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Reliability and validity of motion sensor and radar for measuring shuttlecock velocity in badminton. *Reliability and validity to measure velocity in badminton*

Fiabilidad y validez del sensor de movimiento y el radar para medir la velocidad del volante en bádminton. *Fiabilidad y validez para medir la velocidad en bádminton*

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Abstract

Radar doppler and inertial measurement unit are often used to analyze the projectile velocity. The aim of the present study was to analyse the reliability and validity of a specifically motion sensor (named: Zepp Tennis) and a radar (Doppler-radar gun) for measuring projectile velocity. Thirty-four (novice, intermediate and expert) stroke badminton smash in a located target. Projectile velocity from five smashes were extracted using Zepp Tennis and Doppler-radar gun data. Between reproducibility of measures was determined by comparing the two sessions. Zepp Tennis and Doppler-radar gun measures were compared with high-frequency video data to establish validity. Both instruments were highly reproducible between trials at different velocity (intra-class correlation coefficient: 0.88-0.94 for radar and 0.78-0.89 for motion sensor). In addition, the positioning of the radar (front of the projectile and angulation) and the placement of the motion sensor and the complexity of the movement (forearm extension and pronation) affect the reproducibility. In terms of validity, radar and motion sensor provides an accurate measure but underestimate projectile velocity (-9.7% and -13.6% respectively).

Keywords: *Shuttle run, performance analysis, ecological validity, lunge.*

Resumen

El radar Doppler y la unidad de medición inercial se utilizan a menudo para analizar la velocidad del proyectil. El objetivo de este estudio fue analizar la fiabilidad y la validez de un sensor de movimiento (denominado Zepp Tennis) y un radar (pistola de radar Doppler) para medir la velocidad del proyectil. Treinta y cuatro jugadores (novatos, intermedios y expertos) realizaron golpes de bádminton en un objetivo localizado. Se extrajo la velocidad del proyectil de cinco golpes utilizando los datos del Zepp Tennis y de la pistola de radar Doppler. La reproducibilidad entre las medidas se determinó comparando las dos sesiones. Las medidas del Zepp Tennis y de la pistola de radar Doppler se compararon con los datos de vídeo de alta frecuencia para establecer su validez. Ambos instrumentos fueron altamente reproducibles entre las pruebas a diferente velocidad (coeficiente de correlación intraclase: 0,88-0,94 para el radar y 0,78-0,89 para el sensor de movimiento). Además, la ubicación del radar (en frente del proyectil y angulación), la ubicación del sensor de movimiento y la complejidad del movimiento (extensión y pronación del antebrazo) afectan a la reproducibilidad. En términos de validez, el radar y el sensor de movimiento proporcionan una medida precisa, pero subestiman la velocidad del proyectil (-9,7% y -13,6% respectivamente).

Palabras clave: *Carrera, análisis del rendimiento, validez ecológica, zancada.*

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INTRODUCTION

The ability to produce a high projectile velocity during a stroke or a shot is one of the main performance factors in sports such as table tennis, tennis, football and baseball. Furthermore, high velocity is correlated with performance in several sports (Laffaye et al., 2012). Projectile can include objects (ball, shuttlecock…) or athletes in flight. In Badminton, the shuttlecock velocity evolved linearly with skill levels (Phomsoupha & Laffaye, 2020).

Especially in badminton, many studies investigated the shuttlecocks velocity to find the biomechanical principles that optimize the motion. In badminton games, the highest velocity is obtained during the smash stroke, which generally allows to finish a rally (Rambely et al., 2005). A recent study showed that during the different Olympic Games finals in men's single, smash is used in about 10 to 14% of the total strokes (Laffaye et al., 2015). The smash can be defined as an aggressive overhead shot with a downward trajectory (Phomsoupha & Laffaye, 2015). At this time, the record of shuttlecock velocity is 493 km/h performed by the Malaysian Tan Boon Heong (Yonex, 2013).

In such a context, assessing the shuttlecock velocity with accuracy is a main stake for athlete monitoring or testing. To record performance, image processing is applied to various fields of sports, such as motion analysis, game analysis (Laffaye et al., 2015), and physical education (Nagasawa et al., 2012). The information including data from the science staff is needed by the player, the supervisor, and the coach to improve the performance (Nagasawa et al., 2012; Takahashi & Kawahara, 2011). Furthermore, this is information feedback of the player's performance.

