DOI: 10.30827/Digibug.---

Original Investigation

Validation of wearables for technical analysis of tennis players

Validación de vestibles para análisis técnico de tenistas

Gabriel Delgado García [1], Jesús Siquier Coll [1], Santiago Castro Infantes [2], Emilio J. Ruiz Malagón [2], Berta Benito Colio [1] *, and Francisco Tomás González Fernández [3]

1 Department of Physical Activity and Sports Sciences, Comillas Pontifical University. CESAG, Mallorca, Spain.
2 Faculty of Physic Activity and Sport. University of Granada, Granada, Spain.
3 Department of Physical Activity and Sports Sciences, University of Granada. Ciencias de la Educación y del Deporte, Melilla University, Spain.

Received: 06-05-22

Accepted: 17-03-23

Abstract

The aim of the study was to study the validity of two well-known commercial sensors (Zepp and Qlipp) by comparing the speed data they provide with those of a speed radar and a 3D photogrammetric system. Four tennis players of different levels were part of the present study: one was of competition level (male; 29 years old; 1.89 m; 79 kg) and the other three were of initiation level (20-30 years old and a 24-year-old female). They performed a total of 77 strokes after receiving through a ball machine at a speed of 70 km/h and with the minimum lift effect allowed by the machine. The ball speed measured with the Zepp sensor and with the Qlipp sensor was compared with the speed recorded by a radar (Stalker Pro II, USA) and with a photogrammetric system composed of 4 USB cameras (ELP, China) recording at 100 Hz. The ball and the end of the racket were digitized on the video using the freeware Kinovea and their real 3D coordinates were obtained by applying the DLT algorithm, using the Kinemat tool in the mathematical analysis software GNU Octave. The velocity was calculated by deriving the 3D coordinates using a fifth-degree spline. The data of the present work indicate that the hitting kinematics of each player affects the accuracy of the sensor, so we consider that further studies are required to evaluate the error in players of different levels and playing styles. The inertial sensors evaluated in this work seem adequate to measure ball speed in intra-subject studies and the Lin CCC values in the first study and the adjusted values in the second study were almost all greater than 0.75.

Keywords: *Tennis, performance, validation, racket sports, photogrammetry.*

Resumen

El objetivo del estudio fue analizar la validez de dos sensores comerciales conocidos (Zepp y Qlipp) comparando los datos de velocidad que proporcionan con los de un radar de velocidad y con los de un sistema fotogramétrico 3D. Cuatro tenistas de diferentes niveles formaron parte del presente estudio: uno era de nivel de competición (varón; 29 años; 1.89 m; 79 kg) y los otros tres eran de nivel iniciación (20-30 años y una mujer de 24 años). Estos realizaron un total de 77 golpes después de recibir a través una máquina lanzapelotas a una velocidad de 70 km/h y con el mínimo efecto liftado permitido por la máquina. La velocidad de la pelota medida con el sensor Zepp y con el sensor Qlipp se comparó con la velocidad registrada por un radar (Stalker Pro II, USA) y con un sistema fotogramétrico compuesto por 4 cámaras USB (ELP, China) grabando a 100 Hz. La pelota y el extremo de la raqueta fueron digitalizados en el vídeo utilizando el freeware Kinovea y se obtuvieron sus coordenadas 3D reales aplicando el algoritmo DLT, usando la herramienta Kinemat en el software de análisis matemático GNU Octave. La velocidad fue calculada derivando las coordenadas 3D mediante un spline de quinto grado. Los datos del presente trabajo indican que la cinemática de golpeo de cada jugador afecta sobre la precisión del sensor, por lo que consideramos que se requieren más estudios para evaluar el error en jugadores de diferentes niveles y estilos de juego. Los sensores inerciales evaluados en este trabajo parecen adecuados para medir la velocidad de pelota en estudios intra-sujeto y los valores Lin CCC en el primer estudio y los valores ajustados en el segundo estudio fueron casi todos mayores de 0.75.

Palabras clave: *Tenis, rendimiento, validación, deportes de raqueta, fotogrametría.*

Corresponding author: Berta Benito Colio, bbenitocolio@gmail.com

Cite this article as:
Delgado García, G., Siquier Coll, J., Castro Infantes, S., Ruiz Malagón, E. J., Benito-Colio, B., & González-Fernández, F. T. (2022). Validation of wearables for technical analysis of tennis players. *International Journal of Racket Sports Science*, 4(2), 56-60.

This is an open access article under the CC BY license (https://creativecommons.org/licenses/by/4.0/).

