ESTIMATION OF THE JUMP HEIGHT FOR THE VOLLEYBALL SPIKE BY A MOBILE IMU UNIT

Thomas Jaitner, Georg Ebker and Marcus Schmidt

Institute for Sports and Sports Science, TU Dortmund University, Dortmund, Germany

The maximal jumping height can be considered as a determining factor of spike as well as overall game performance. The purpose of this study was to develop and validate a mobile device based on inertial sensors as an alternative for in-field diagnostics. 23 female and male volleyball players performed 106 spikes with an IMU fixed at each ankle. An OptojumpNext^{TM} system (OJ) served as reference. Interclass correlation analysis computed a coefficient of r=.995. Bland-Altman-plot showed 95% limits of agreement between 2.9cm and -1,2cm. Hence, the mobile IMU device determines jumping height in real competition conditions with an accuracy of approximately ±2cm. We consider this as acceptable for application in volleyball training, e.g., but further effort is necessary to optimize the detection algorithms to achieve higher accuracy.

KEY WORDS: Volleyball, Inertial Sensors, Performance Analysis

INTRODUCTION: In general, volleyball players try to spike the ball at maximal height as this increases the chance to pass the block successfully and to place the ball in the opponent's field due to an optimized release angle. Besides other technical skills, the release height is mainly determined by the vertical jumping height. The ability to jump as high as possible can therefore be considered as a determining factor of spiking performance in particular as well as of the overall playing performance (Petersen et al., 2002; Wagner et al., 2009). Performance tests such as counter movement jumps are very often applied to determine the vertical jumping abilities, but they allow only a rough estimate of the jumping height that will be achieved if a real spike is performed. As the spiker needs to exactly coordinate his own movements regarding the trajectory of the ball and the positioning of the opponent players, he cannot completely concentrate on jumping and hence may reach a lower jumping height.

In-field determination of jumping height seems therefore eligible to analyse playing performance. High speed video analysis, e.g., is an appropriate measure device for such analysis and has been applied in several studies (Jaitner & Brach, 2005; Kuhlmann et al., 2011; McGuine & Keene, 2006; Verhagen et al., 2004; Wagner et al., 2009). However, for an accurate assessment of the jumping height a full body three-dimensional analysis is affordable to calculate the center of gravity of the player's body over flight time. This needs a full view of at least two cameras without any occlusion by other players or equipment. Automatic tracking is often not possible, which increases effort and time for analysis. In addition, other measurement systems based on light barriers or force plates, e.g. are typically not applicable for in-field analysis in team sports.

Inertial sensor units (IMU) offer a promising alternative for in-field performance analysis as they are not bound to the restrictions stated above. Picerno et al. (2011) already applied inertial sensors to determine flight time and to estimate jump height in counter movement jumps and reported a correlation of r=.87 with parameters derived from an optometrical system (Vicon^{TM}). For the drop jump, high correlations of .98 were found between reactive strength indexes, both calculated indirectly by flight time derived from force plate data and accelerometer data (Patterson & Caulfield, 2010). For ground reaction forces and peak acceleration only moderate correlations of r=.55-.70 were observed (Beard et al., 1993).

In previous studies, we developed our own mobile IMU device that has also been successfully validated for the analysis of drop jump performance (Jaitner et al., 2016). Calculating jumping height from the flight time using the equations of motion, mean differences between our IMU device and force plate data were less than 0.6cm. The purpose of this study was to further develop this device for in-field analysis of the volleyball spike and to validate jump height estimation.

METHODS: The wearable inertial sensor unit consisted of an IMU (MPU-9150, InvenSense™) that combined a 3-axis accelerometer (up to 1 kHz sampling rate with a resolution of 16 bit and ±16g range), 3-axis gyroscope (up to 8 kHz sampling rate with a resolution of 16 bit and ±2000 deg./s. range) and 3-axis magnet field sensor (up to 100Hz sampling rate with a resolution of 13 bit and ±1.2mT range), a microprocessor (ARM Cortex M3 Giant Gecko, Silicon Labs™) as well as an Bluetooth Low Energy (BLE) communication unit (Nordic™ nRF8001).Overall size and weight were 80x56x24mm³ and 63 g, respectively. In this study, all data were stored on an internal microSD card for later analysis. Generally, this device supports onboard processing of the raw data in combination with wireless data transmission of calculated parameters to an external device (Jaitner et al., 2016).

