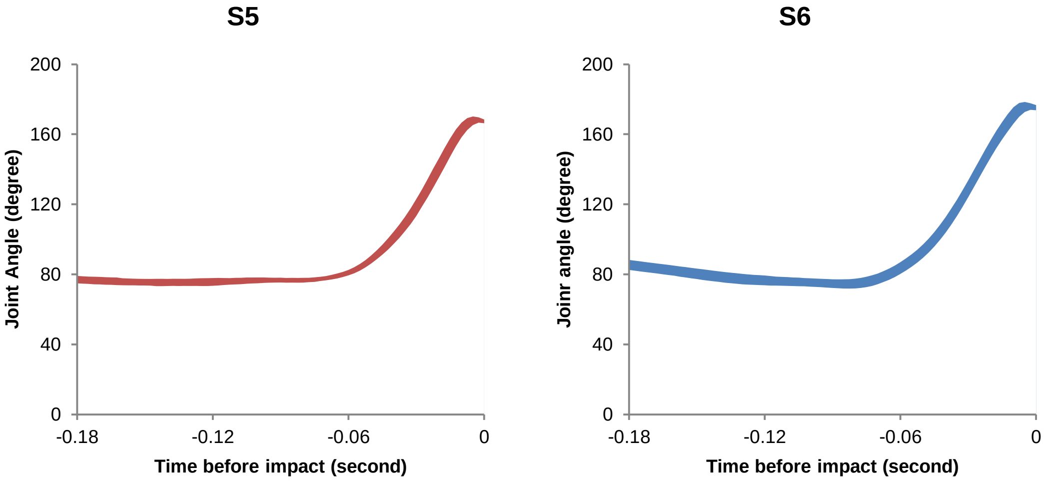

Figure 12. The variability of the elbow flexion and extension (all trials nine plotted).

Table 3. The timings of key instants after maximum knee bend

	take-off	swing start	maximum height	impact
S5	0.23(0.03)	0.36(0.03)	0.49(0.02)	0.56(0.03)
S6	0.23(0.02)	0.39(0.03)	0.49(0.02)	0.59(0.03)

The variability of the wrist flexion / extension angle for S5 was smaller than the variability for S6. The shape was similar although the wrist extended before the wrist flexed in S6 while in S5, the angle remained relatively static before the wrist flexed. The average angle of S5 was also higher than S6 (Figure 13).

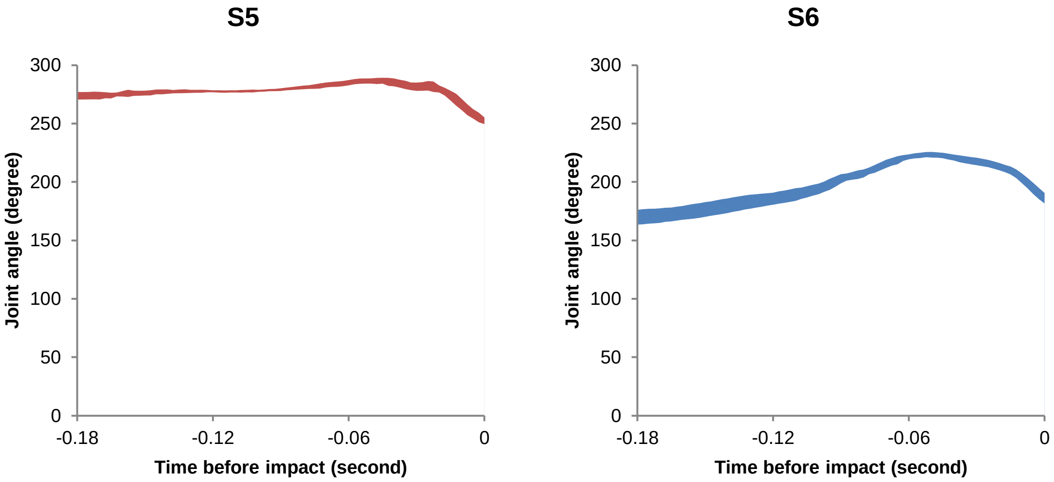

Figure 13. The variability of the wrist flexion and extension (all trials plotted).

Discussion

The instantaneous shuttlecock velocity of all subjects ranged between 55-105 m/s. These numbers are higher than in the published previous studies which ranged between 55-75 m/s for jump smashes performed by elite players (Tsai et al., 1998). This is most likely due sampling frequency used in the two studies. Tsai et al. (1998) used cameras operating at 120 Hz, compared with 400 Hz in the present study. The lower sampling frequency might have underestimated the velocity due to the rapid decayed in shuttlecock velocity seen immediately after impact. It was reported in 2013 that Tan Boon Hoeng had a smash speed of 137 m/s and Lee Chong Wei had a smash speed of 127 m/s (calculated from high speed video recordings). These speeds appear to be in line with the speeds calculated in the current study where elite but not full international players were used, and it is to be expected that the very best in the world have higher smash speeds.

