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Evaluation of a Freely Available Sensor Racket as a Diagnostic and Training Tool in Elite Badminton

Evaluación de una raqueta con sensor disponible comercialmente como herramienta de diagnóstico y entrenamiento para bádminton de élite

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Abstract

To avoid the drawbacks of optical video-based motion capture systems and due to the ongoing miniaturization of integrated sensors, an increasing variety of sensor-based systems has been used for motion capture in sports. Meanwhile, there are ready-made, commercially available solutions that claim to be capable of recording reliable kinematic data. This research project focuses on the question of whether a commercially available badminton racket with an integrated sensor device (Oliver® Plasma TX 5) provides meaningful data for diagnostic and training purposes in elite sports. Therefore, 16 elite badminton players executed jump smashes using this sensor racket while the kinematics of the stroke technique were recorded using a high speed video-based system. Bland-Altman plots were applied to analyze the agreement between the two systems. The plots revealed a systematic bias and 95% limits of agreement ranging from 6% to 23%: The detection of stroke techniques showed a 42% rate of success. These data show that the measurement accuracy of the sensor racket is not sufficient for use in diagnostics or training. Future development of the sensor racket could include a method to calibrate the system prior to a measurement, in addition to correcting the underlying algorithm to reduce the bias.

Keywords: *Inertial sensor systems, movement analysis, racket sports, badminton.*

Resumen

Para evitar las desventajas de los sistemas ópticos de captura de movimiento basados en video y debido a la continua miniaturización de los sensores integrados, una creciente variedad de sistemas basados en sensores se ha usado para la captura de movimiento en deportes. Entretanto, existen soluciones ya terminadas y comercialmente disponibles que afirman ser capaces de registrar datos cinemáticos confiables. Este proyecto de investigación se enfoca en la pregunta de si una raqueta de bádminton disponible comercialmente con un sensor integrado (Oliver® Plasma TX 5) proporciona datos relevantes para el diagnóstico y entrenamiento en deportes de élite. Por tanto, 16 jugadores de bádminton de élite ejecutaron remates en salto usando la raqueta con sensor mientras la cinemática de la técnica del golpe era grabada con un sistema de alta velocidad basado en video. Los gráficos de Bland-Altman se usaron para analizar la concordancia entre los dos sistemas. Los gráficos revelaron un sesgo sistemático y límites de concordancia del 95% entre 6% y 23%. La detección de las técnicas del golpe evidenció una tasa de éxito del 42%. Estos datos demuestran que la precisión en la medición de la raqueta con sensor no es suficiente para usarla en diagnóstico o entrenamiento. El desarrollo futuro de la raqueta con sensor podría incluir un método para calibrar el sistema antes de hacer una medición, además de corregir el algoritmo subyacente para reducir el sesgo.

Palabras clave: *Sistema de sensor inercial, análisis del movimiento, deportes de raqueta, bádminton.*

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INTRODUCTION

When facing the task of conducting valid movement analyses, the high movement velocities in most sports are challenging. The use of optical video-based motion capture systems, for example, is usually accompanied by some crucial constraints, i. e. the necessity of a high sampling rate, the large data volume when using high frequency systems, the confined spatial frame, and the large effort required to extract the kinematic data (Krüger & Edelmann-Nusser, 2010; Wang et al., 2016). To minimize these drawbacks, and due to the ongoing miniaturization of integrated sensors, an increasing variety of sensor-based systems has been developed and used for motion capture in sports (e.g., Gawin, 2010; Jaitner & Gawin, 2010; Pei et al., 2017). In this context, the question arises whether these sensor systems provide the same accuracy and reliability as extensive optical video-based analyses. Taha, Hassan, Yap and Yeo (2016) combined an integrated sensor unit and the Kinect depth sensor that utilizes infrared light for motion capture. The kinematics of a subject's wrist movements while executing badminton smash movement patterns with the upper limb were recorded simultaneously by the two systems. Even though the measured average accelerations differed between the two systems, the authors concluded that the outcome patterns revealed by the Kinect depth sensor were comparable to the values of the integrated sensors.