Two IMU devices were attached at the right and left ankle. By the time courses of the vertical acceleration, the end point of take-off and the beginning of the landing were determined (figure 1). The ground contact of the first leg landing marked the end of the flight time. The equations of motion was used to calculate jumping height from the flight time.

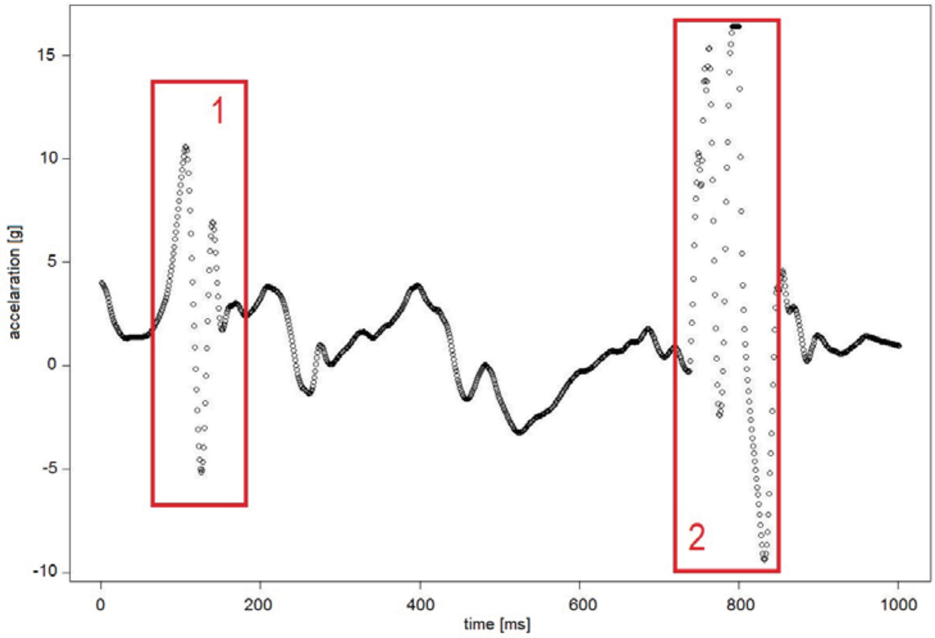

Figure 1: Vertical acceleration at one ankle during a volleyball spike. Area 1 shows the take-off, whereas landing occurred in area 2.

23 volleyball players (9 female, 14 male, 4th & 5th national league) performed each five volleyball spikes from the outside hitter position (left side). From the 115 trials 8 had to be excluded for technical reasons. Altogether 106 trials (a minimum of three per athlete) could be analysed. An OptojumpNext™ system (OJ) served as reference. Contact and flight times were measured based on light barriers at a sampling rate of 1 kHz.

For statistical analyses, interclass correlation (ICC) and Bland-Altman-plots (BAP) of the jumping height derived from IMU and reference system were calculated.

RESULTS: Table 1 shows the mean jumping heights calculated from IMU and OJ data, respectively. The deviations in jumping height derived from both measurements were in a range of 4.2cm with a mean difference of 0.9cm. Intraclass correlation result in an ICC coefficient of r=.995. The Bland-Altman-Plot in figure 2 shows the 95% limits of agreement with an upper boundary at 2.9cm and a lower boundary at -1.2cm.

Table 1
Performance parameters derived from IMU and reference data (OJ)

Parameter	Value
Mean jumping height (IMU)	46.5±10.5 cm
Mean jumping height (OJ)	45.7±10.1 cm
Mean difference (IMU-OJ)	0.9± 1.1 cm
Maximum difference (IMU-OJ)	4.2 cm
Minimal difference (IMU-OJ)	0.0 cm

