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Title: Using the Trajectory of the Shuttlecock as a Measure of Performance Accuracy in the Badminton Short Serve

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Abstract
Accuracy of a projectile is typically quantified as the proportion of successful target hits, or the distance an object finishes from the target. Serving in sports such as badminton differs since the shuttlecock is usually intercepted by the opponent before landing on the target (i.e. court surface). Therefore, landing accuracy measures are inappropriate and a new method of determining accuracy of the serve is needed. During interviews, elite coaches and players described an accurate short serve as crossing the net with low clearance and having an apex before the net. Three-dimensional trajectory of the shuttlecock was therefore tracked from eight national-level players who performed 30 short serves in simulated match conditions (i.e. with an opponent). 27% of all serves were classified as 'accurate', 27% of serves as 'inaccurate', 21% with a 'good apex' position, and 25% with a 'good clearance' height. The proposed method of assessing shuttlecock trajectory as a measure of accuracy could be adopted by coaches and players to assess and improve short serve accuracy. Furthermore, this method is more representative of a match environment since the shuttlecock rarely lands because the opponent returns the serve.

***Keywords*: Shuttlecock; Constraints; Methodological; Target.**

Introduction

In many sports involving projectiles, such as balls, arrows and shuttlecocks, the accuracy of projecting the object to a specific place on a field, court or target is important for success [1,2]. Performance is often evaluated from endpoint accuracy, i.e. either hitting the target, or by how far the object finishes from the target [3]. For example, in throwing darts, points are scored depending on where the dart lands on the board [4], and in goal-based sports such as soccer and hockey the ball must land within the net [5,6]. How accurately the task is performed will subsequently influence game-play, as well as the outcome of the match [7].

However, accuracy definition is specific to a sport. For example, free throw accuracy in competitive basketball games is assessed by counting the success rate of all throws [8,9]. In baseball pitching, the functional throwing-performance index measures accuracy by the number of throws landing within the target square [3,10,11]. Tennis coaches determine the accuracy of groundstrokes by using target areas in the opponent's side of the court, lower scores for balls landing short and down the middle of the court, and higher scores for balls landing toward the side and top areas of the court [13].

Badminton is another sport where projectile accuracy (shuttlecock) is important, yet although the shuttlecock usually does not land because the opponent intercepts it before it can reach court floor, similar protocols have been used to measure serve accuracy. There are four types of serves performed in competitive badminton matches, however the participants of this study were part of the national doubles badminton squad, thus the short serve was chosen to analyse since it is the most commonly used type of serve in the doubles discipline. The short serve - sometimes referred to as the 'low' serve – is where the shuttlecock travels very close to the net and drops steeply has it passes over the net. One of the first tests developed to measure short serve accuracy was the French short serve test

[13], which uses a tight rope placed 20 cm above the net and small targets in the opponent's service square. Serves are scored based on whether the shuttlecock travels underneath the rope (i.e. between the net and rope) and the point of landing of the shuttlecock. Other tests use ground-based targets and accuracy is measured according to the landing location of the shuttlecock, but net clearance is not considered [4]. In training, players often perform hundreds of serves per session to a target in the opponent's service square without a receiver, with serve accuracy based on the landing location. Nonetheless, a projectile can land in the same location with varying trajectories, i.e. two projectiles following distinctly different trajectories can have the same "accuracy" [14,15]. Landing accuracy is currently the only method used to assess short serve accuracy, however, In a match the shuttlecock does not usually land on the ground because it is hit back by the opponent, so the training task is not perfectly relevant to match conditions. Therefore landing accuracy is not a suitable measure of accuracy. Using a location that is not often reached is therefore inappropriate to measure serve accuracy. The participants of this study were part of the national doubles badminton squad, thus the short serve was the chosen serve to analyse since it is the most commonly used type of serve in the doubles discipline. Therefore, the purpose of this study was to develop a new method that better reflects match conditions to measure short serve accuracy by using the trajectory of the shuttlecock.

