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## A mobile measure device for the analysis of highly dynamic movement techniques

Thomas Jaitner<sup>a,b,\*</sup>, Wolf Gawin<sup>c</sup>

<sup>a</sup>University of Kaiserslautern, Human Movement and Exercise Science, Kaiserslautern, Germany

<sup>b</sup>University of Augsburg, Augsburg, Germany

<sup>c</sup>Institute of Applied Training Science, Leipzig, Germany

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### Abstract

A mobile measure device was developed to analyze the smash in Badminton. Kinematic data of the arm and the racket were measured by inertial sensors, stored and transferred via Wi-Fi. Data of 26 Badminton players were collected. Additionally, the shuttle velocity was determined by high-speed video analysis. The resultant racket acceleration showed highest correlation with the ball velocity ( $r=.84$ ). Differences between international and national players were observed in the means and standard deviations of the racket acceleration and in the negative acceleration of the lower arm. It is suggested that an abrupt stopping of the lower arm supports the generation of high racket acceleration.

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### 1. Introduction

Badminton is one of the fastest racket sports. It can be characterized by spectacular rallies that consist of hard smashes, short drop and long clears and force the player to act and react in an extremely rapid manner. About 20% of the attacks during a game are performed as smashes or jump smashes [1]. Therefore, the smash is performed second most, and it is also considered to be the most effective technique in Badminton, especially for the double.

The main goal in smashing is to hit the ball as fast as possible. For expert players, shuttle velocities from 250 to 414 km/h are reported [2;3]. To achieve such high velocities the Badminton player generates a maximum impulse within a minimum of time (approx. 250 ms) [4]. The impulse is transferred from the racket to the shuttle and results mainly from a highly dynamic movement of the arm. Luthanen and Blomquist [5] observed increasing peak joint velocities from the shoulder to the hand. In addition, Lee [6] showed that the linear velocity of the racket head is directly proportional to the sum of the angular velocities and of the arm joints. The influence of the longitudinal rotation of the arm segments on the shuttle velocity has also been highlighted in several studies [7-9]. Gowitzke and

\* Corresponding author. Tel.: +49-0821-598-2824; fax: +49-821-598-2828.

E-mail address: [Thomas.Jaitner@sport.uni-augsburg.de](mailto:Thomas.Jaitner@sport.uni-augsburg.de).

colleagues stated that up to 53% of the shuttle velocity can be explained by the final rotation of the shoulder and the elbow [7].

In general, highly dynamic movements are analyzed by high-speed optometric systems that capture the movement with high spatial and temporal resolution and therefore provide a detailed insight in the underlying kinematics. However, there are certain limitations that come along with these techniques. First, these measures are performed in a more or less laboratory setting, which does not comply well with the real training conditions. Secondly, the analysis takes a certain amount of time delay and results cannot be presented immediately.

Micro-Electro-Mechanical Sensors (MEMS) can be considered as an alternative to optical analysis systems [10]. Inertial sensors allow a data collection with a high sample rate and a wide measuring range. Because of their small size and weight athletes are merely limited in their performance [11]. However, inertial sensors have been primarily used to analyze vibration and impact [12;13] or movements at low velocities such as gait and running [14] or skiing [15]. They are also widely used to determine the amount of physical activity in recreational and workaday settings [16]. Enumerable studies deal with the analysis of fast or highly dynamic movement. Ohta and colleagues presented a feedback training system in which inertial sensors were used to determine the joint torques during the rotational movement in hammer throwing. In Badminton, the acceleration of the racket has been measured with a special focus on modeling and design of the racket [17].

A mobile measure device has been developed to analyze the movements of the arm and the racket in Badminton. This system will be applied in real training conditions with a primarily focus on the smash. By wireless communication between the data logger and an external notebook immediate feedback can be presented to trainers and athletes to improve the quality of training. The focus of this study is on the validation of the measure device and a first application in high performance sports. A data based strategy has been chosen (1) to identify parameters of racket acceleration that are closely related to the shuttle velocity and (2) to specify the influence of partial arm movement on racket acceleration. Further, results of first analyses of international and national experts are presented.