To record the maximal velocity of the projectile, studies habitually used standard video camera (Hussain & Arshad Bari, 2011; Laffaye et al., 2014). However, this method reveals two main weaknesses. The standard error of measurement depended of the ratio of the launch velocity on the number of frame per second and resolution of the system (Nagasawa et al., 2012). The moment of the peak velocity has to be as close as possible of the moment the shuttlecock quits the racket. The contact between rackets, specifically the string and the ball happens at a very short time (about 5-6 ms) (Miller, 2006). Phomsoupha & Laffaye (2014) showed that the shuttlecock velocity *V* (in $m.s^{-1}$) is a logarithmic function of time *T* (in ms) as follow: $V = -9.2 \ln(T) + 2.4$, meaning that the velocity is divided by two times just 0.05 sec after the end of the racket contact. The difference of velocity between elite and high skilled players is about 10 $m.s^{-1}$ (Phomsoupha & Laffaye, 2014), whereas the velocity accuracy of a camera at 50 fps is about 5 $m.s^{-1}$. This showed that it is impossible to assess a badminton shuttlecock velocity with such devices.

The measurement of the velocity of projectile used in sport games is becoming increasingly common. Such speeds are usually measured using radar guns (Robinson & Robinson, 2016). These devices measure the frequency difference between the reflected signal and the transmitted signal to relate the relative speed of the ball and the radar (Halliday et al., 2011). An increase in frequency of the reflected signal shows the projectile is approaching and a decrease indicates an increase of the distance. Moreover, radar gun devices measure only the radial velocity and will always under-estimate the real velocity (French, 1968; Resnick, 1968).

With advances in microelectronics, wearables recently gained significant attention in sports (Coyle et al., 2009). Specifically, for racket sports, the machine learning methods detect and classify a basic set of shot classes such as forehand and backhand (Petkovic et al., 2001). Moreover, inertial measurement unit (IMU) including accelerometer, gyroscopes, and magnetometer could be used to detect the occurrence of shots (Connaghan et al., 2010). Beyond academic research, few devices have been made and marketed for players and trainers. The most prominent are certainly Babolat Play and Zepp Tennis. An IMU with a wireless transmitting device is attached on the racket handle and data is sent to a smartphone or a tablet for further analysis.

To obtain a better accuracy, some studies used 3D motion analysis system and high speed camera to record the shuttlecock velocity (Domone et al., 2012; Huang et al., 2002; Jaitner & Wolf, 2007; Lee, 1993; Strohmeyer et al., 2009; Tsai et al., 2005, 2006, 2008; Tsai, Chang, et al., 2000; Tsai, Huang, et al., 2000). High speed camera allows that the projectile to evolves in a plan, to avoid parallax error of measurement, whereas 3D motion analysis is free of this kind of error. This allows to obtain an accuracy between 12 and 50 $m.s^{-1}$, depending on the camera frequency (120 and 500 fps in studies) and it could be considered for the measurement of velocity as the gold standard. However, these devices are expensive for coaches and personal trainers and their use is largely confined to University laboratories and elite sports clubs (Balsalobre-Fernándeza et al., 2015). Furthermore, some of these instruments need specific computer software to analyse the data.

However, to the best of our knowledge, there are no studies validating a motion sensor coupled with a smartphone application or a radar for measuring shuttlecock velocity. The aim of the present study, therefore, was to analyse the validity and reliability of a specifically radar (*Doppler-radar gun*) and a motion sensor or IMU (named: *Zepp Tennis*) for measuring projectile velocity, by comparing with a 'gold standard' measurement system, the Vicon high speed camera system.

MATERIAL AND METHODS

Participants

Thirty-four healthy volunteers (12 novices, 11 intermediates and 11 experts) free of injury (age = 20.1 ± 3.5 years; height = 1.75 ± 10.1 m; body mass = 69.2 ± 13.3 kg; training experienced 8.3 ± 3.1 years) participated in this study (Table 1). Their skills were reflected according to their year of experience and are labelled as followed: novice (lower than 1 year); intermediate (between 3 to 5 years of practice) and experts (more than 5 years of practice). All participants were physically healthy, in good physical condition, and reported no injuries during the time of the study. They were fully informed about the protocol before participating in this study. Informed consent was obtained prior to all testing from all subjects, in accordance with the approval of the local ethical committee and adhered to the latest amendments of the Declaration of Helsinki. The written informed consent was obtained from each participant before experiment. The sample was divided on three groups to obtain different maximal shuttlecock velocity during a smash. The year of practice permit to obtain different velocity.