Another attempt to compare a sensor-based system and a common video-based system is a study by Kerner and Witt (2013). To test the usability of a sensor-based whole-body system (Xsens Technologies, https://www.xsens.com/) for kinematic analyses, somersault movements of a female gymnast were recorded using this system and synchronously videotaped using a common videometry system (Simi Motion, http://www.simi.com/de/home.html). A strong deviation between the two systems from 30% up to 43% was revealed for the center of gravity of the athlete´s body and the amplitudes of the arm movement velocities.

The analysis of movements in the racket sport badminton is also characterized by high movement velocities, especially when the shuttle, the racket, and the upper body segments are addressed (e. g., Kwan et al., 2011; Tsai & Chang, 1998). In elite badminton, shuttle velocities of approximately 100 m/s and racket speeds of more than 50 m/s were reported (Jaitner & Gawin, 2010; Kwan et al., 2011). A manufacturer of racket sport equipment has reported an initial shuttle speed of 116.9 m/s (Yonex Corporation, 2010). This value was recorded, while an international top player executed jump smashes, the stroke technique in badminton, where the highest shuttle velocities are generated (Tsai & Chang, 1998). When performing a jump smash, a player hits the shuttle as hard as possible downwards into the opponent´s court while airborne after a jump. The aim is to generate the highest possible shuttle velocity.

Because of these high movement velocities, there have been many possible solutions generated to obtain kinematic data using different sensor-based measurement systems in the field of badminton. Jaitner and Gawin (2010) developed a mobile measurement device to analyze the movements of the racket arm and the racket (Jaitner & Gawin, 2007, 2010). The usability of the mobile device that was based on two-dimensional piezoelectric accelerometers (working at a sample rate of 1000 Hz) that were attached to the racket arm and racket was evaluated using a three-dimensional high-frequency video system (Basler, sample rate 250 Hz, https://www.baslerweb.com/). The comparison between the obtained high-frequency video data and the values from the accelerometers revealed moderate correlations between the acceleration of the racket arm and the racket with the shuttle velocities (Jaitner & Gawin, 2010). The reliable recording of exact position data by the sensor based system, however, was not possible, because the utilized technology only included 2D-accelerometers, no gyroscopes and no magnetic field sensors.

Other approaches to determine kinematic or performance parameters using various sensor measurement set-ups were, for example, the combination of high-frequency videometry and strain gauges at the racket (Kwan et al., 2010; Kwan & Rasmussen, 2010), inertial sensors (Kiang et al., 2009; Wang et al., 2016), acoustic sensors (Kiang et al., 2009) or electrocardiographic equipment (Sakurai & Ohtsuki, 2000; Tsai et al., 2006; Tsai, Huang, et al., 2005; Tsai, Yang, et al., 2005, for an overview see Wang et al., 2016).

Meanwhile, in the follow-up of these scientific attempts to develop and evaluate reliable measurement devices for movement analysis in racket sports, there are now ready-made commercially available solutions. One example in badminton is a sensor racket made by Oliver (Plasma TX 5, https://www.oliver-sport.de/plasma-tx5-rds/). An inertial sensor unit has been integrated into the grip of this racket (figure 1) to record velocities, recognize stroke techniques, and measure physical activity.

This racket with the integrated sensor succeeded in matching the weight (88 g.), balance, and price of common badminton rackets without integrated sensors. The balance remains unaffected by the sensor unit, as the weight of the replaced grip material is similar to the weight of the sensor unit.

Regarding the difficulties determining valid kinematic data in the sport of badminton, the recent research project focuses on whether the output of the above-mentioned sensor racket agrees with high speed video data. The measurement of valid velocities would be a valuable tool for performance analysis in the training process of skilled badminton players.

Figure 1. The sensor unit applied to the racket grip after cover has been removed.

