OPTIMUM PERFORMANCE IN THE BADMINTON JUMP SMASH

R. Miller, P.J. Felton, S.A. McErlain-Naylor, H. Towler, M.A. King

School of Sport, Exercise and Health Sciences, Loughborough University,
Leicestershire, LE11 3TU, UK. (email: M.A.King@lboro.ac.uk)

## Introduction

The badminton smash is an essential component of a player's repertoire and a significant stroke in gaining success as it is the most common winning shot, accounting for 53.9% of winning shots (Tsai and Chang, 1998; Tong and Hong, 2000; Rambely et al., 2005). The speed of the shuttlecock exceeds that of any other racket sport projectile with a maximum shuttle speed of 493 km/h (306 mph) reported in 2013 by Tan Boon Heong. If a player is able to cause the shuttle to travel at a higher velocity and give the opponent less reaction time to the shot, it would be expected that the smash would be a more effective weapon (Kollath, 1996; Sakurai and Ohtsuki, 2000).

There is limited research exploring the biomechanics involved in the badminton smash. However research into other sports, involving motions very similar to the badminton smash (tennis serve, overarm throw), are also able to help give insight into the mechanisms involved in the badminton smash. Waddell and Gowitzke (2000); Lees (2002) and Lees et al. (2008) demonstrate that several biomechanical principles can be applied to the badminton smash, and suggest how these can improve performance and shuttle velocity. These are increasing the range of motion of joint actions to allow a greater acceleration and more use of muscular force, the use of proximal-to-distal sequencing and the stretch-shortening cycle.

It was originally thought that much of the power of the badminton smash was generated through what was termed the 'wrist snap' (palmar flexion). Much of the early research investigating power shots (clear and smash) in badminton used three-dimensional cinematography and relatively qualitative research methods. An early hypothesis, based on static photographs and self-analysis, suggested that power emanates from pronation. The majority of the early research emphasised the importance of shoulder internal rotation and radio-ulnar pronation (Johnson and Hartung, 1974; Gowitzke and Waddell, 1977; Tang et al., 1995), whilst dismissing the contribution of palmar flexion (Poole, 1969, Gowitzke and Waddell, 1977 and Rantzmayer, 1977). Several studies aimed to quantify the contributions of specific joint movements and rotations to both the badminton smash and tennis serve. The majority of findings indicated that internal shoulder rotation made the largest contribution (up to 66%) to shuttlecock velocity or racket-head speed in the badminton smash or tennis serve (Sprigings et al., 1994; Elliot et al., 1995; Lui et al., 2002; Tanabe and Ito, 2007).

Jumping while performing the smash is the most popular technique chosen by the world top ranked badminton players (Rambely et al., 2005). In the badminton smash, arm movement patterns have been shown to play an important role in the execution of the stroke (Ariff et al., 2008). However, there has been some disagreement as to whether wrist action or forearm rotation is the best movement to generate racket head velocity. In previous research it has been found that the wrist played a major role in the forward swing mechanics of the racket. Since it gave power to the forehand smash, the contribution to linear racket head velocity was higher than those of the shoulder and elbow (Tsai et al., 2000). Previous research by Poole (1970) established that most of the velocity developed in overhead badminton stroking is a function of lower arm mechanics.

Currently there is no consensus regarding which aspects of the badminton smash technique are the best indicators of shuttlecock velocity after impact. As has been described, a variety of different elements of technique have been reported to be linked to shuttlecock velocity by previous investigators. The purpose of this study was to identify the technique factors that contribute to players producing high shuttlecock velocities, with the aim of being able to inform coaches what to encourage in players when coaching, or recognise during the talent identification process.

**Methods**

Eighteen players (mean ± standard deviation: age 24.9 ± 6.5 years; height 1.84 ± 0.08 m; body mass 78.9 ± 9.0 kg) participated in this investigation. Each player performed twenty-four maximum velocity jump smashes from which the fastest trial with minimal marker loss for each player was chosen for subsequent analysis. All players were at least county standard up to members of the current England squad. No subjects were aware of any injury/illness that would have affected their performance within the testing protocol. The testing procedures were explained to each subject in accordance with Loughborough University ethical guidelines and an informed consent form was signed. All subjects conducted a thorough warm-up before the prior to the start of the data collection session.