Table 1.
Age and anthropometric characteristics of the three samples (mean and standard deviation).

Variables	**Novice**	**Intermediate**	**Expert**
Age (years)	24.5 ± 7.6	21.1 ± 4.4	24.4 ± 8.1
Height (cm)	182.3 ± 7.2	179.9 ± 6.3	176.9 ± 9.7
Weight (kg)	76.5 ± 9.8	72.8 ± 9.3	74.3 ± 1.7
Training experienced (years)	0.2 ± 0.7	4.1 ± 1.3	10.6 ± 2.9

Study design

The participant completed a general 10-min warm-up composed of jogging, upper body dynamic stretches and stroke with the racket. Then, each participant performed five badminton smash strokes in a target located in front of him (2m x 2m). During each trial, participants were not informed of their performance. Each smash stroke was separated by 30 sec passive rest period. A shuttlecock was suspended from the ceiling with a string at the player’s preferred hitting height. When in contact with the racket, the shuttlecock is pulling away from the celling to produce the trajectory of the smash. No participant expressed residual fatigue from preceding procedure. The experiment took place in two sessions with a minimum of 2 separated days between each one.

Badminton smash strokes

Participants performed badminton smash strokes with the same racket (Wilson Draco Blx; height = 674 mm; weight = 86 g; flexibility = semi-rigid; string tension = 10.5 kg). No instruction was given to the participants on how to proceed during a badminton smash stroke. They were only instructed to stroke as hard as possible.

Equipment

Sports radar. A Doppler-radar gun- Stalker Sport system (Texas, United States) at a frequency of 250 Hz and an accuracy claimed by the constructor of ± 0.027 m/s was used to measure the projectile velocity. The radar permitted to obtain the maximal and the evolution of the velocity during each trial. The experimenter is located 2 meters behind the player in the player-target axis at approximately 2m50 (Chelly & Denis, 2001).

Motion sensor. To record the shuttlecock velocity with *Zepp Tennis*, a mount was attached to the handle of the racket and the sensor was inserted into the mount. The application was designed for analysing the velocity of the racket and the velocity potential of the projectile. Zepp Tennis is available on the Appstore (Apple Inc., USA) and on Google play (Google Inc., USA).

High speed camera reference. The high-speed camera recorded by nine *Vicon V8i* motion capture system at a frequency of 500 Hz (Vicon Peak, Oxford, UK) in order to measure the projectile velocity. A reflective marker of 14 mm diameter was affixed on the front of the shuttlecock. The Vicon system was connected to a PC equipped with the software to analyse and obtain the maximal projectile velocity (Vicon Motion System Ltd., UK). The video-based system is considered as the gold standard reference for establishing concurrent validity of the velocity. The materiel permitted to compare the error of the measure with the other materials.

Statistical analyses

Several analyses were conducted to determine the reliability and validity of badminton smash strokes using the motion sensor and the radar in the present study. To summarise the data from all participants and each trial, descriptive statistics were realised. All data were normally distributed on the basis of Shapiro-Wilk test.

i) Relative reliability is related to the degree to which system maintain their position in a sample with repeated measurements (Atkinson & Nevill, 1998). To analyse the test-retest reliability of both instruments between trials of measurements, intra-class correlation coefficient (ICC) was performed. These coefficients were computed as [$ICC = 1- (SEM/SD)^2$], where SEM is the standard error in measurement and SD is the mean between participant SD of the trial obtained by weighing the variances on the basis of their degrees of freedom (Hopkins, 2000). The SEM was computed as [SEM = SD (between-trial difference in measures) /$\sqrt{2}$]. To analyse the reliability of the motion sensor and the radar when measuring smash stroke of each participant, the coefficient of variation (CV) was used, on the basis of [CV = (SEM/mean)/100%], where the mean takes into consideration all participants and both trials (Atkinson & Nevill, 1998; Hopkins, 2000). To detect systematic bias between trials, Student's t-test was performed (Atkinson & Nevill, 1998).

ii) Data set used concurrent validity has normal distribution. The difference between the materials was examined using a one-way analysis of variance. When a significant F-value was found ($p < 0.05$), the Bonferroni post-hoc was applied (Cohen, 1988). In complement, the bivariate Pearson product moment correlation coefficient (R) was used.

iii) Bland-Altman plots were created, which are known to give a good representation of the agreement between the three instruments (Bland & Altman, 1986). To quantify the statistical dispersion, a White's test was used (White, 1980) to obtain the level of heteroscedasticity.