There was no significant difference between the shuttlecock serve location at three metres high in S5 and S6 although there was still variability in the shuttlecock feeds. The coach was able to serve the shuttlecock feeds consistently. Furthermore, the subjects were able to move their body to the desired location before take-off and perform the jump smash. It could be seen from the shuttlecock location relative to the toe at take-off that S5 had a different approach than S6 in the context of positioning the body relative to the shuttlecock. The RMS distance of the shuttlecock location of S5 was smaller than S6. This implied that S5 placed their toe more consistently than S6. This was interesting as the instantaneous shuttlecock velocity and the impact point of S5 were more variable than S6.

In terms of the shoulder position relative to the shuttle both players had little variability in the hitting direction (Figure 10) and a similar range of values in the medio-lateral X direction. Although the average position in the medio-lateral position for S6 was outside the line of the shoulder whereas for S5 it was close to being in front of the hitting shoulder (Figure 10).

The mass centre pattern showed that both subjects hit the shuttlecock after they had reached the peak height of the jump. However, S6 hit the shuttlecock later after the peak height than S5. S5 and S6 took-off at the same time after the maximum knee bend. The total movement durations of S5 (0.56 seconds) and S6 (0.59 seconds) were in agreement with the previous research by Tsai et al. (1998). The variability of the timing was low with the maximum standard deviation of 0.03 seconds. This means that both S5 and S6 were reasonably consistent with their timings. S6 delayed the start of the swing by 0.03 seconds compared to S5. This means S6 had 0.03 seconds longer than S5 to potentially observe where the shuttlecock was and make the appropriate adjustments. By doing so, S6 may have been able to adjust the arm and racket position to hit the shuttlecock at the desired impact point on the racket more consistently than S5. This also means that S6 was planning to hit at that timing since the jump was pre-planned. Therefore, the location of the shuttlecock was at the desired position when the impact occurred.

The temporal consistency of a rapid movement like the badminton smash could also be increased by making the swing more rapid. There were several studies (Newell et al., 1979; Newell et al., 1980; Schmidt et al., 1979) that showed that the decrease in movement time would also decrease the movement time variability. Therefore, having a more rapid smash was one way to increase temporal consistency. Contrary to the normal speed-accuracy trade off assumption, in a co-incidence timing activity (i.e. racket with moving shuttlecock) the faster the movement of the racket and arm the closer to impact in time the movement can be initiated. The reduction in temporal error in the co-incidence of the two bodies with a faster movements timing is believed to be as a result of having more time to make a better estimate of when the impact will occur (Schmidt et al., 1979).

Conclusion

Several differences have been identified between the more and less consistent player. The differences in strategy between the two players started from the initial placement of the body and then subsequent adjustment in order to perform the jump smash optimally. Both players were consistent in the timings of their arm action and had similar swing durations. However, the more consistent player started the swing later than the less consistent player. This strategy may have allowed the player to observe the location of the shuttlecock for longer and therefore improve the consistency of the impact. The elbow flexion / extension movements for both players were similar, but the wrist flexion / extension movements were different. Future work should look at other key joints in the body including the shoulder for internal / external rotation, timing of movements between the different joints and a kinetic analysis of the hitting arm to provide a more detailed understanding of the consistency of the jump smash. The main findings of this study are:

1. Clear differences in consistency were identified between the players, specifically in terms of the variability in shuttlecock impact location and speed post racket impact.

2. The less consistent player in terms of the performance outcomes appeared to be more consistent in terms of foot placement prior to the jump relative to the shuttlecock. However, the more consistent player had a similar pattern of shoulder location at take-off and shuttle impact. This may suggest that the more consistent player had a foot placement that resulted in a less demanding jump in terms of orienting the shoulder relative to the shuttlecock. It was interesting that both players had a similar and consistent pattern of shoulder location relative to the shuttle at impact, particularly in the anterior-posterior direction.

3. The subjects were identified based on their consistency in terms of the variability in shuttlecock impact location and speed post racket impact. However, it is unclear whether they were adopting the same strategy. Some of the variability in post racket impact shuttle velocity (speed) in the less consistent player may have resulted from the off centre racket locations, but it is unlikely that this would have been the sole cause. All subjects were asked to smash as hard and accurate as possible. This will naturally lead to a speed-accuracy trade off. Although both players had very similar average shuttle speeds they may well have adopted different strategies. It may be that the more consistent player is capable of smashing harder, but choses to work within himself in order to be more accurate since this leads to a more successful game performance. Conversely the less consistent player may have adopted a smash hard priority and sacrificed some accuracy, leading to inconsistency in the performance outcome. In order to establish whether this was the case and where the current players were on the speed-accuracy trade off information regarding the accuracy of the shot to target and maximal smash shuttle speed would be required. It may be possible to obtain some of this information regarding the shot accuracy. It would be interesting to establish for the less consistent player whether reducing smash speed would lead to greater consistency in the outcome measures and whether these in turn would lead to a more successful strategy in the game environment.

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Acknowledgement

Badminton World Federation is acknowledged for the partial financial support provided.