### Nomenclature

$v_s$	Shuttle velocity [ $\text{m/s}^2$ ]
$a_{xy}$	Maximum resultant acceleration of the racket [ $\text{m/s}^2$ ]
$a_y$	Peak acceleration of the racket (parallel plane) [ $\text{m/s}^2$ ]
$a_x$	Peak acceleration of the racket (sagittal plane) [ $\text{m/s}^2$ ]
$c_{xint}$	Integral of negative acceleration of the upper arm (flexion/extension component) [m/s]
$c_{yint}$	Integral of negative acceleration of the upper arm (lateral/rotational component) [m/s]
$b_{y1int}$	Integral of positive acceleration of the lower arm (lateral/rotational component) [m/s]
$b_{y2int}$	Integral of negative acceleration of the lower arm (lateral/rotational component) [m/s]

## 2. Methods

### 2.1. Measure device

Three 2D miniature sensors (BIOVISION) were attached at the racket ( $a_x$ ,  $a_y$ ) as well as the lower ( $b_x$ ,  $b_y$ ) and upper ( $c_x$ ,  $c_y$ ) arm segment (see fig. 1). Each sensor had a dimension of approx. 15x8 mm and a weight of 7g including cable and amplifier. Measure range was  $\pm 50g$  with a tolerance  $<5\%$ .

Accelerations of the racket in direction of the smash (sagittal or orthogonal plane) as well as parallel to the head (parallel plane) were measured. The sensor at the racket was mounted on a bracket that was fixed just above the handle with a tight spot and double adhesive tape. To ensure that the axes were aligned parallel and orthogonal to the strings a specially designed calibration apparatus was used in which the racket was clamped firmly.

The sensors at the arm segments were fixed with neoprene straps. The lower arm sensor was placed on a line between the Epicondylus lateralis and the middle of the wrist joint at the centre of gravity according to Hanavan [18]. The position of the upper arm sensor was derived by the distance between the Epicondylus lateralis and the Acromion. Sensors were aligned carefully to longitudinal and lateral axis of the segments to measure the acceleration following flexion and extension as well as lateral (rotational) movements of the arm. While acceleration in direction of the length of the segment and the racket is not directly related to the movement of the segment or racket, these dimensions were neglected. Raw sensor data were transferred via cable to a portable data logger (COMPAQ IPAQ 5440) that was fixed in a small backpack at the back of the subject. The data logger allowed either to store the data or to transfer data via Wireless LAN to an external computer. Preprocessing and visual presentation routines that enable and support feedback training were implemented on the external notebook.

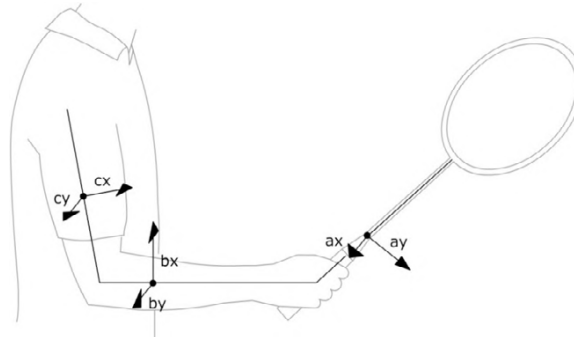


Fig. 1. Sensor configuration

## 2.2. Data collection and data processing

Two different data sets were analyzed. The first set was collected to validate the measure device and included data of 26 Badminton players (11 male/15 female subjects) from national to regional level. The main objective of this analysis was to identify accelerometer-based variables of the racket kinematics that are closely related to the shuttle velocity and therefore may be considered as crucial parameters of smashing performance. All measures followed a standardized routine: Subjects performed series of five smashes following a high pass from the opposite site of the net. They were told to smash as hard as they could with their preferred technique. All male subjects performed jump smashes whereas most of the females smashed in a standing position. Subjects were equipped with inertial sensors and wore the data logger. Each subject performed at least one complete series and the trial that gained maximum shuttle velocity was considered for analysis.

A second group consisted of 15 male players: One was an international expert (IE), ranked within the Top Five of the world, the others were national experts (N1-14) with best rankings within the Top 30. These data were analyzed with two objectives: first, to quantify the influence of variables that describe the movement of the arm during the hitting phase of the smash on the parameters of racket acceleration identified by the previous analyses, secondly, to compare smashing performance of elite male Badminton players. Within this sample, the international experts served as a reference. Data acquisition procedure was the same as described above, with the exception that no high-speed videos were taken. Five trials of each subject were analyzed.