Concurrent validity was assessed by comparing the mean of trials performed at the maximal performance between two systems. Similar statistical measures to those used to assess reliability were employed for concurrent validity. More precisely, we computed Student's t-test for paired samples (systematic bias), ICC values (relative validity), between-system differences in means (absolute validity in raw units and %) and CVs (absolute validity in %). To obtain a better result, the error size and a maximal error of 5% is considered to be acceptable for a practical application compared to high-speed cameras. On the basis of commonly used thresholds, the relative reliability and validity measures were considered poor, fair and good when the corresponding ICC values were <0.4; 0.4-0.75; >0.75 (Portney & Watkins, 2009). The absolute reliability and validity of measures were considered adequate when the corresponding CV values were equal to or lower than 10% (Stokes, 1985). All calculations were performed using Statistica 10 software (StatSoft Inc., Tulsa, OK), Microsoft Excel 2010 (Microsoft Corp., Redmont, WA, USA) and software R (www.r-project.org).

The intra-session error is free of methodological errors and may be considered as "intrinsic variation" and served as an appropriate baseline for comparisons, remaining independent of other error sources. Intra-session reliability of projectile performance is critically important to ensure that observed differences between testing trials, are not due to systematic bias, such as learning effect, fatigue, or random error due to possible biological or mechanical variation. This variability is usually caused by the emotional state of the participants between the trials and their level of adaptation with the measuring system.

RESULTS

Test-retest reliability

The velocity parameters for each projectile and the mean between-trial difference are reported in Table 2 for the three systems. The between-trial difference in projectile velocity across the level (novice, intermediate and expert) were 5.4 ± 3.7 $m.s^{-1}$, 5.5 ± 2.8 $m.s^{-1}$ and 4.8 ± 3.4 $m.s^{-1}$ for the radar; 6.6 ± 6.4, 4.9 ± 4.2 $m.s^{-1}$ and 5.1 ± 3.4 $m.s^{-1}$ for the motion sensor and 5.2 ± 4.9 $m.s^{-1}$, 4.9 ± 2.9 $m.s^{-1}$ and 5.5 ± 3.0 $m.s^{-1}$ for the high-speed cameras.

The ICC and CV values specific to the reliability at the different test speeds are reported in Table 2 for the three systems. The means of the ICCs was 0.907 ± 0.027 (range 0.88-0.94), 0.840 ± 0.054 (range 0.78-0.89) and 0.940 ± 0.018 (range 0.92-0.96) for the radar, the motion sensor and the high-speed cameras, respectively. Their corresponding mean CV values were 5.8 ± 0.7 (range 5.3-6.6), 7.7 ± 1.8 (range 6.1-9.6) and 4.3 ± 1.0 (range 3.5-5.4). Overall, all three systems demonstrated a good relative and adequate absolute reliability for projectile velocity (Table 3).

Table 2.
Projectile velocity stride parameters calculated using the radar, the motion sensor and the high-speed camera systems.

	Radar			Motion sensor			High speed camera		
Parameter (unit)	Session 1	Session 2	Δ [%]	Session 1	Session 2	Δ (%)	Session 1	Session 2	Δ (%)
				Velocity ($m.s^{-1}$)					
Novice	34.9 ± 8.9	33.3 ± 7.8	4.6	33.6 ± 10.1	33.4 ± 8.4	0.8	37.5 ± 9.1	37.2 ± 7.5	0.9
Intermediate	45.1 ± 6.2	46.2 ± 7.9	-2.6	47.9 ± 4.5	46.6 ± 7.7	2.7	48.1 ± 6.1	49.1 ± 8.9	-1.9
Expert	57.1 ± 9.9	57.9 ± 8.7	-1.5	53.8 ± 8.3	54.4 ± 7.3	-1.3	56.7 ± 9.5	60.4 ± 10.8	-1.2

Note: The mean ± SD for each trial and test velocity, and the difference between trials (Δ, in %) are reported.