INTRODUCTION

The use of wearable technology for technical analysis of tennis players is becoming increasingly common (Shan et al., 2015; Kos et al., 2016). These technologies in addition to performance enhancement allow the quantification of training load, thus being able to help prevent overuse injuries such as epicondylitis (Keaney & Reid, 2018). Some brands that market these sensors are Babolat, Zepp, Qlipp or Sony. These devices usually provide information of the stroke speed (either they estimate the speed of the racket or the ball), the spin of the stroke, the type of stroke and the impact point of the ball on the racket. We have found only one scientific work indexed in the Journal Citation Report, concerning the validity of the Babolat sensor and the Zepp sensor (Keaney & Reid, 2018). In this work the sample consisted of a single athlete, so more studies validating these devices with a more heterogeneous sample are required. In other racket sports there are also similar publications and for example Jaitner and Gawin (2010) found high correlations between racket speed measured with an inertial sensor and badminton shuttlecock speed.

There are other publications showing other inertial sensors for technical analysis oriented to racket sports. Yang et al. (2017) develop a sensor (TennisMaster), and evaluate its performance by collecting the acceleration and angular velocity data of 1030 serves performed by 12 subjects of different playing levels. The evaluation results showed that the TennisMaster device achieves an accuracy in serve detection of 96% and an accuracy in splitting the phases of the stroke of 95%. Kos et al. (2016) also obtained high accuracy (above 95%) using algorithms for classification of forehand, backhand and serve strokes.

Considering that the quantification of training load is fundamental for both training improvement and musculoskeletal injury prevention the aim of the study was to study the validity of two known commercial sensors (Zepp and Qlipp) by comparing the speed data they provide with those of a speed radar and with those of a 3D photogrammetric system, including tennis players of different levels of play.

METHODS

Participants

The total number of participants were 4 tennis players who performed a total of 77 strokes. One of the subjects was of competition level (male; 29 years old; 1.89 m; 79 kg) and the other three were of initiation level (three males between 20 and 30 years old and a 24-year-old female). All of them signed an informed consent form and complied with the guidelines established in the Declaration of Helsinki for research in humans.

Procedures

Part 1: On-track evaluation

The ball was launched by a ball launcher (Lobster GrandSlam 4, see figure 1) at a speed of 70 km/h and with the minimum lift effect allowed by the machine. Different types of strokes were performed. Table 1 shows the strokes made by each player. The competition player performed only forehands, using either slice or topspin.

Table 1. Players included in the study and strokes made by each player.

Player number	Level	Characteristics	Analyzed strokes
1	Comp.	Male, 28 y.o.	15 forehands*
2	Amat.	Male; 48 y.o.	16 forehands
3	Amat.	Male, 28 y.o.	16 serves
4	Amat.	Female, 26 y.o.	9 drives, 11 backhand & 10 serves

Notes: Comp.: Competition; Amat.: Amateur.
*The competition player performed forehands varying the hitting effect (flat, clipped o topspin).

The ball velocity measured with the Zepp sensor and with the Qlipp sensor was compared with the velocity recorded by a radar (Stalker Pro II, USA, see figure 1) and with a photogrammetric system composed of 4 USB cameras (ELP, China) recording at 100 Hz. The ball and the end of the racket were digitized using the freeware Kinovea and their real 3D coordinates were obtained by applying the DLT algorithm using the Kinemat tool (Reinschmidt & van den Bogert, 1997) in the mathematical analysis software GNU Octave. The velocity was calculated by deriving the 3D coordinates using a fifth-degree spline (also included in the Kinemat tool).

Part 2: Laboratory evaluation

The Zepp device was placed on the cuff and a reflective marker on the end of the racket and the player was asked to perform 20 forehand and 20 backhand strokes against a ball attached to a springy stick. The resulting racket velocity was measured with Qualisys and the Zepp device.

Statistical procedures

The following statistical parameters were used to evaluate the validity of the sensor: RMSE, MAE, Pearson's r, Lin CCC and Bland-Altman (BA) plots. In order to analyze the quality of the correlations, the Evans scale (1996) was used.

In the second study, a separate analysis was performed according to the type of stroke (forehand or backhand). Both the whole sample and each subject independently were taken into account. In addition, the sample was divided in two: I) the first allowed the calculation of a line of fit of the data (slope and ordinate at the origin); II) the rest of the data were fitted based on the calculated regression line and compared with the gold standard.