METHODS

Sample

Sixteen highly skilled male badminton players (age 23.56 ± 4.63 years), all members of the German national team and without exception experienced in national and international competitions, participated in this study.

Instruments

The aim was to compare the inertial sensor racket by Oliver® with an approved method for obtaining kinematic data – in the current project an optical video-based camera system consisting of two industrial high-speed cameras (Optronis, Kehl, Germany, https://optronis.com/machine-vision/). These cameras are capable of recording video footage with a sampling rate of up to 16,000 Hz. For this study the cameras were adjusted to 500 Hz. This system allows the three dimensional capture of badminton stroke techniques with a sufficient sampling rate and high accuracy. For an evaluation of this method see Gawin, Beyer, Büsch and Høi (2012).

The variables that were recorded by the video system were shuttle and the racket velocities at the time of impact and racket angle (in relation to the horizontal plane) at impact. The core of the inertial sensor system consisted of a three axis accelerometer and gyroscope (figure 2). The recorded data were transferred in real time via Bluetooth® to a mobile device (smartphone, Samsung X-Cover) that was positioned near the court. The mobile device calculated and displayed the results in the system software Smart Badminton (Coolang, Shenzhen, China).

The variables of interest collected by the inertial system were velocity, stroke technique, and angle. As, unfortunately, the software manual does not provide information as to which velocity and angle are calculated, we contacted the manufacturer and were told that the computed variables represent racket velocity and racket angle at impact. However, the sampling rate is unknown.

Study Design and Implementation

Each participant performed a standardized 10-minute warm up. After the warm up, twelve jump smashes after single serves by an opponent were executed (figure 2).

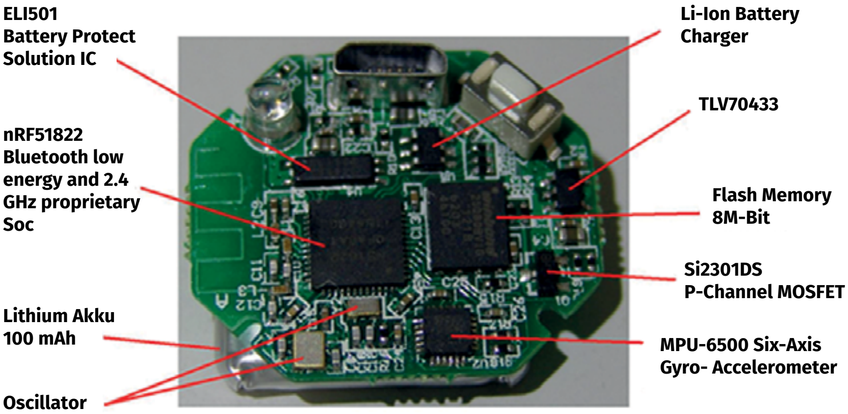

Figure 2. The board with sensor components in the racket grip.

Each subject used the sensor racket Plasma TX 5 for the smashes. After every stroke, the mobile device displayed the velocity, angle, and stroke technique. This data was notated immediately after every smash. Simultaneously, the execution of each smash was recorded by the high frequency camera system from two perspectives. The cameras were positioned at an angle of about 90° to each other beside the court.

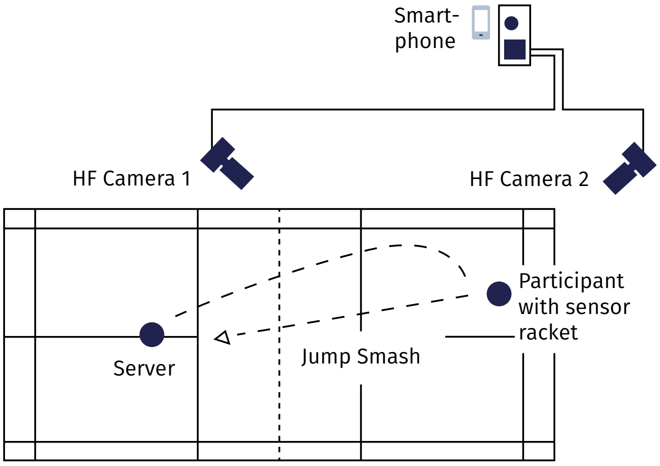

Figure 3. Experimental set up.