Methods

We interviewed two national-level coaches and six national players and asked them to describe their criteria for an effective short serve. Each player and coach were interviewed separately to ensure there were no influences on their answers. Moreover, the interviews were conducted 12 months prior to data collection to ensure that the results were not biased toward the answers previously provided. They agreed that the apex of the shuttlecock trajectory should occur before the net, with low net clearance (see Figure 1). We therefore propose two new variables to measure accuracy of the trajectory 1) anterior-posterior location of the shuttlecock at its apex relative to the net, 2) vertical height of the shuttlecock as it crosses the net.

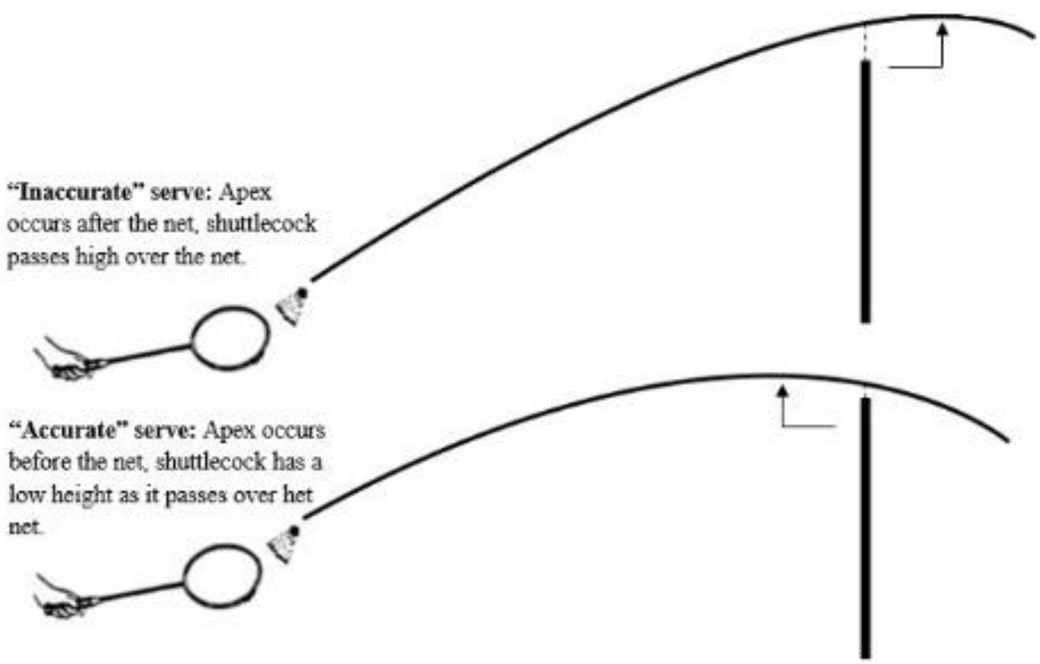

Figure 1. Diagram in side view indicating the trajectory of accurate and inaccurate short serves. Solid arrow represents apex location and dotted line represents net clearance.

Data Collection

Eight national-level badminton players volunteered for the study (age: 23.4 ± 5.1 years, body mass: 73.2 ± 11.1 kg, height: 175 ± 8.6 cm). All players were free from injury at the time of testing, wore their normal match attire, and used their own racquets. A badminton court was marked out on an indoor court at the Australian Institute of Sport, a net was placed in accordance with the International Badminton Federation standards. Players performed badminton-specific play for warm-up and to familiarize themselves with the testing environment. Players were instructed to serve their normal short serve and performed 30 serves to the edge of the opponents' service square near the line that bisects the service squares, i.e. the most common area during a competitive match.

To undertake three-dimensional motion analysis to track the trajectory of the shuttlecock for the short serve, reflective tape was placed around the base of the head of the shuttlecock and a 22 camera motion-capture system with a sampling rate of 250 Hz (VICON Oxford Metrics Ltd., Oxford, UK) was used. Shuttlecock trajectories were filtered using a 6 Hz (which was determined using residual analysis) low-pass Butterworth filter [16]. To replicate match conditions as best as possible, an opponent was present to return each serve, meaning the shuttlecock was tracked from racquet-shuttlecock contact to the final frame before the opponent returned the shuttlecock. The study was approved by Edith Cowan University Human Ethics Committee and players gave informed consent prior to testing.