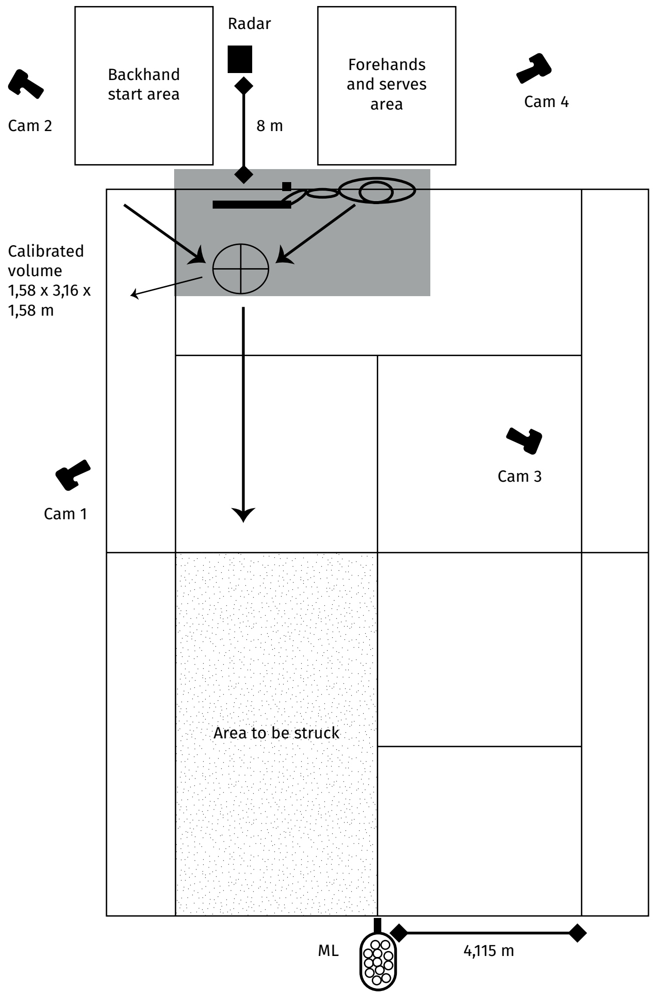

Figure 1. Scheme of the experiment carried out on track for the validation of the Zepp and Qlipp devices.
ML: Ball machine. Cam 1 and Cam 2 allow to analyze the serve and forehand and Cam 3 and Cam 4 the backhand.

RESULTS

Part 1: On-track evaluation

The ball velocity measured with the Zepp device had a high correlation with the velocity determined with the other devices, while in the case of the Qlipp sensor the correlations were moderate (see table 2).

The values of *MAE* were (V = Velocity):

- V Radar vs. V *Zepp* = 23 km/h; V Radar vs. V *Qlipp* = 18 km/h; V Radar vs. V Ball *3D* = 5 km/h.
- V Racket *3D* vs. V *Zepp* = 7 km/h; V Racket *3D* vs. V *Qlipp* = 22 km/h.
- V Ball *3D* vs. V *Zepp* = 25 km/h; V Ball *3D* vs. V *Qlipp* = 21 km/h.

Figure 2 shows the BA plots of the racket speed measured with the Zepp and the racket speed measured with the 3D system. Differences in error are observed as a function of player and stroke type.