When the racket hit the shuttle, the measuring signal rose suddenly and oscillated at high frequency due to the vibration of the strings and the racket head. Therefore, shuttle contact could be determined clearly from the acceleration data. For all trials maximal values as well as the amount of the racket acceleration within the last 60ms prior to shuttle contact were measured for each sensor dimension separately. Further, the maximum resultant acceleration was determined. A high acceleration of the racket is produced by an (positive) acceleration of the arm segments that is transferred by a kinematics chain due to abruptly stopping the movement (negative acceleration). Therefore, peak values as well as the amount of the positive and negative acceleration were calculated for the upper and lower arm segments.

Additional kinematic data were taken for the first set only. Two high-speed video cameras (DRS LIGHTNING) recorded smashing performance at a frame rate 250 Hz and a shutter speed of 1/1000s to 1/1500s. Maximum shuttle velocity was derived from video metric data. Further, the position of the shoulder, elbow and wrist joint as well as the racket at shuttle contact were determined.

The statistics included a correlation analysis. Pearson's coefficient was used to determine the relationship between shuttle velocity and racket parameters or racket and arm parameters, respectively.

### 3. Results

In the first experiment, subjects achieved maximum shuttle velocities  $v_s$  from 48,6 to 83,8 m/s (table 1). The large range results from a heterogeneous sample that included male and female Badminton players from regional, resp. junior level to international level. The maximum resultant racket acceleration  $a_{xy}$  ranged from 244,0 to 570,8  $\text{m/s}^2$ . The peak acceleration in the sagittal plane (orthogonal to the strings)  $a_x$  is in general higher than the corresponding acceleration in the parallel plane ( $a_y$ ). For the individual, these variables show considerable deviations. Two tendencies can be observed: Higher values for  $a_x$  than for  $a_y$  are found for 14 subjects. The remaining ten subjects perform with  $a_y$  higher than  $a_x$ . The relationship  $a_x/a_y$  remains more or less stable within the individual. Quantitative video analyses indicate that subjects with higher acceleration in the sagittal plane perform the smash with an extended arm at the impact whereas subjects with higher acceleration in the parallel plane can be characterized by higher flexion. We assume that higher peak acceleration in the parallel plane comes along with a reduced extension of the arm in combination with a pronounced final rotational of the elbow and the shoulder. According to shuttle velocities, neither strategy shows any advantage.

Table 1. Maximum, minimum and mean values of shuttle velocity and racket acceleration (n=28)

Variable	minimum value	maximum value	Mean	standard deviation
$v_s[\text{m/s}]$	48,6	83,8	69,7	8,5
$a_{xy} [\text{m/s}^2]$	244,0	570,8	429,8	92,3
$a_y[\text{m/s}^2]$	123,9	457,5	274,4	95,4
$a_x[\text{m/s}^2]$	131,4	489,5	301,9	99,9

The correlation analysis revealed significant coefficients at  $p < .01$  for all variables listed in table 1. Values ranged between  $r = .50$  to  $r = .83$ . Highest correlation was determined for the shuttle velocity  $v_s$  and the maximal resultant acceleration of the racket  $a_{xy}$  ( $r = .83$ ). Due to its close relation to shuttle velocity  $a_{xy}$  is considered as a highly relevant indicator of smashing performance. For subsequent analyses that include no direct measurement of shuttle velocity this parameter represents the target value of hard smashing.

In the second experiment, a more homogenous sample of male Badminton players on a high level of performance was analyzed. In a first step, correlations between variables that describe the movement of the arm and the racket acceleration  $a_{xy}$  were determined to specify parameters that may have a considerable effect on smashing performance. Table 2 lists the variables with highest correlation coefficients.

Table 2. Correlation between racket acceleration  $a_{xy}$  and kinematic variables of the arm segments for international and national experts

Correlation coefficients	$b_{y1int}$	$b_{y2int}$	$c_{xint}$	$c_{yint}$
$a_{xy}$	.52	-.72**	-.35	-.63*

\*\*  $p < .01$ , \*  $p < .025$

Highest correlation was found for the integral of negative acceleration of the lower arm (lateral/rotational component)  $b_{y2int}$  ( $r = -.72$ ,  $p < .01$ ), followed by the integral of negative acceleration of the upper arm (lateral/rotational component)  $c_{yint}$  ( $r = -.63$ ,  $p < .025$ ). Both variables quantify the parallel component of the acceleration of the arm segments in the reverse direction of the smash. It is assumed that this causes a deceleration or braking of the lower arm to enhance impulse transfer on the racket as part of the kinematic chain of the hitting.