Variables

Using the video footage, shuttle and racket velocities, as well as the racket angle in relation to the horizontal plane were calculated. The kinematic variables obtained by the high frequency camera system were obtained by tracking the racket and the shuttle manually using the software Simi Motion for the analysis of 3D video data (Simi Reality Motion Systems, Germany).

The calculated variables had to meet certain criteria to provide comparability to similar studies. For shuttle speed, the temporal space that is utilized to calculate the speed is crucial, because the shuttle velocity decreases dramatically only ms after impact. According to former studies (Gawin et al., 2012), the time interval to compute the shuttle velocities was 12 ms immediately after impact. Shuttle velocity was averaged over this time interval.

As far as racket speed is concerned, the time frame comprised ten ms, beginning eight ms before and ending two ms after impact - a time interval within which the racket usually reaches its highest speed (Jaitner & Gawin, 2010; Kwan et al., 2011). Racket speed was calculated every two ms beginning eight ms before impact. The reference point for the measurement of racket speed was the t-joint. The obtained values were smoothed by the moving average over three frames, and then the highest speed in this ten ms interval was used to compare the two kinematic measurement systems.

The racket angle is the inclination of the racket (using the t-joint and the lowest point of the grip) in relation to a theoretical horizontal plane through the lowest point of the grip.

Statistics

Bland-Altman-Plots were established (Bland & Altman, 1986; Bland & Altman, 1999) to compare the two different methods. Bland-Altman-Plots serve to discover the differences between two methods that are to be compared by plotting the differences of the paired data against the mean values of the data tuples. To express the size of the deviation, limits of agreement must be computed that, following the definition by Bland and Altman, confine an interval within which 95 % of the differences between the two methods are expected to lie (Bland & Altman, 1999). In general, limits of agreement (LoA) are analysed in a graphical manner using Bland-Altman-Plots, where the difference between the two methods is plotted against their average as a point cloud. The point cloud is accompanied by lines indicating the average difference between methods (bias), as well as the upper and lower limits of agreement between the two methods.

Since we obtained several repeated trials per subject, we applied the method described by Bland & Altman (Bland & Altman, 2007) to compute limits of agreement for repeated measurements within subjects, as well as the "conventional" LoA method of deviations between methods for the average trial of each subject. If a relationship was found between the differences and the magnitude of the measurement, the LoAs were calculated using a linear regression approach for non-constant differences across the range of measured values (Bland & Altman, 1999).

The calculation of the LoAs itself provides no information about the significance of disagreement between methods. A sufficient amount of agreement has to be defined prior to the measurement. In this study, a deviation of no more than 5 % was defined as adequate for the useful application of the inertial measuring system for diagnostic and training purposes. Since Bland-Altman plots were used, this limit was calculated on the basis of the average values. The average values reached a maximum of 43.49 m/s for the racket velocities, and a maximum racket angle of 101.43°. This resulted in defined maximum limits of agreement of no more than 2.67 m/s for the racket velocities, and 5.07° for racket angle, respectively, based on the assumption that the maximal deviation does not exceed 5 %. LoA analyses and plots were created using R 3.4.2 (R_Core_Team, 2017).

RESULTS

The overall mean of the shuttle velocities counted for 84.14 m/s (±5.72 m/s) with a maximum of 100.35

m/s and a minimum of 67.10 m/s. The individual mean values for each subject are depicted in figure 4.

Figure 5 shows the differences-plot of the individual and average values for each subject for racket velocities. This plot reveals a clear relationship between the differences and the magnitude of the measurement. The underlying algorithm to calculate racket speed and angle was not able to correct these deviations.