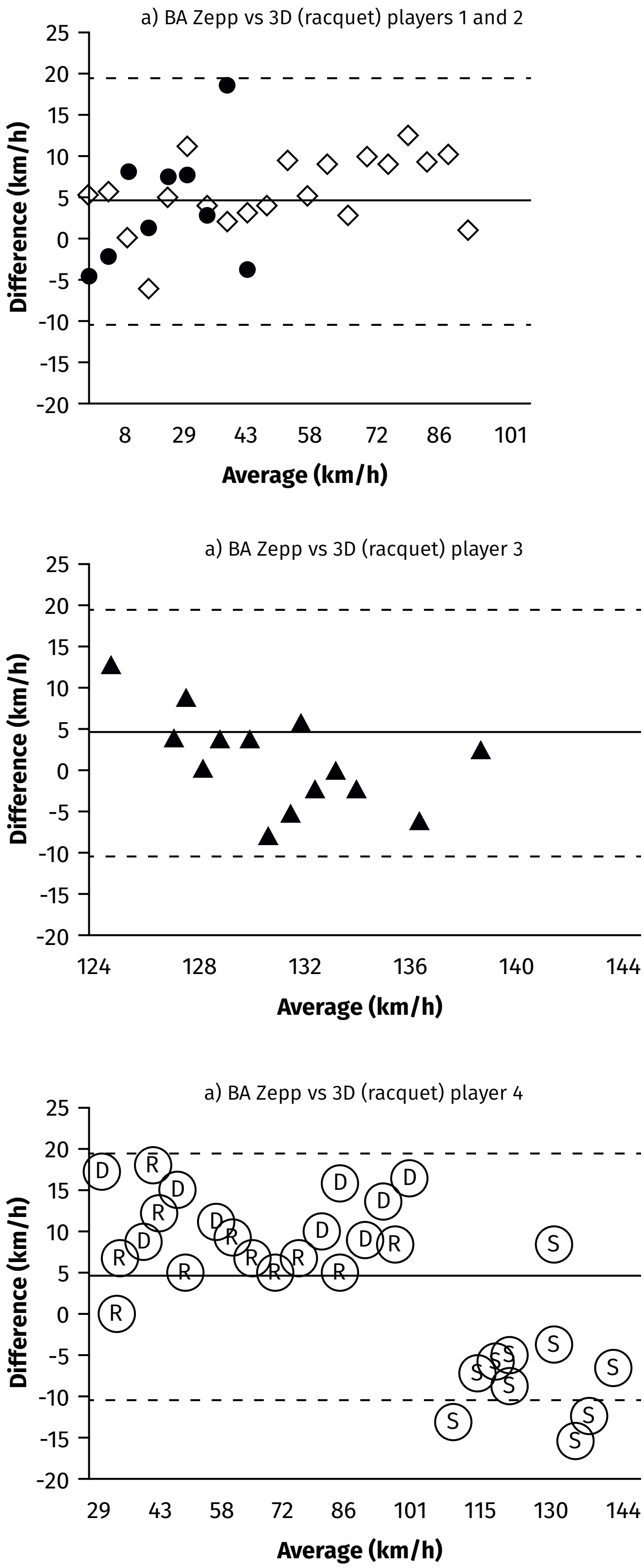

Figure 2. Bland-Altman (BA) plots of Zepp vs. 3D (racket) speed comparisons. * For player 4, each type of stroke is indicated by letters (D being forehand, R being backhand and S being serve).

Table 2. Lin CCC and Pearson's r between the speed measurements taken with different.

	VB Rad (km/h)	VR (3D) (km/h)	VB (3D) (km/h)	VR Qlipp (km/h)	VR Zepp (km/h)
VB Rad (km/h)	1	0.58	0.98	0.72	0.57
VR (3D) (km/h)	0.86	1	0.55	0.49	0.91
VB (3D) (km/h)	0.99	0.83	1	0.64	0.55
VR Qlipp (km/h)	0.75	0.71	0.66	1	0.57
VR Zepp (km/h)	0.85	0.95	0.83	0.8	1

*Above the diagonal, the values are shown as follows Lin CCC and below Pearson's R-values;
V: velocity; R: racket; B: ball.

Part 2: Laboratory evaluation

This section shows the data for the unadjusted values and the data for the adjusted values in parentheses. When all strokes were taken into account the Lin CCC value was 0.66 (0.75) and the MAE value was approximately 9 km/h (7 km/h). The mean error was approximately -7 km/h ± 10 km/h (0 ± 9.62 km/h), with the Zepp device measuring higher velocity values than Qualisys. At the intra-subject level, the highest MAE value found was 18 km/h (13 km/h) and the lowest was 4 km/h (4 km/h). When the strokes were evaluated according to the type of stroke, the following data were obtained for the forehand stroke:

- *Lin CCC* = 0.75 (0.85).
- *MAE* ~ 8 km/h (6 km/h).
- Maximum *MAE* ~ 15 km/h (10 km/h).
- Minimum *MAE* ~ 4 km/h (3 km/h).
- Mean error ~ -8 km/h ± 8 km/h (0 ± 7 km/h).

In the case of the backhand stroke the data were as follows:

- *Lin CCC* = 0.56 (0.67).
- *MAE* ~ 11 km/h (9 km/h).
- Maximum valor *MAE* ~ 20 km/h (13 km/h).
- Minimum valor *MAE* ~ 4 km/h (3 km/h).
- Mean error ~ -8 km/h ± 11 km/h (1 ± 11 km/h).

DISCUSSION

The use of wearable devices for technical analysis is becoming increasingly common both in the field of training and in research. Although there are numerous companies that have developed this type of devices in tennis, the studies that analyze their validity and reliability are scarce, this experiment being one of the few in this regard. We think that the error of the devices is sufficient for use in training, but not for research, where we advise the use of photogrammetric systems. We also recommend the use of sports radars, which show good accuracy and are portable.

