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AUTHORS: Antoine Fleureau[1,2], Mathieu Lacome[1,2], Martin Buchheit[1,2], Antoine Couturier[2], Giuseppe Rabita[2]

[1] Performance Department, Paris Saint Germain, Saint-Germain-En-Laye, France
[2] Research Department, Laboratory Sport, Expertise and Performance (EA 7370), French Institute of Sport (INSEP), Paris, France

Corresponding author:
Antoine Fleureau
Performance Department, Paris Saint Germain, Saint-Germain-En-Laye, France
E-mail: antoinefleureau@live.fr

ABSTRACT: The aim of this study was to examine the concurrent validity of the Kinexon local positioning system (LPS) in comparison with the Vicon motion capture system used as the reference. Five recreationally active men performed ten repetitions of linear sprints, medio-lateral side-to-side and handball-specific movements both in the centre and on the side of an indoor field. Validity was assessed for peak speed, peak acceleration and peak deceleration using standardised biases, Pearson coefficient of correlation (r), and standardised typical error of the estimate. With the exception of peak decelerations during specific movements in the centre and peak acceleration and deceleration during linear sprints on the side of the field, the standardised typical error of the estimate (TEE) values were all small to moderate (0.06–0.48), standardised bias ranged between 0.01 and 2.85 and Pearson coefficient values were all > 0.90 for all variables in all conditions. Peak acceleration and deceleration during linear sprints on the side of the field showed the largest TEEs and the greatest differences between the two systems. The ultra-wideband based (UWB) local positioning system had acceptable validity compared with Vicon to assess players' movements in handball with the exception of high accelerations and decelerations during linear sprints on the side of the field.

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INTRODUCTION

In elite team sports, daily monitoring of a player's physical load is needed to optimize the periodization of training, prevent injuries and organize the player's return to play [1, 2]. Over the past two decades, the use of Global Positioning Systems (GPS) has grown exponentially to measure players' external load using mainly locomotion-related variables (e.g. distance travelled, speed and acceleration of locomotion) [2–5]. However, while GPS systems offer the great advantage of being portable and non-invasive, they remain unusable in indoor conditions.

For indoor sports, many other technological solutions are now available to monitor player's movements using for example local positioning systems (LPS). Many of them (e.g., radio frequency identification, wireless local area network or Bluetooth) are unfortunately not suitable for precise position measurements due to a lack of accuracy, instability or interference issues [6]. Recently, new tools based on ultra-wideband technology (UWB) have been developed specifically to track players' position indoor. However, the validity of the different tools using this technology is still questionable. Two groups of researchers examined, in indoor conditions, the concurrent validity of the ClearSky LPS based on UWB technology (using 10 or 20 Hz sampling frequency) using a motion capture device (100 Hz motion capture system, Vicon or Qualisys) as the reference criterion [7, 8]. The system was assessed during linear movements at different speeds and successive 45° changes of direction. The main results of the Serpiello et al. study [7] were that the LPS had acceptable validity for evaluating locomotor patterns of indoor sports compared to motion capture systems. Differences vs. the Vicon were in the range of 0.2–12.0%, with a typical error of the estimate (TEE) between 1.2 and 9.3% for distance, mean/peak speed, and mean/peak acceleration. Luteberget et al. [8] showed LPS measurements to be more representative of the player's position and displacements in the centre of the playing field than on the sides. There were substantial differences in comparison to the criterion for both distances travelled and average speed, which were greater on the side of the court (15–30%) than in the centre (1–3%). However, it was concluded that the ClearSky system could be considered as valid from those later studies. Another LPS system, Kinexon (Kinexon GMBH, Munich, Germany) may be preferred for various reasons including

its supposed better ability to measure acceleration and decelerations and the reduced size of the chips worn by the athletes in comparison with the ClearSky system. The validity of the Kinexon LPS UWB-based system, studied by Hoppe et al. [9], was in fact shown to be better than that of two other GPS systems, which were previously considered as 'valid' [5, 10–13]. The main result of this study was a TEE for the distance covered of 1.0–6.0% for the LPS system versus 1.6–8.0% and 3.0–12.9% for the two GPS systems. Unfortunately, in this latter study, locomotor patterns (including maximal velocity, acceleration, or deceleration) were only examined using overall distance covered and timing gates. Furthermore, they did not test the effect of the field location (centre vs. side) on this validity.

Therefore, the purpose of this study was to examine the concurrent validity of the UWB Kinexon positioning system during a range of handball-specific movements in comparison to the Vicon motion capture system used as the reference. The effect of the field location (centre vs. side) was also examined.

MATERIALS AND METHODS

Participants and experimental overview

Five recreationally active male subjects (age: 29.2 ± 4.1 years, height: 1.76 ± 0.11 m, and body mass: 77.0 ± 8.0 kg) volunteered to participate in this study. The participants were informed of the purposes, procedures, and potential risks of the study and provided