Table 3.
The relative (intra-class correlation coefficient, ICC) and absolute (coefficient of variation, CV) reproducibility of projectile velocity stride parameters calculated using the radar, the motion sensor and the high-speed camera system.

	Radar		Motion sensor		High speed camera	
Parameter (unit)	ICC	CV (%)	ICC	CV (%)	ICC	CV (%)
			Velocity ($m.s^{-1}$)			
Novice	0.937	6.6	0.893	9.6	0.940	5.4
Intermediate	0.884	5.5	0.785	7.5	0.921	4.1
Expert	0.901	5.3	0.842	6.1	0.957	3.5

Note: ICC < 0.75 and CV > 10% are italicised and represent fair relative reproducibility and less than adequate absolute reproducibility of measures, respectively.

Also, the Pearson product moment correlation coefficient showed almost perfect correlation between the radar and the high-speed camera measurements for velocity (r= 0.917; p < 0.001); and good correlation between the motion sensor and the high-speed camera measurements (r=0.682; p < 0.001) (figure 1 et 2)

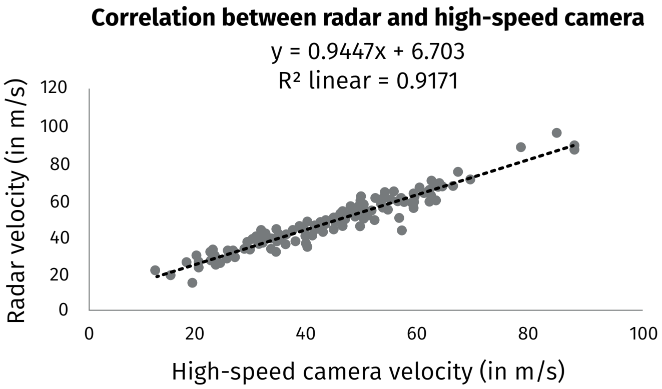

Figure 1. Concurrent validity between radar and high-speed camera.

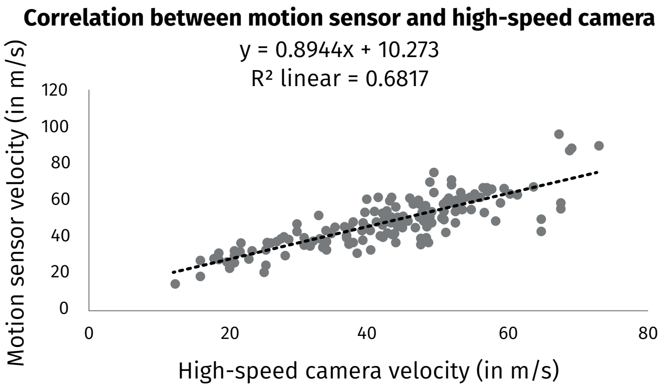

Figure 2. Concurrent validity between motion sensor and high-speed camera.

Validity

The mean of both trials is presented in Table 3 for each system, as are the differences between radar and motion sensor and the reference system (high-speed cameras). Radar and motion sensor recorded significantly shorter velocity compared to the high-speed cameras (Table 4). In contrast, level parameters recorded using the radar and the motion sensor showed no significant differences (all levels, P > 0.05).

The ICC and CV values describing the concurrent validity of projectile velocity calculated using the high-speed camera, against the two reference systems are reported in Table 5. The absolute (ICC) concurrent validity of the radar and the motion sensor was overall fair for projectile velocity against the high-speed cameras (0.757 ± 0.207 and 0.866 ± 0.029 respectively). The corresponding relative (CV) concurrent validity measures were higher than adequate (12.5 ± 1.99 and 12.1 ± 0.46%).

Radar and motion sensor values were significantly lower than those obtained with the high-speed camera (p < 0.05) (figure 3 and 4).

Table 4.
Projectile velocity stride parameters calculated using the radar, the motion sensor and the high-speed camera systems.