An 18 camera Vicon Motion Analysis System (OMG Plc., Oxford, UK), operating at 400 Hz, was used to record kinematic data. The camera set-up was positioned to include the half of the court that the participant was performing in, approximately 7 x 6 x 3 m. Forty-four 14 mm retro-reflective markers were positioned over bony landmarks in accordance with a marker set developed specifically for this project (Figure 1). The players used their own racket for the data collection. Each racket was fitted with seven strips of retro-reflective tape plus a marker on the base of the racket (Figure 2) and Yonex AS40 shuttles were used with a strip of retro-reflective tape attached to the base of the shuttle (Figure 2).

Figure 1. Subject with markers attached ready for data collection.

Figure 2. The location of the reflective tape on the racket and shuttle.

For each trial three key instants were identified; the preparation (prep), end of retraction (ER), and shuttle contact (SC). The instant of preparation was identified as when the knee angle was most flexed prior to jumping. The instant of ER was identified by the lowest vertical position of the racket in the backswing. The instant of SC was identified as the frame where the shuttle and racket were closest. Kinematic data were filtered using a fourth order Butterworth filter (double–pass) with a low pass cut off frequency (with the exception of the shuttle which was left as raw data points and fitted using a curve – see below). The determination of cut- off frequency to use was compromise between the amount of signal distortion and the amount of noise allowed through Winter (1990). A cut-off frequency of 30 Hz was chosen to be applied to all marker positions; this reduced the noise in the velocities and accelerations but made little difference to the position of the markers. Curves were fit separately to the pre- and post- impact phases (identified from the change in anterior-posterior direction) of the shuttlecock coordinate data in the vertical, anterior-posterior, and medio-lateral; planes in accordance to Equation 1 (McErlain-Naylor et al., 2015).

$$x = \frac{1}{k} \cdot \ln(1 + k \cdot v_0 \cdot t), \quad (1)$$

where $x$ = displacement, $t$ = time, $k$ and $v_0$ are constants.

Curves were fitted in MATLAB (Version 8.0, The MathWorks Inc., Natick, MA, 2012) utilising a Trust-Region algorithm to determine values for k and v0. Time of impact was determined as the mean time at which the pre- and post-impact curves crossed in each plane, with differentiation of the three post-impact curves enabling the determination of the resultant instantaneous velocity at this time (McErlain-Naylor et al., 2015). Twenty-four parameters were calculated for each trial, describing elements of badminton smash technique which have previously been linked to shuttlecock velocity in literature or thought to be linked to shuttlecock velocity (Table 1). All statistical analysis was performed within Statistical Package for Social Sciences v 22 (SPSS Corporation, US). The variation observed in each technique parameters were assessed using stepwise linear regression. A maximum of three variables were included in the predictive equation with the requirement for inclusion of a variable being $P < 0.05$.

## Results

The eighteen badminton players participating in this study had shuttlecock velocity of 164 mph – 211 mph (194 mph ± 14 mph). For each of the 21 variables calculated there was a range of techniques used (Table 1).

Table 1. Details of the min, max, mean, and SD of each technique parameter calculated

| | min | max. | mean ± SD |
|---|---|---|---|
| shuttle velocity | 164 mph | 211 mph | 195 ± 12 mph |
| knee extension; prep | 84° | 136° | 110 ± 12° |
| trunk rotation; ER | 6° | 33° | 20 ± 8° |
| trunk rotation; SC | -10° | 6° | -2 ± 5° |
| trunk extension; ER - SC | 203° | 233° | 214 ± 7° |
| trunk flexion; ER - SC | 165° | 202° | 183 ± 9° |
| trunk lateral flexion; max, ER - SC | -24° | 3° | -12 ± 7° |
| shoulder external rotation; max, ER - SC | 105° | 142° | 122 ± 10° |
| shoulder internal rotation; ER - SC | -129° | -40° | -91 ± 24° |
| shoulder abduction; ER - SC | 9° | 39° | 24 ± 8° |
| elbow extension angle; ER | 54° | 82° | 65 ± 8° |
| elbow extension angle; SC | 157° | 174° | 165 ± 5° |
| elbow pronation; ER | -111° | -35° | -81 ± 20° |
| elbow pronation; SC | -111° | -44° | -81 ± 18° |
| elbow pronation; ER - SC | -35° | 35° | 0 ± 18° |
| elbow pronation; max, ER - SC | -109° | -35° | -69 ± 20° |
| elbow pronation; min, ER - SC | -125° | -71° | -98 ± 14° |
| wrist extension; ER | 255° | 281° | 270 ± 6° |
| wrist extension; SC | 236° | 268° | 248 ± 10° |
| timing; prep to SC | 0.22 s | 0.70 s | 0.58 ± 0.12 s |
| timing; prep to ER | 0.12 s | 0.57 s | 0.45 ± 0.11 s |
| timing; ER to SC | 0.10 s | 0.16 s | 0.13 ± 0.01 s |