The negative prefix indicates that smashes with high values of  $a_{xy}$  are associated with high values of  $b_{y2int}$  and  $c_{yint}$ . No significances were shown for any other variable. Especially variables that quantify the positive acceleration of the arm segments such as  $b_{y1int}$  seem to be lower correlated to  $a_{xy}$  ( $r=.52$ ).

The mean values of all variables listed in table 3 are higher for the international elite player (IE) than for the national elite players (N1-14). Compared to this reference, national level athletes achieve 12 to 42% lower racket acceleration ( $a_{xy}$ ). The differences for the kinematic variables of the arm range from 1% ( $c_{xint}$ , N3) to approximately 100% ( $b_{y2int}$ , N10) whereas the smallest deviations can be observed for  $b_{y1int}$  (8-35%). According to  $b_{y2int}$  the best performing national player (N3) reaches about 37% of the performance of the international expert. This variable shows the largest differences to the reference and spread from 63 % up to 100%. Within the sample of the national elite, a large range of variation between subject and variables can be stated with no overall tendencies observable.

Table 1. Kinematic variables of the racket and the arm for international and national experts(mean of 5 trials)

Subject	$b_{y1int}[m/s]$	$b_{y2int}[m/s]$	$c_{xint}[m/s]$	$c_{yint}[m/s]$	$a_{xy} [m/s^2]$
IE	15,7	-4,0	-5,3	-4,6	713,6
N1	12,1	-1,1	-2,1	-3,1	626,8
N2	10,5	-1,2	-4,5	-4,2	553,7
N3	10,4	-1,5	-5,3	-0,7	528,7
N4	14,5	-1,2	-3,2	-3,8	527,1
N5	12,3	-0,8	-3,6	-1,4	508,2
N6	13,0	-1,4	-2,2	-2,3	506,7
N7	11,0	-0,8	-2,2	-2,4	496,6
N8	12,1	-1,1	-2,7	-2,9	485,0
N9	10,2	-1,3	-2,8	-1,1	470,7
N10	13,9	-0,01	-1,0	-1,9	463,3
N11	12,2	-1,4	-2,8	-1,3	460,5
N13	10,65	-0,81	-4,65	-2,49	430,41
N14	11,05	-1,20	-3,01	-2,01	416,39

#### 4. Discussion and conclusion

A mobile measure device for the analysis of high dynamic smashing movements in Badminton has been developed and validated by first experiments. It has been stated that about 70% of the variance of the shuttle velocities can be explained by the acceleration of the racket. Therefore, this parameter can be used as an indicator of smashing performance. The remaining 30% might be explained by racket properties such as stiffness, string gauge and string stiffness or even by a non-optimal contact of the ball on the racket. Further, according to a sample of male high level Badminton players the deceleration of the arm segments seems to be closely related to the racket acceleration and should be considered as an influencing factor.

In comparison to an international elite player national Badminton players achieve lower mean racket acceleration. Major differences can also be observed for the negative acceleration of the lower arm segments. Overall, the results of the correlation analysis as well as the detailed examination of the kinematic parameters support the notion that within a more or less homogenous sample of male athletes a high acceleration of the arm seems to be a necessary constrain for the generation of high racket acceleration that must be fulfilled by all athletes on an equal level of performance and therefore does not differ systematically between these players. Differing performances might rather be explained by the deceleration or stopping of the lower and upper arm in order to gain an optimized transfer of the movement energy or impulse on the racket.

Based on the first analyses, the mobile measure device based on accelerometer measurement presented in this paper seems to be an appropriate approach for the analysis of highly dynamic movement such as Badminton smashes in competitive or training conditions that can be considered as an alternative to elaborate optometric

systems. Some major advantages of this device are the short time availability of the data that enables feedback training and little restrictions of the moving space of the athletes. However, further work is required to validate the device as well as to extract crucial parameters of smashing performance.

The primarily results are based on correlation analysis only and therefore need to be considered with caution. Due to the limited set of data, more sophisticated analyses such as multiple regression analysis were not applied. Moreover, non-linear relations between variables will not be identified by these procedures. This will also be in focus in future.

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