Parameter (units)	Radar	Motion sensor	High speed camera	Radar vs high speed camera	Motion sensor vs high speed camera
	Velocity (m.s^{1})			Δ (%)	
Novice	32.8 ± 8.6	32.2 ± 9.4	37.4 ± 8.3	-14.1*	-16.2**
Intermediate	44.3 ± 7.1	44.1 ± 6.1	48.6 ± 7.1	-9.8	-10.3*
Expert	56.2 ± 9.4	52.8 ± 7.8	60.1 ± 10.1	-6.9	-13.6*

Notes: The mean ± SD for both trials combined at each test speed for each system, and the differences between the high-speed camera and the other two systems (Δ in %) are reported.
*P < 0.05; ** P< 0.01, significant difference between the high-speed camera and the radar or the motion sensor using paired t-tests.

Table 5.
The relative (intra-class correlation coefficient, ICC) and absolute (coefficient of variation, CV) concurrent validity of projectile velocity calculated using the high-speed camera systems against the radar and the motion sensor.

	Radar vs High speed Camera		Motion sensor vs High speed Camera	
Parameter (units)	ICC	CV (%)	ICC	CV (%)
	Velocity (m.s^{-1})			
Novice	0.911	*24.8****	0.627	26.5***
Intermediate	0.841	*16.7****	0.303	14.9***
Expert	0.825	*16.8****	0.295	17.2***

Note: ICC < 0.75 and CV > 10% are italicised and represent fair relative reproducibility and less than adequate absolute reproducibility of measures, respectively.
*** P< 0.001, significant difference between the high-speed camera and the radar or the motion sensor using paired t-tests.

DISCUSSION

The purpose of this study was to analyse the concurrent validity and reliability of a radar (*Doppler-radar gun*) and a motion sensor (*Zepp Tennis*). The radar and motion sensor were reliable, but radar and motion sensor underestimated velocity compared to high-speed cameras. Hence, radar and motion sensor can be considered as a reliable system for computing projectile velocity during a badminton smash stroke ranging from novices to experts. However, motion sensor did not demonstrate good concurrent validity for each level measures and only for novice for radar, warranting caution against the comparisons of results between the high-speed cameras and radar. Intermediate and expert level obtained from the radar proved to be highly reliable and valid compared to our refence systems.

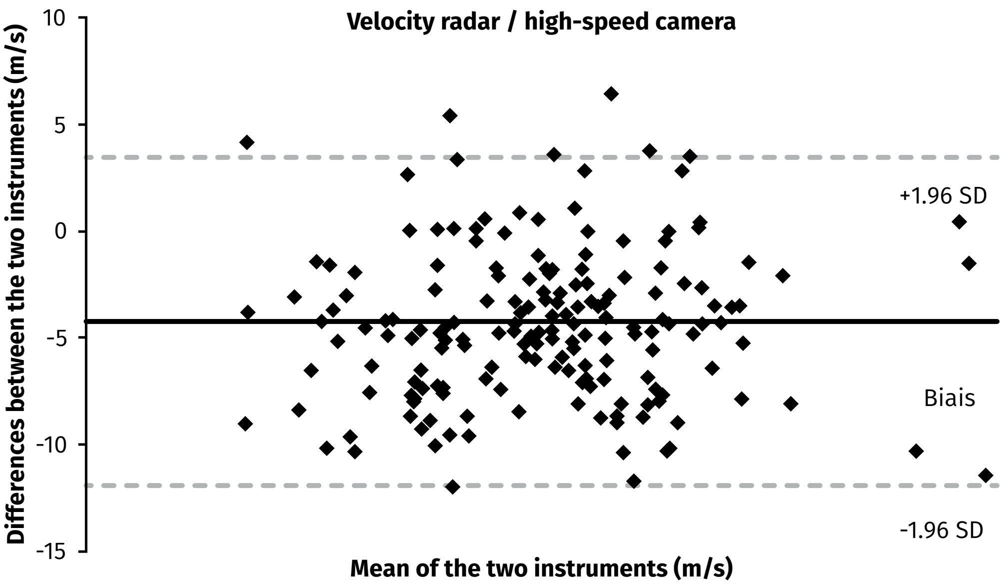

Figure 3. Bland-Altman plots for radar and high-speed camera velocity data. The central line represents the absolute average difference between instruments, while the upper and the lower lines represent ±1.96 SD.