Data Analysis

The trajectory of the shuttlecock was tracked and processed using VICON Nexus software (VICON Oxford Metrics Ltd., Oxford, UK). A global coordinate system was used, and (0,0,0) reference point was created where the player was serving from, thus the shuttlecock positions were positive from racquet-shuttlecock contact point. Shuttlecock position at apex and net clearance were calculated using custom-written code in Matlab (v 9.2, The Mathworks Inc, Chatswood, NSW, AU). Apex location was determined by finding the position (anterior-posterior axis) of the shuttlecock at its most vertical point and was subtracted from the net position. The net clearance of the shuttlecock as it passed over the net was subtracted from the net height to calculate net clearance. Since the short serve usually travels over the centre of the net and the service position is close to the centre line, the side to side (medio-lateral position) was ignored. The median was selected as an indicator of individual and group accuracy as some players performed many more accurate serves than the other players, therefore the data were skewed. The median better represents the most typical value in the data set. Median apex location and median net clearance for each player was calculated. An accurate serve had an apex location closer to the server than the median and net clearance below the median. Serves where the apex location was further than the median and net clearance was greater than the median were classified as 'inaccurate' serves. Serves that met only one of the criteria were classified as 'apex good' or 'clearance good' as appropriate.

Results

The two components of trajectory accuracy are shown in Figure 2 for each of the eight players separately and collectively (Figure 2 – ALL). The vertical dashed line indicates the group median for apex location, and the horizontal dashed line indicates the group median for net clearance. Zero on both axes indicates the position of the net. Serves that fell below the median for apex location and net clearance are located in the bottom left quadrant (green), and were classified as 'accurate' serves, while the trials located in the top right quadrant (red) did not meet either of the criteria and were classified as 'inaccurate'. Serves in the top left quadrant (black) had good apex location, but were higher over the net than the median. Similarly, serves in the bottom right quadrant (black) had low net clearance but the apex was closer to the server than the median. These serves were classified as either 'apex good', or 'clearance good', respectively. In the sub-plots for each player (Figure 2: P1 to P8) the horizontal and vertical dotted lines indicate the individual player's median for apex location and net clearance. Table 1 shows the percentage of serves that were classified as accurate, inaccurate, apex location, or clearance good for each player.

According to this method of assessing accuracy, the most accurate server of the group was player 5, followed by player 2, whilst the least accurate players were 3, 4, and 7. Players 1, 6, and 8 had several more accurate than inaccurate serves. The most accurate servers also produced the least number of inaccurate serves. Although some of the players had a low total number of accurate serves analysed, they often satisfied either apex location or net clearance. For example, players 3 and 4 did not meet both criteria in any serves, however 57% and 55% of their serves had net clearance below the group median. Similarly, for player 8, 62% of serves were below the group median for apex location but all of the net clearances were higher than the group median.

