THE CONTRIBUTION OF UPPER LIMB JOINTS IN THE DEVELOPMENT OF RACKET VELOCITY IN THE BADMINTON SMASH

Azmin Sham Rambely[1], Noor Azuan Abu Osman[2], Juliana Usman[2] and Wan Abu Bakar Wan Abas[2]
[1]Centre of Mathematical Sciences, Faculty of Science & Technology, National University of Malaysia, Bangi, West Malaysia
[2]Biomedical Engineering Department, Faculty of Engineering, University Malaya, Kuala Lumpur, W.Malaysia

The contributions of the upper limb joints in developing the racket-head velocity were calculated using the 3D video analysis technique. The performance of 13 male players in the single and double competitions during the Thomas/Uber Cup 2000 was recorded. The major contributor to the mean racket-head's linear velocity of 34.6 ms^{-1} at impact was the wrist (26.5 %). The statistical analysis carried out showed that the dynamics of wrist served to increase the speed of the racket at impact. However, the study showed no significant correlation between the racket speed at impact and the velocity of the shuttlecock after impact. A relationship between racket speed and post-impact acceleration of shuttlecock did exist.

KEY WORDS: badminton smash, biomechanical analysis, correlation analysis

INTRODUCTION: In badminton games, a smash is the most common killing shot, which accounted for 53.9% of the distribution of the killing shot (Tong and Hong, 2000). Sakurai and Ohtsuki (2000) stated that power/speed of the badminton smash is a very offensive weapon. Thus to finish a rally in his favor, a player needs to produce a high velocity smash. Since the velocity of the shuttlecock cannot be increased once in flight, the velocity of the racket-head at impact is presumably the most important factor in determining the post-impact velocity of the shuttlecock. In the study of kinematics of the upper limb movements during a badminton smash, Tsai et al (2000) concluded that the wrist is the most powerful joint in all the different strokes (smash, clear, drop) compared to the elbow and the shoulder. However, the contribution of each joint rotation during a smash has not been widely reported, especially in the development of the racket-head velocity.
Therefore, the objective of the current study was to examine the linear velocities of each joint of the upper limb (that is the shoulder, elbow and wrist) in developing the racket-head velocity in a badminton smash, as well as the relationship of the racket-head velocity and the height of jump with the velocity and acceleration of shuttlecock immediately after impact.

METHODS: Video data were collected on badminton games during the men's singles and doubles semi-final and final events of the Thomas/Uber Cup 2000 competition held in Kuala Lumpur, Malaysia, from 11 May to 21 May 2000. The Thomas Cup is a top-rank international competition and features world-class players. Thirteen male players in the single and double competitions were studied. Nine of the players were right-handed and four were left-handed. The motion of a player during the smash stroke is shown in Figure 1. The numbered points represent the shuttlecock and they are marked in accordance with the respective motions: preparation (1), back swing (2-4), forward swing (4-5), contact (5), and follow-through (6-9), (Figure 1). The Direct Linear Transformation (DLT) method (Abdel-Aziz & Karara, 1971) was used in the three-dimensional space reconstruction from three-dimensional images. The best smash strokes made by each player during the games were selected. The stroke referred to what was perceived, through manual observation, to produce the fastest shuttlecock speed. For each selected player, eight trials for the singles (number of players = 5) and three trials for the doubles (number of players = 8) in the semi-finals, and five trials for doubles during the finals (number of players = 4) were used in the analysis. Thus a total of 84 trials were involved. Each trial consists of, on average, 60 frames starting from the action of getting ready to the landing position after the smashing stroke.

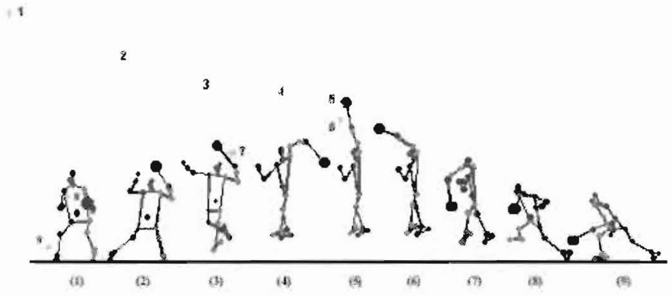

Figure 1 The motion of the smash stroke.

The recording system consisted of six sets of 50 Hz shuttered CCTV cameras (WV-CP450/WV-CP454 Panasonic) with color S-video, genlock and 6x zoom capabilities, 6 time-code generators (Norita SR-50), six 9-system portable color televisions (CA688 Fumiyama), and 6 Peak-computerized and controlled video cassette recorder (NV-SD570AM Panasonic) with playback and record capabilities. For calibration, the cameras captured a reference structure with 25 markers of known coordinates in space encompassing the whole court, which was divided into nine location points. The structure was assembled and moved into the court at the end of the day, after all the matches were completed. The cameras were directly genlocked to provide shutter synchronization and identical frame rates.