We have only found one research paper in a journal indexed in the Journal Citation Report studying the validity of the Zepp device (Keaney & Reid, 2018). Although a high precision photogrammetric system was used as the gold standard the sample consisted of a single player and only 24 strokes were analyzed. The data of the present work indicate that the stroke kinematics of each player affects the accuracy of the sensor (for example, in 2a it is observed that in the player represented with white diamonds the magnitude of the error is lower than that of the player represented with black circles), so we consider that more studies are required to evaluate the error in players of different levels and styles of play. The type of stroke also seems to affect accuracy and for example in the player analyzed the Zepp overestimated the speed of the serve while underestimating the speed of the rest of the strokes. The aforementioned article indicates that the Zepp sensor and the Babolat branded smart racket, determined the volume and intensity of the strokes with good accuracy (mean error for stroke speed was 2.69 ± 5.63 km/h), but were less effective in identifying the type of stroke or the location of the impact on the racket.

Keaney & Reid (2018) point out that quantifying training using these types of sensors is critical, but that further validation studies are required. They also indicate that there is a need to improve inertial sensors for technical analysis of tennis players so that they can accurately measure impact location. This is of great interest, both for performance improvement and injury prevention, taking into account that this variable (point of impact of the ball on the racket) is related - in addition to the speed of exit of the ball after impact - with the vibrations transmitted from the racket to the arm and therefore with musculoskeletal injuries such as epicondylitis (8).

PRACTICAL APPLICATIONS

Despite the importance of deepening the subject of this research, inertial sensors that may be suitable for measuring tennis ball velocity in intra-subject studies are observed.

CONCLUSIONS

The inertial sensors evaluated in this work (Zepp and Qlipp) seem adequate for measuring ball velocity in intra-subject studies (the Lin CCC values in the first study and the adjusted values in the second study were almost all greater than 0.75). Specifically, the Zepp brand sensor obtained higher values. However, the Zepp errors were approximately 10 km/h when evaluating the unadjusted data and approximately 7 km/h for the adjusted data (in the laboratory study). The correlations appear similar to those in the Keaney & Reid (2018) study. We think that the measurement error of the Zepp is high in case of use with high-level players, where changes in velocity after a training program may be unnoticeable. In the case of amateur players, it could be useful since the changes after a training program will surely be more evident. It is necessary to validate the rest of the variables provided by these sensors (type of stroke, location of the impact on the racket, and stroke effect) and to include a larger number of players, taking into account that the stroke pattern could affect the sensor measurements.

REFERENCES

Evans, J. D. (1996). *Straightforward statistics for the behavioral sciences*. Thomson Brooks/Cole Publishing Co.

Jaitner, T., & Gawin, W. (2010). *A mobile measure device for the analysis of highly dynamic movement techniques, 2*(2), 3005-3010. https://doi.org/10.1016/j.proeng.2010.04.102

Keaney, E. M., & Reid, M. (2018). Quantifying hitting activity in tennis with racket sensors: new dawn or false dawn?. *Sports Biomechanics, 19*(6), 831-839. https://doi.org/10.1080/14763141.2018.1535619

Kos, M., Zenko, J., Vlaj, D., & Kramberger, I. (2016). Tennis stroke detection and classification using miniature wearable IMU device. *2016 International Conference on Systems, Signals and Image Processing (IWSSIP)*, 1-4.

Reinschmidt, C., & Van den Bogert, T. (1997). *KineMat. A MATLAB Toolbox for Three-Dimensional Kinematic Analyses. Calgary, Canada: Human Performance Laboratory, The University of Calgary.; 1997* [cited 2020 Jul 22]. https://isbweb.org/software/movanal/kinemat/

Shan, C. Z., Sen, S. L., Che Fai, Y., & Su Lee Ming, E. (2015). Investigation of Sensor-based Quantitative Model for Badminton Skill Analysis and Assessment. *Journal Teknologi, 72*(2). https://doi.org/10.11113/jt.v72.3891

Yang, D., Tang, J., Huang Y., Xu, C., Li, J., Hu, L., Shen, G., Liang, C-J., & Liu, H. (2017). *TennisMaster: an IMU-based online serve performance evaluation system. In Proceedings of the 8th Augmented Human International Conference (AH '17).* Association for Computing Machinery, New York, NY, USA, (17), 1–8. https://doi.org/10.1145/3041164.3041186