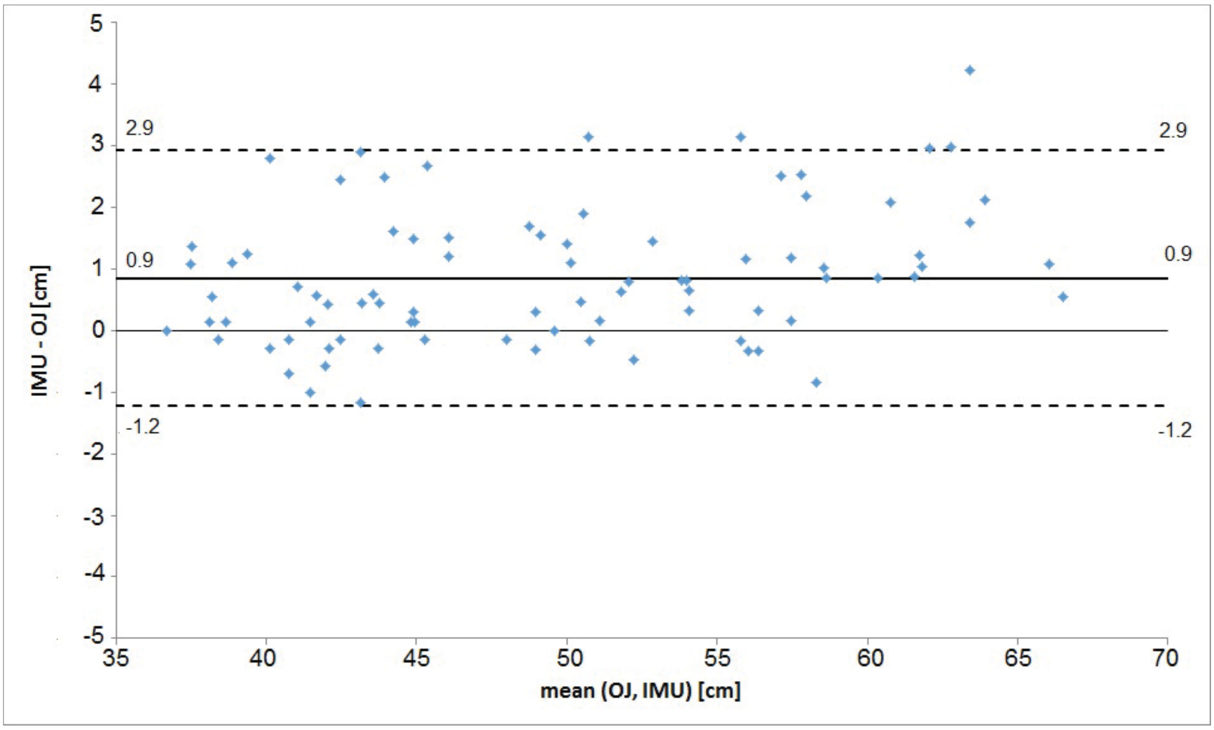

Figure 2: Bland-Altman-plots of jumping heights derived from IMU and OJ

DISCUSSION: Overall, the IMU device reveals jumping heights that in mean are approximately 1 cm lower than parameters derived from the reference system, but data from both measurements are also highly correlated. This is in line with results of Glatthorn et al. (2011), who showed that OJ underestimates jumping heights during vertical jumps with a mean error of 1.06 cm compared to a force plate (Glatthorn et al., 2011). Considering these results and implementing a correction factor allows the estimation of jumping height with an accuracy of approximately ±2cm. We assume that this accuracy is acceptable for the application in volleyball training, especially if immediate feedback is desired. However, as a limitation of this study it has to be stated that neither of the devices measured jump height directly.

The IMU device has been designed to support a monitoring of multiple athletes at the same time (Jaitner et al., 2016). Hence, an automatic detection algorithm will be implemented on the IMU nodes in future, which enables to calculate jumping heights onboard and to send parameters to an external device (e.g. tablet). The data from several IMU nodes can then be received and displayed by one device handed to the trainer.

Further effort will be made to optimize the algorithm for the detection of take-off and landing. Accuracy might be enhanced by implementing filtering routines at the raw data as well as by an optimized positioning of the sensors. According to further experiences in track and field disciplines (Nichols et al., 1999), it also seems to be a promising approach to take individual movement characteristics into account for the optimization.

CONCLUSION: In this study, an IMU based measure device for the analysis of volleyball performance was presented that offers an alternative to elaborate biomechanical methods. With a high flexibility and practicability, it might approve especially for routine applications in volleyball training if a particular high accuracy is not mandatory. Further research will focus on the enhancement of measurement accuracy as well as on usability aspects.

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