As expected, the single values show a broader variance, with LoAs of ±10.05 m/s, than the average values, with LoAs of ±7.10 m/s. However, both LoAs are not acceptable, because they exceed the defined maximum deviation of 5 %.

It should be mentioned that the regression line changed its direction when averaging the single values. This is because the outlying single values are smoothed by the calculation of the players´ average values.

For the racket angle at impact, the interval between the limits of agreement was smaller, with a range of ±12.21° for the single values and ±6.41° for the means, respectively (figure 6). These are intervals that nearly meet the required limit of 5.07° that depicts a deviation of 5 %.

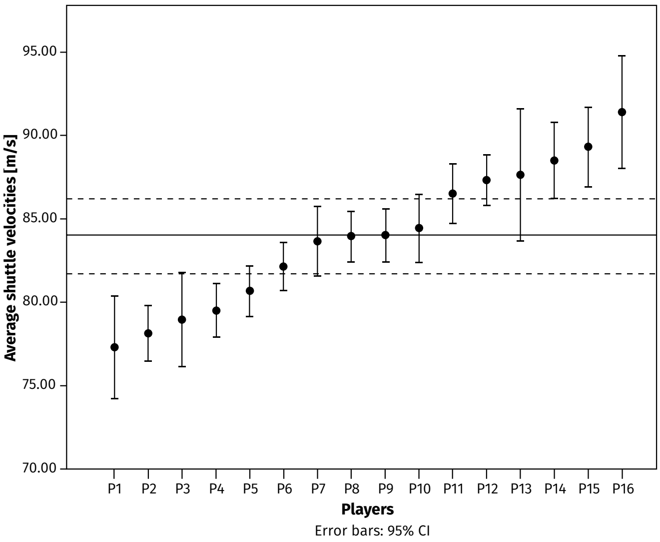

Figure 4. Average shuttle velocities.

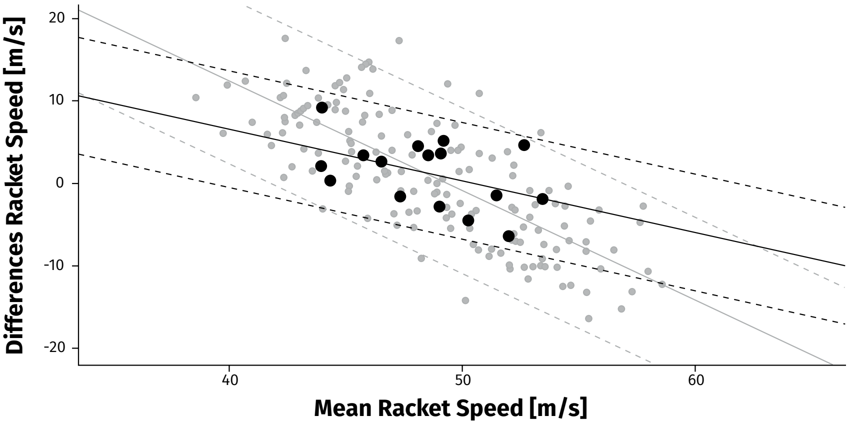

Figure 5. Plot of the differences (camera – sensor) against the average of the data tuples camera – sensor for the racket speeds. The black dots depict the mean values of each player, the light grey dots the single values.