During the video capture, the cameras were zoomed out to cover the whole court. Multiple cameras were used during the video capture. Two cameras (C1 and C4) were positioned with the optical axes approximately perpendicular to the court and another two cameras (C2 and C5) were placed with their optical axes nearly parallel to the court to obtain the front (or back) view of the players. The other two cameras (C3 and C6) were placed approximately 45° to the court. Cameras 1, 2, and 3 were used to determine the three-dimensional coordinates for the right-hand side of the court while cameras 4, 5, and 6 to determine those for the left-hand side of the court.

The videotapes were edited using an industrial standard NTSC Panasonic AG-7350 videocassette recorder and an IBM-compatible personal computer with 256 MB RAM. Included in the computer set-up were the miroVIDEO DC30 Plus Video Capture Card, On board SCSI-2 Controller and network interface connector, and a 15-in. SVGA monitor. The Peak Motus 2000 software was used to digitize the trials.

Body segment parameters from the Dempster (1955) model were used but adjusted to include the shuttlecock and the badminton racket (rear and bottom). In each video image, 25 control points, 21 anatomical landmarks representing the endpoints of 24 segments, 1 point for center of mass, 2 points on the racket (top and rear), and 1 point for the shuttlecock were digitized manually. Each half court was divided into three section with each section further divided into three parts, A1, A2, A3, B1, B2, B3 and so on. After the digitizing the calibration frame, the chosen trials were edited and digitized. If a chosen smash action took place in location B2, then the calibration frame taken in the B2 location was used. Subsequent to digitizing, the raw data were smoothed using the Butterworth digital filter with the cut-off frequency of 3 Hz.

Calculations were done to determine selected resultant linear velocities, angular velocities, coordinates of the center of mass of the body and the contribution that each of the upper limb joints made to the racket-head velocity at impact. Pre- and post-impact linear velocities and accelerations of the shuttlecock were calculated as well.

RESULTS AND DISCUSSION: A mean velocity-at-impact of 34.6 ms^{-1} for the top of the racket-head was obtained. The mean peak velocity of the top of the racket-head for the total sample was 37.5 ms^{-1}. This was recorded to occur 0.009 s ($\pm$ 0.014 s) prior to impact.

Table 1 Mean (± SD) racket-head linear velocity contributions of the upper limb joint in a badminton smash (n = 84).

	Peak (ms^{-1})		Time (s)		Impact (ms^{-1})		Contribution (%)
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	
Shoulder	4.5	1.6	0.08	0.03	2.5	1.1	7.4%
Elbow	8.3	1.4	0.08	0.02	3.2	1.1	9.4%
Wrist	11.7	2.6	0.03	0.01	9.2	2.7	26.5%
Top of racket-head	37.5	3.8	0.01	0.01	34.6	6.3	
Shuttlecock	57.4	8.7	-0.02	0.01	37.1	9.9	

Table 2 Mean (± SD) angular velocities of the upper limb joints.

	Peak (deg s^{-1})		Time (s)		Impact (deg s^{-1})	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Shoulder	806.2	222.6	0.07	0.02	-177.4	285.5
Elbow	1348.7	355.5	0.04	0.02	171.4	544.9
Wrist	1448.7	449.5	0.02	0.01	339.4	818.3

A shoulder velocity mean peak value of 4.5 ms^{-1} was recorded 0.075 s prior to impact. At impact, the shoulder velocity decreased to 2.5 ms^{-1}, which contributed 7.4 % to the linear racket-head velocity at impact (Table 1). A mean peak shoulder angular velocity of 806.2 deg s^{-1} was recorded for the total sample of 84 trials 0.076 s prior to impact (Table 2). This mean peak value fell to –177.4 deg s^{-1} at impact.

Previous researches showed that pronation of the radio-ulnar system were the important joint action during a forehand smash (Tang et al, 1995). However, results of the current study indicated that the linear velocity of the elbow joint did not, to a large extent, contribute to the racket-head velocity. A mean value of 3.2 ms^{-1} at impact for 84 trials was recorded, which contributed 9.4 % to linear racket-head velocity. The mean peak velocity of the elbow was 8.3 ms^{-1} and this value was recorded 0.08 s prior to impact. The fact that the elbow was almost fully extended during the first stage of the forward swing (which commenced at the end of the back swing) meant that the influence of the movement in generating the racket-head velocity was not that significant. A mean peak elbow angular velocity of 1348.8 deg s^{-1} was recorded 0.045 s before contact.