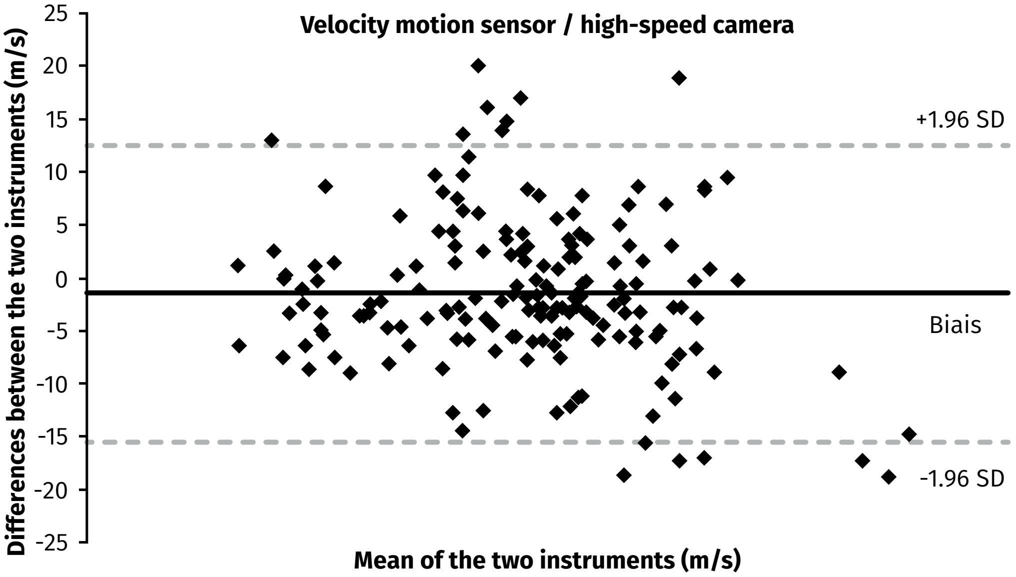

Figure 4. Bland-Altman plots for motion sensor and high-speed camera velocity data. The central line represents the absolute average difference between instruments, while the upper and the lower lines represent ±1.96 SD.

The two systems demonstrated a good homoscedasticity with no significant differences with the White's test on the quantification of the statistical dispersion for radar and for motion sensor (both devices, $p < 0.05$).

The use of several statistical parameters is recommended for quantifying the reliability of measures (Atkinson & Nevill, 1998). In this study, all statistical indicators implied high reliability of velocity derived from the three different systems. The fine distinction in projectile velocity and technique between trials is normal variations expected in any testing situation. Hence the importance of establishing the reproducibility of measures determine which differences exceed typical variations in performance (Gindre et al., 2016). Other than measurement noise, individual variations in stroke biomechanics in the arm movement contributed to the imperfect reliability of measures analysed in the three systems. Kinematics movements of the arm are different and depending of the level that produced different shuttlecock velocity (Phomsoupha & Laffaye, 2020) and contributed to the imperfect reliability of measures in all three systems. The differences in stroke technique between each trial are normal variations expected in any testing situation. The importance of establishing the reproducibility of test measures to determine which differences exceed typical variations in performance (Gindre et al., 2016).

For radar specifically, the between-trial ICCs were all above 0.880; and CVs below 10%. These results tend to highlight that radar recorded the maximal speed during each stroke. Our indicators of reliability of radar device parameters tend to show that the projectile generated higher maximal velocity than racket head (Rambely et al., 2005). In addition, these results tend to highlight that the positioning of the radar (i.e. in front of the projectile and identic angulation) substantially affect the reproducibility of radar parameters (Robinson & Robinson, 2016). For motion sensor specifically, the between-trial ICCs were all above 0.780; and CVs below 10%. These results show that this device has a good reliability. Moreover, neither the positioning of the device (i.e handle or wrist) nor the direction of complexity of the movement (i.e. forearm extension and radio-ulnar pronation) substantially affect the reproducibility of accelerometer derived parameters. The confirmation of the reproducibility of velocity parameters during smash stroke using radar and motion sensor allowed practitioners to be confident in their ability to record these speeds over time using their device.