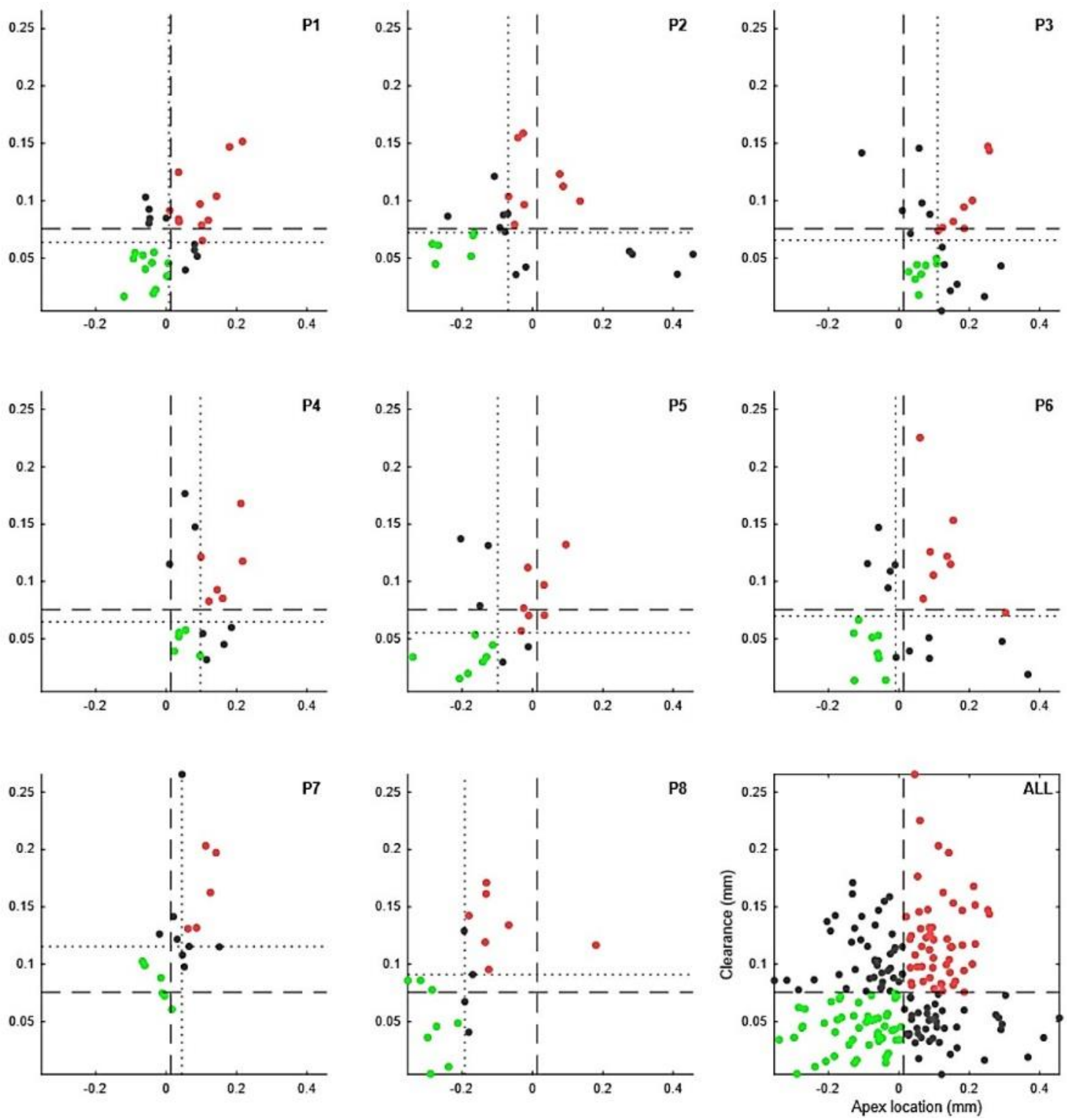

Figure 2. Shuttlecock positions at apex and net clearance for P1-P8. X-axis is the position of the shuttlecock at its apex (mm). Y-axis is the position of the shuttlecock clearance

relative to the net (mm). Dash line represents median apex location (horizontal) and net clearance (vertical) location of shuttlecock as a *group* (bottom right). Dotted line represents median apex and net clearance of shuttle for *individual* players. Bottom left quadrant indicates good apex location and net clearance, while top right quadrant indicates bad apex location and net clearance, top left or bottom right quadrant represents serves that met only one of the criteria.

Table 1. Percentage of individual accuracy scores against the group median.

	Individual accuracy scores (%)			
Player	**% Accurate**	**% Inaccurate**	**% Apex Good**	**% Clearance Good**
1	34	25	16	19
2	40	13	33	13
3	0	37	7	57
4	0	40	5	55
5	60	10	25	5
6	36	25	18	21
7	11	63	21	5
8	33	5	62	0

Note. Comparison of individual accuracy scores with group median.

Discussion

This new method of assessing accuracy based on the trajectory of the shuttlecock was developed following discussion with national-level coaches and athletes. Service practice in which an emphasis is placed on optimizing landing location accuracy without regard for trajectory accuracy reinforces techniques that produce serves that have a different trajectory to those required in competition. Instead, we propose that athletes practice creating a trajectory with the optimum features of apex location and net clearance.