Note: prep: preparation; ER: end of retraction; SC shuttle contact

The best individual predictor of shuttlecock velocity after impact was the elbow extension angle at ER, explaining 51.5% of the variation in shuttlecock velocity. The badminton players with the fastest shuttlecock velocity had a smaller elbow angle at this instant in time. The use of two technique parameters in the predictive equation increased the percentage variation explained to 69.9%, those parameters being elbow extension angle at ER and wrist extension angle at SC. Adding timing from prep to SC to the first two variables gave a three parameter function that explained 84% of variation in shuttle velocity (Table 2, Figure 3).

Table 2. Stepwise linear regression results

| technique parameter(s) | coefficient | P-Value | percent explained |
|---|---|---|---|
| elbow extension; ER | -1.266 | 0.001 | 51.5% |
| | | | |
| elbow extension; ER | -1.419 | 0.000 | 69.9% |
| wrist extension; SC | 0.607 | 0.009 | |
| | | | |
| elbow extension; ER | -1.357 | 0.000 | 83.8% |
| wrist extension; SC | 0.632 | 0.001 | |
| timing; prep to SC | 43.118 | 0.004 | |

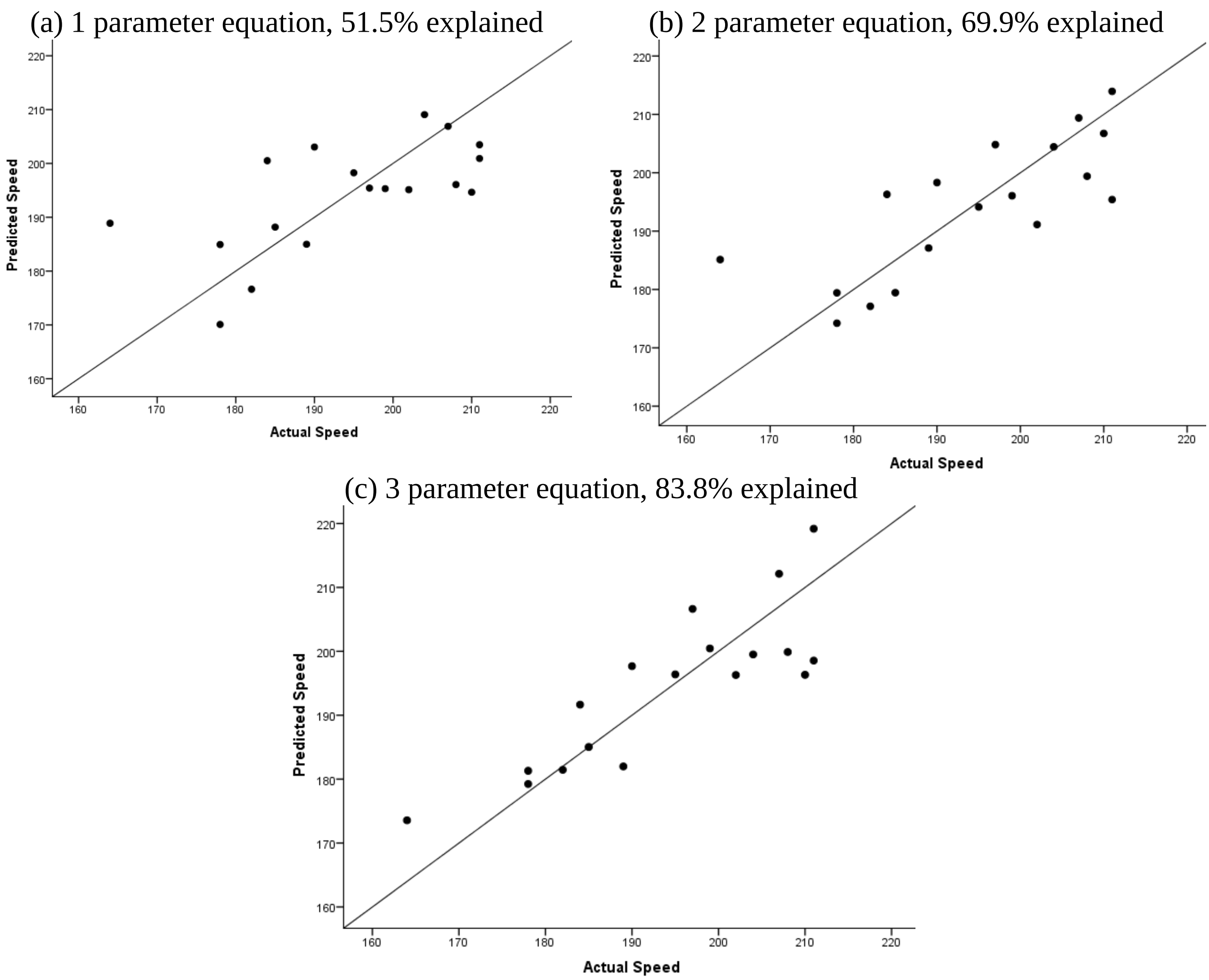


Figure 3. Comparison of predicted and actual smash speeds for the three regression equations.

## Discussion

Previous studies have reported correlations between shuttlecock velocity after impact and a variety of different elements of the badminton jump smash technique. There is currently no consensus as to which aspects of the technique are the most important in terms of determining shuttlecock jump smash. This study used stepwise linear regression in order to account for interactions between technique parameters with the aim of identifying the key variables that determines shuttlecock velocity after impact. The results of this investigation suggest the main variations in shuttlecock velocity after impact among elite badminton players can be explained by using three technique parameters; elbow extension angle at ER, wrist extension angle at SC and timing between prep and SC.

The strongest predictor of smash speed was the elbow extension angle at ER with the badminton players with the faster smashes having a smaller elbow angle at ER than the slower ones. At the end of the retraction phase players are getting ready to bring their arm forward in a throwing type movement. Having a smaller elbow angle at this time gives a larger range of motion at the elbow prior to shuttle impact over which to generate speed, and also potentially puts the arm in a better position to use shoulder internal rotation to generate wrist and consequently racket and shuttle speed. For the first of these two mechanisms it would be expected that the smaller the elbow angle the better as this will give a larger range of motion prior to shuttle impact, for the second mechanism it would be expected that an optimum elbow extension angle of around 90º exists as this gives the largest moment arm about the elbow to generate speed at the racket. With the data collected within this study it was not possible to investigate these mechanisms any further, but this should be looked at in further in detail in the future perhaps using simulation modelling where specific elements of technique can be investigated in isolation.