The concurrent validity of projectile velocity between radar / high-speed cameras and motion sensor / high-speed cameras was fair. On average, radar underestimated projectile velocity by -9.7% and motion sensor by -13.6% between high-speed cameras. These results showed a different way between-system difference in capture velocity and treatment methods. On one hand, the motion sensor consists of an extrapolation of the velocity by the integration formula of the acceleration on three dimensions and the addition of the lever arm. The two major drawbacks of the motion sensor are that there is a possibility that few projectile velocities will not be recorded and the lack of consideration of the racket deflection. The dynamics obtained with a deflexion coupled with a high acceleration of the wrist contribute to racket head velocity (Phomsoupha et al., 2015). Greater flexibility increases the capacity of the racket to store and release more strain energy and to increase the projectile velocity. In addition, the motion sensor seems unable to capture a projectile velocity higher than 325 km/h (≈ 95 m/s). This material is able to measure projectile velocity accurately for all populations, including trained athletes but this is not possible for experts and high speed. There is no requirement and any experience to use and to analyse the data from motion sensor. On the other hand, the radar consists of both a receiver and a transmitter. It sends a radio wave that is reflected of by any object that is in the path. To calculate the speed, the radar gets the echo and uses the principle of Doppler shift. However, the major drawback is the tilt on the sagittal plane which could record the racket instead of the projectile. To ensure better forming results, the radar gun should be positioned near the participant (1 meter at shuttlecock height during the stroke) and the experimenter have to be careful with the recommendation of the manufacturer about the field of angle accuracy. During the experimentation, around 20% of the projectile velocity was not reported. Clinicians and scientist must be aware of these between-system deviations, particularly when comparing results from different studies, laboratory or clinics, and acquiring new equipment for the purpose of quantifying projectile velocity. The data of projectile were homoscedasticity between radar and high-speed cameras and between motion sensor and high-speed cameras.

Considering the low reliability with a low validity of the radar and the motion sensor to measure shuttlecock velocity, correction factors to valid absolute values and to facilitate cross-study comparisons of results may be proposed. Linear regression analyses on our data suggests using the following equation to obtain velocity (xv) from the high-speed camera that are comparable to those from the radar (0.945xv + 6.703) and the motion sensor (0.894xv + 10.273) when individuals velocity ranging from novices to experts (figure 1 and 2).

When analysing the reliability of the motion sensor and radar for measuring the projectile velocity for each participant, the results showed values that were close to the ones obtained with the high-speed camera, despite differences between devices in sampling frequency. Furthermore, the radar and the motion sensor data showed in Bland-Altman plots (Figure 3 and 4) that several of the projectile velocities were close to the mean of the high-speed camera. This is representing a low level of concordance velocities between motion sensor and high-speed cameras (Bland & Altman, 1986). The high ICC showed that motion sensor is no reliability and the results should be tempered and could be increased accuracy with the linear regression.

There are no previous studies that compared different technology for measuring projectile velocity with high-speed camera data. However, some studies used the high-speed camera, which seem to be the best way to record and analyse projectile velocity. This allows to obtain specific values about the highest velocity during the stroke and the time to require it. For the moment, the most accurate systems for measuring projectile velocity are professional and laboratory high speed cameras. This type of camera permits to record at 500 to 1000 Hz compared to 60 Hz for commercial camera. The risk with a standard camera was the maximal velocity could be not recorded during the impact. Thus, experimental data could miss the higher values. Nevertheless, the advancement of new technologies will permit to integrate higher recording frequencies in the future on standard camera (Balsalobre-Fernándeza et al., 2015).

Thus, the orientation has a great impact of the performance data. However, an experience in the use of the radar was required in order to record the correct velocity. This is the first study that validates a motion sensor and radar for measuring the projectile velocity.

CONCLUSION

The ability to evaluate and monitor projectile velocity ability is important in areas of talent identification and sporting performance. The results of the present study showed that projectile velocity can be evaluated using two instruments. Motion sensor could be oriented to the racket sports (tennis, squash…) and golf. Radar was also more efficient for the throwing projectile sports (baseball, football, volleyball…). These findings could help coaches and trainers who wish to monitor the projectile velocity ability of their athletes or clients in a valid and economic way with some ideas of the limitation of each material.

CONFLICT OF INTEREST

All authors have declared there is not any potential conflict of interests concerning this article.

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