Few players achieved high overall accuracy scores, however most players were still able to satisfy one of the two accuracy requirements (i.e. below the group median) even when both apex location and net clearance weren't simultaneously achieved. Knowing which aspect of the trajectory is less accurate allows athletes to alter trajectory to improve accuracy. In order to optimize accuracy, various constraints can be created in the practice environment to encourage different trajectories, such as barriers and hoops at different distances and heights [2]. However, an opponent will often move toward the net once the server has made contact with the shuttlecock in a match, and these match-specific constraints should also be incorporated into the practice environment.

The medio-lateral (or side-to-side) movement of the shuttlecock was not deemed an important component for a short serve by the coaches and players as the vast majority of short serves travel over the centre (i.e. lowest point) of the net. The purpose of this is so the shuttlecock takes the lowest trajectory over the net, ensuring the opponent contacts the shuttlecock from a lower point, providing a greater advantage for the server, therefore the medio-lateral component was not analysed. However, this study has created a simpler 2D methodology (Figure 3) to use as a training aid or as a quantification measure to record short serve accuracy for coaches and players. Short serve trajectory accuracy can be measured using a single camera and standard biomechanical procedures; the camera should be aligned perpendicular to the net at an appropriate distance to capture the trajectory of the shuttlecock (see Figure 3) with a sampling rate of 200 Hz and a shutter speed of 1/500 s [17]. Calibration of the camera can be performed using an object of known size so that the digitized image can be converted into metric units [18]. A range of free and licensed tracking and digitizing software is available (e.g. Kinovea, SIMI Motion, etc.) to track and obtain the position of the shuttlecock at apex location and net clearance. Once these two variables are obtained, accuracy scores can be reported individually or as a group (as shown above).

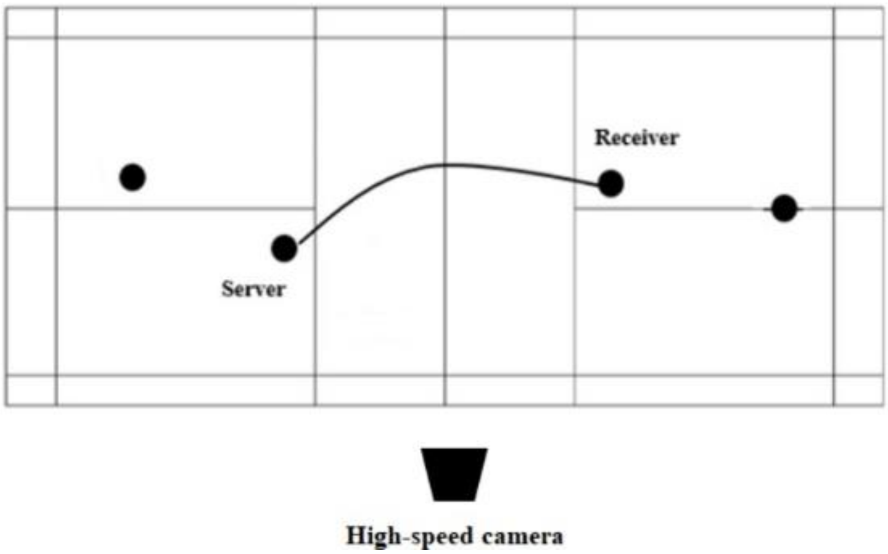

Figure 3. A schematic of the proposed single camera setup to capture the trajectory of the shuttlecock for the short serve to be used by coaches and athletes.

Conclusion

The proposed method of assessing shuttlecock trajectory as a measure of accuracy could be adopted by coaches and players to assess and improve short serve accuracy. Furthermore, this method is more representative of a match environment since the shuttlecock rarely lands because the opponent returns the serve. Future research should examine whether the shuttlecock trajectory observed under match conditions would land in (or near) the target locations used in practice; although the rules require the serve to land in the service box, it is unclear whether this would be the case because the opponent returns the shuttlecock before it lands. This would determine whether the focus on shuttlecock trajectory, which is essential in matches, then reduces landing accuracy i.e. are the two forms of accuracy mutually exclusive.

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Conflict of interest disclosure

The author(s) declared no conflicts of interested with respect to this research article.

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