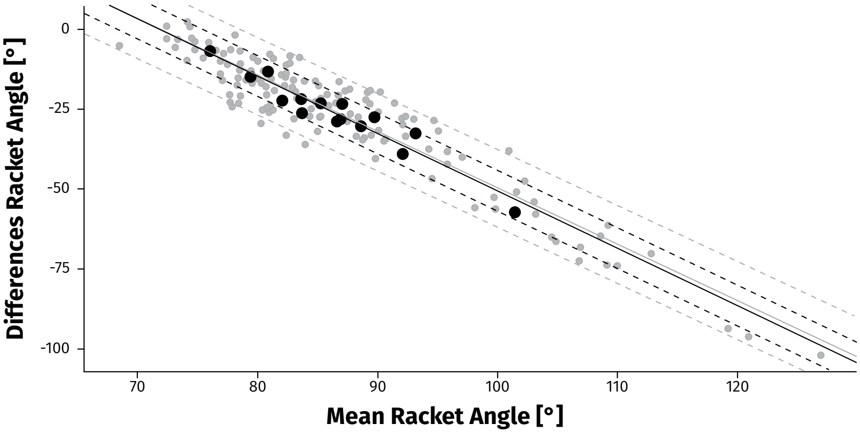

Figure 6. Plot of the differences (camera – sensor) against the average of the data tuples camera – sensor for the racket angle. The black dots depict the average values of each player, the grey dots the single values.

Concerning stroke techniques, the sensor racket detected four different kinds of strokes instead of just one, although the participants consistently performed smashes. The sensor racket correctly sensed the stroke type in 40.33 % of all recorded trials, but did not in 59.67 % of the trials.

DISCUSSION

The aim of evaluating the badminton sensor racket was to analyze the agreement between a standard video-based motion capture system and an integrated sensor system with regard to the latter's practical application as a diagnostic or training device.

When attempting to recognize stroke techniques, the sensor racket had a success rate of about 40 %, which is not sufficient for any practical use. As Pei and colleagues (Pei et al., 2017) have shown in tennis, the stroke technique detection bases on the course of the accelerometric data and has a highly specific event detection algorithm. A closer look to the stroke technique categories in the software of the analyzed racket reveals that there are techniques listed that are much more common in tennis, like slice or block, and other significant badminton stroke techniques are missing, like all kind of backhand stroke techniques. It is thinkable that the software of the sensor racket was not specifically designed for badminton. This could be a possible explanation for the poor recognition rate of the sensor racket.

For the variables racket speed and racket angle, the sensor racket results contain systematic bias and poor agreement to the camera system. The 95-%-limits of agreement range from ±16 % to ±23 % for racket velocities, and from about ±6 % to ±12 % for racket angles, respectively. The lower values depict the averaged, and the higher values the single performance values of each participant. As expected, the calculation of averages reduced the impact of the outliers and led to smaller LoAs and better agreement between the methods.

However, the agreement between the two systems for the average recordings for each player was insufficient for any practical application, even if the limits of agreement for the racket angles came close to meeting the demanded criteria. From a practical point of view, however, it is worth discussing how calculating racket angle can be used in a beneficial way by coaches or players when performing a smash.

Possible reasons for these between-subject deviations could be the grip position in the player´s racket hand, and the tendency of accelerometers to overestimate measurement (Alanen et al., 2021). Usually, highly skilled players use a very stable grip technique, especially in a highly automatized and fast movement technique like the jump smash. However, there are slight between-subject differences in the allocation of the racket grip in the hand within a group of players, deviating a few degrees from each other. If the alignment of the grip and therefore the orientation and the angle of the racket deviates between players, the axes of the accelerometer in the grip will also have a different orientation between the players, and will be subject to different amounts of cross-talk. Very likely the analyzed sensor unit will not be capable to successfully eliminate this cross-talk when calculating the velocities because of the complex algorithms to obtain velocities from accelerometric raw data. These algorithms have to imply three dimensional integrating of the accelerometric signals, calculating the inclination of the device by the gyroscopes to separate rotational from translational movements and filtering noise in real time. For these calculations a computing power is afforded that most probably the sensor of the analyzed racket will not provide. According to our results the comparison of independent subjects is not possible with the given sensor system.

A valuable future development of the sensor-based system could be a method that enables the user to individually calibrate the system and setting all signals to zero prior to a measurement, to reduce noise and cross-talk. However, it is not likely that an individual calibration would fix the problem of the strong relationship found between the differences and the magnitudes of the measurements. A correction of the system software, the sensor architecture and the underlying algorithm seems to be necessary.

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