There was a high degree of variability in the wrist angle at SC, but together with elbow extension angle at ER this helped explain 69.9% of the variability in shuttle speed. This emphasises that the wrist is clearly important to generating a high smashing speed and is agreement with other studies in the literature (e.g. Tsai et al., 2000). The variability in wrist angle at SC makes it difficult to make specific recommendations around the optimal amount of wrist extension. The variability in this measure may in part be due to the identification of SC as the frame nearest to SC. In the future it may be possible to interpolate between frames to improve the accuracy of the data at shuttle contact but this was beyond the scope of this study. In addition the grip used by each player should be taken into account where possible as this would affect the angles calculated at the wrist.

The three parameter equation explained 84% of the variance in smash speed and included the time from the start of the preparation phase through to shuttle contact along with both elbow extension angle at ER and wrist angle at shuttle contact. Longer times were found to be advantageous to greater shuttle speeds and this is probably in part due to a longer flight time prior to impact (due to a greater jump height) as well as a greater range of movement of the racket swing itself. Interestingly other more specific timings were not chosen for the stepwise linear regression. For example it might be expected that to a point a longer time between ER and SC would be advantageous to generating racket head and shuttle speed. This needs further investigation in the future and it may be that there is an optimum time to generate racket head speed which a more complex analysis could reveal.

## Conclusion

Although there was quite a range of standard amongst the group of 18 players in this study from good county players to players competing internationally, it was possible to identify three elements of technique that could explain 84% of the variation in shuttle smash speed across the entire group. In particular, those players that had the fastest smashes had a relatively smaller elbow extension angle at the lowest vertical position of the racket in the backswing, an appropriate wrist extension angle at shuttle contact and a relatively longer time between the start of the jump smash movement. Although further work is needed to full understand why some players can smash the shuttle faster than others this investigation provides a basis for further study. The key parameters identified in this study results can be useful in the coaching of the badminton jump smash.