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 (26.5 %) was higher than those of the shoulder and the elbow. The mean peak velocity of the wrist was 11.7 ms^{-1} recorded at 0.034 s prior to impact. At impact, this value dropped to 9.17 ms^{-1}, resulting in the velocity of the shuttlecock achieving its peak in the range of 50 to 71 ms^{-1}, 0.02 s after impact. The range of the wrist contribution obtained stretched from 20.3 % to 37.3 %. The mean peak angular velocity of the wrist was recorded 0.02 s prior to impact.

Another parameter studied was the height of jump (HOJ). HOJ is defined as the difference between the maximum and minimum values of the center of mass. The mean HOJ for the group was recorded as 0.54 m and the mean speed of the shuttle after impact was recorded as 57.4 ms^{-1}. It is found that there is no definite correlation between the HOJ during a smash and the post-impact shuttlecock velocity, (Figure 2). A similar scatter was obtained for any individual player. Analysis on the tactics of play may be able to shed more light on this phenomenon.

A correlation analysis for the linear velocities of the racket-head and the shuttlecock and shuttlecock acceleration was performed (Table 3). The result showed that there was no correlation between the speed of the racket-head and the post-impact velocity of the shuttlecock. Such uncorrelated pattern is also obtained when any player is analyzed individually. The speed of the racket-head immediately after impact has a significant relation with the acceleration of the shuttlecock (r = 0.4, p = 0.01).

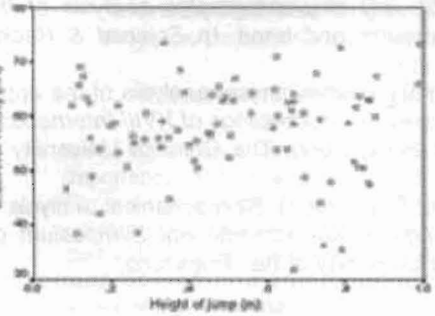

Figure 2 Scatterplot of height of jump (HOJ) and shuttlecock velocity during the smash.

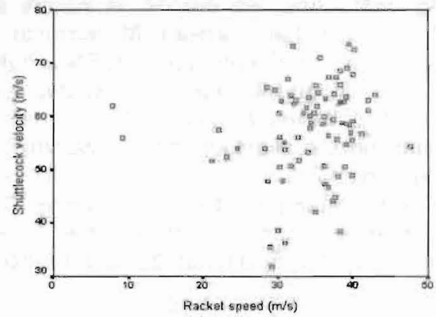

Figure 3 Scatterplot of racket speed and shuttlecock velocity during the smash.

Table 3 The correlation analysis of the linear velocity of the parameters at impact and shuttlecock accelerations during the jumping smash.

	Linear velocity					
	Racket-head (impact)	Racket-head (peak)	Shoulder	Elbow	Wrist	Shuttlecock
Linear velocity						
Racket-head at impact	1	0.679**	0.081	0.19	0.317**	0.175
Peak racket-head	0.679**	1	-0.069	0.203	0.291**	0.144
Shoulder	0.081	-0.069	1	0.208	0.008	-0.053
Elbow	0.19	0.203	0.208	1	0.512**	0.068
Wrist	0.317**	0.291**	0.008	0.512**	1	0.454**
Shuttlecock	0.175	0.144	-0.053	0.068	0.454**	1
Angular velocity						
Shoulder	-0.027	-0.316**	-0.174	-0.096	-0.097	0.1
Elbow	0.192	0.013	0.037	0.018	0.035	0.072
Wrist	0.133	-0.048	-0.036	0.014	0.367**	0.159
Linear acceleration						
Shuttlecock at impact	0.274*	0.398**	-0.083	0.032	0.341**	0.398**
Post-impact shuttlecock	0.076	0.142	0.1	0.17	0.329**	0.061

**Correlation is significant at the 0.01 level of confidence.
*Correlation is significant at the 0.05 level of confidence.

CONCLUSIONS: The wrist was found to contribute the most (26.5 %) to the racket-head velocity when compared to the elbow (9.4 %) and the shoulder joint (7.4 %). From the statistical analysis, it can be shown that the wrist acted to increase the speed of the racket at impact. In addition, a higher elbow linear velocity during arm swing produced a higher speed of the wrist at impact. However, the study shows no significant correlation between racket speed at impact and the velocity of the shuttlecock after impact. Notwithstanding that, the racket speed is significantly related to the post-impact acceleration of the shuttlecock. A study on the height of jump indicates that it is not related to the speed of the shuttlecock.

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