## References

Ariff, F.H.M., Rambely A.S., 2008. Determination of torques at upper limb joints during jumping in badminton smash via Kane's method. School of Mathematical Sciences. University Kebangsaan, Malaysia.

Elliott, B.C., Marshall, R.N., Noffal, G.J., 1995. Contributions of upper limb segment rotations during the power serve in tennis. Journal of Applied Biomechanics 11, 433-442.

Johnson, M.L., Hartung, G.H., 1974. Comparison of movement times involving wrist and forehand actions. Perceptual and Motor Skills 39, 202.

Gowitzke, B.A., Waddell, D.B., 1977. The contributions of biomechanics in solving problems in badminton stroke production. Proceedings: International Coaching Conference, Malmo, Sweden.

Kollath, E. 1996. Bewegungsanalyse in den Sportspielen. Kinematisch-dynamische Untersuchungen mit Empfehlungen für die Praxis (Movement analysis in the games. Kinematic and dynamic studies with practical recommendations). Köln: Sport und Buch Strauß.

Kwan, M., Anderson, M.S., Cheng, C., Tang, W., 2010. Investigation of high speed badminton racket kinematics by motion capture. International Journal of Sports Engineering 13, 57-63.
Lees, A., 2002. Technique analysis in sports: a critical review. Journal of Sports Sciences 20, 813-828.
Lees A., Cabello, D., Torres, G., 2008. Science and Racket Sports IV. London: Routledge.
Liu X., Kim W. D., Tan J., 2002. Analysis of the Biomechanics of Arm Movement During Badminton Smash. Singapore: Nanyang Technological University.
McErlain-Naylor, S., Miller, R., King, M., Yeadon, M.R., 2015. Determining instantaneous shuttlecock velocity: Overcoming the effects of a low ballistic coefficient. Proceedings of the 14th ITTF Sports Science Congress and 5th World Racquet Sports Congress, Suzhou.
Poole, J., 1969. Badminton. CA, Pacific Palisades: Goodyear Publishing Co.
Poole, J., 1970. A Cinematographic analysis of the upper executing two badminton strokes. Ph.D. Dissertation. Louisiana State University, Baton Rouge, Louisiana.
Rambely, A.S., Wan Abas, W.A.B., Yusof, M.S., 2005. The analysis of jumping smash in the game of badminton. In Proceedings of XXIII International Symposium on Biomechanics in Sports 671-674. Beijing, China.
Rantzmayer, J., 1977. Wrist snap – myth or reality? Badminton Gazette 58, 128-129.
Sakurai, S., Ohtsuki, T., 2000. Muscle Activity and accuracy of performance of the smash stroke in badminton with reference to skill and practice. Journal of Sports Sciences 18, 901-914.
Sprigings, E., Marshall, R., Elliot, B., Jennings, L., 1994. A three-dimension kinematic method for determining the effectiveness of am segments rotations in producing racket-head speed. Journal of Biomechanics 27, 245-254.
Tanabe, S., Ito, A., 2007. A three-dimensional analysis of the contributions of upper limb joint movements to horizontal racket head velocity at ball impact during tennis serving'. Sports Biomechanics 6, 418-433.
Tang, H.P., Abe, K., Katoh, K. and Ae, M., 1995. Three dimensional cinematographic analysis of the badminton forehand smash: movements of the forearm and hand'. In T. Reilly, M. Hughes and A. Lees (eds.) Science and Racket Sports. London: E & FN SPON, pp.113-120.
Tsai C.L., Chang, S.S., Huang C.F., 1998. Biomechanical analysis of differences in the smash between Taiwan elite and collegiate players. XVI International Symposium on Biomechanics in Sports 259-262.
Tsai, C.L., Huang, C., Lin, D.D., Chang, S.S., 2000. Biomechanical analysis of the upper extremity in three different badminton overhead strokes. Proceedings of XVIII International Symposium on Biomechanics in Sports 831-834.
Waddell, D.B., Gowitzke, B.A., 2000. Biomechanical principles applied to Badminton power strokes. In Y. Hong (eds.) Proceedings of XVIII International symposium on biomechanics in sports. Hong Kong: International Society of Biomechanics in Sport. 817-822.
Winter, D.A., 1990. Biomechanics and motor control of human movement. New York, NY: Wiley.

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