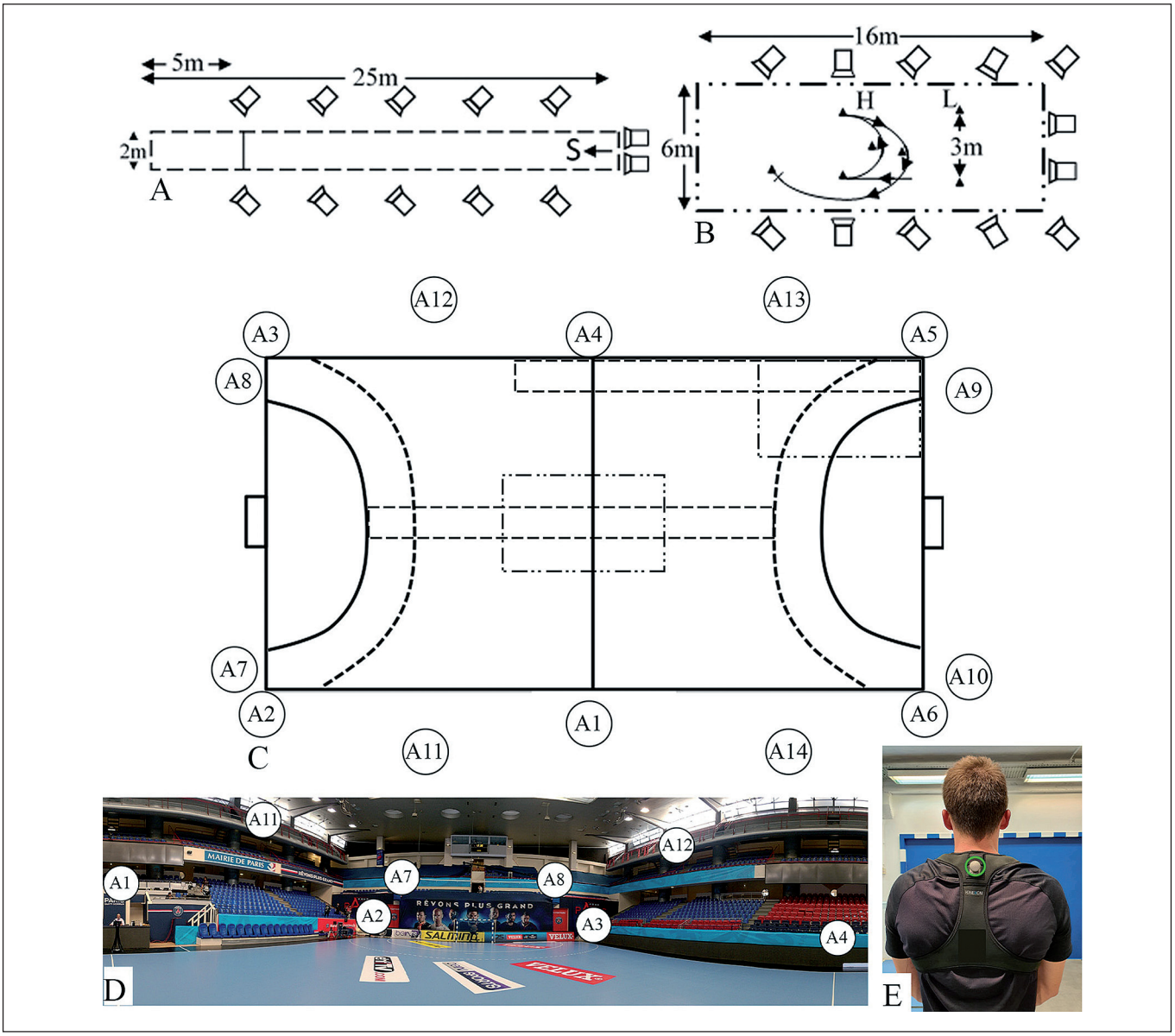

FIG. 1. A: Position of the Vicon camera on configuration for sprints (– —); B: Position of the Vicon camera on configuration for lateral and specific movements (– ·· –); C: Schematic position of the Kinexon antennas and position of testing zones on the field; D: Position of Kinexon antennas; E: Position of the Vicon reflective marker on the Kinexon tag

consent of their approval to participate. All the procedures were conducted in accordance with the Declaration of Helsinki.

Experimental protocol

A first session was carried out in the centre of an indoor handball playing field during which the participants performed three types of movements, as described below. Two days after, a second session was carried out with the same protocol located on the side of the field.

Locomotion activities

Participants performed three different activities repeated ten times in the following order:

- S: Maximal acceleration over a linear course of 25 m with a standing start. After 20 m of running, participants had to decelerate over 5 m and stand still (Figure 1.A).
- L: Lateral movements in the form of medio-lateral side-to-side movement over 3 m (Figure 1.B)
- H: Handball-specific movement in the form of engagement-disengagement in an interval of 2 m, followed by a reengagement out this interval finished by a one-legged jump (Figure 1.B)

Materials

The validity of the Kinexon (Kinexon GMBH, Munich, Germany) was examined while comparing the raw data collected with those obtained using the Vicon. For each test session, two configurations of the Vicon were used, one for lateral and specific movements (Figure 1.A) and one for the sprints (Figure 1.B). In all trials, participants wore simultaneously both a receiver tag connected to the Kinexon antennas and a passive reflective marker to be detected by the motion Vicon capture system.

Kinexon Ultrawide band system

The system used in this study consisted of 14 antennas positioned around the handball playing field (i.e., Coubertin Indoor Stadium, Paris) at three different heights, as shown in Figure 1.C&D. The tag was placed in the centre of the upper back using the manufacturer harness. The data were collected at 20 Hz and processed via the specific Kinexon Software. The signals were transmitted to the antennas using UWB technology in a frequency range of 4.25–7.25 GHz. The field position of the tag was calculated by a proprietary algorithm based on a combination of different methods such as Time Difference of Arrival, Two-Way Ranging and Angle of Arrival [14].

Vicon motion capture system

A 12-camera Vicon motion analysis system (Vicon Nexus T40, Vicon Motion Systems, Oxford Metrics, UK) was implemented in the two configurations shown in Figure 1.A&B. Data were collected at 250 Hz. Only one 14 mm reflective marker (B&L Engineering, Santa Ana, USA) was placed on the Kinexon tag as shown in Figure 1.E.

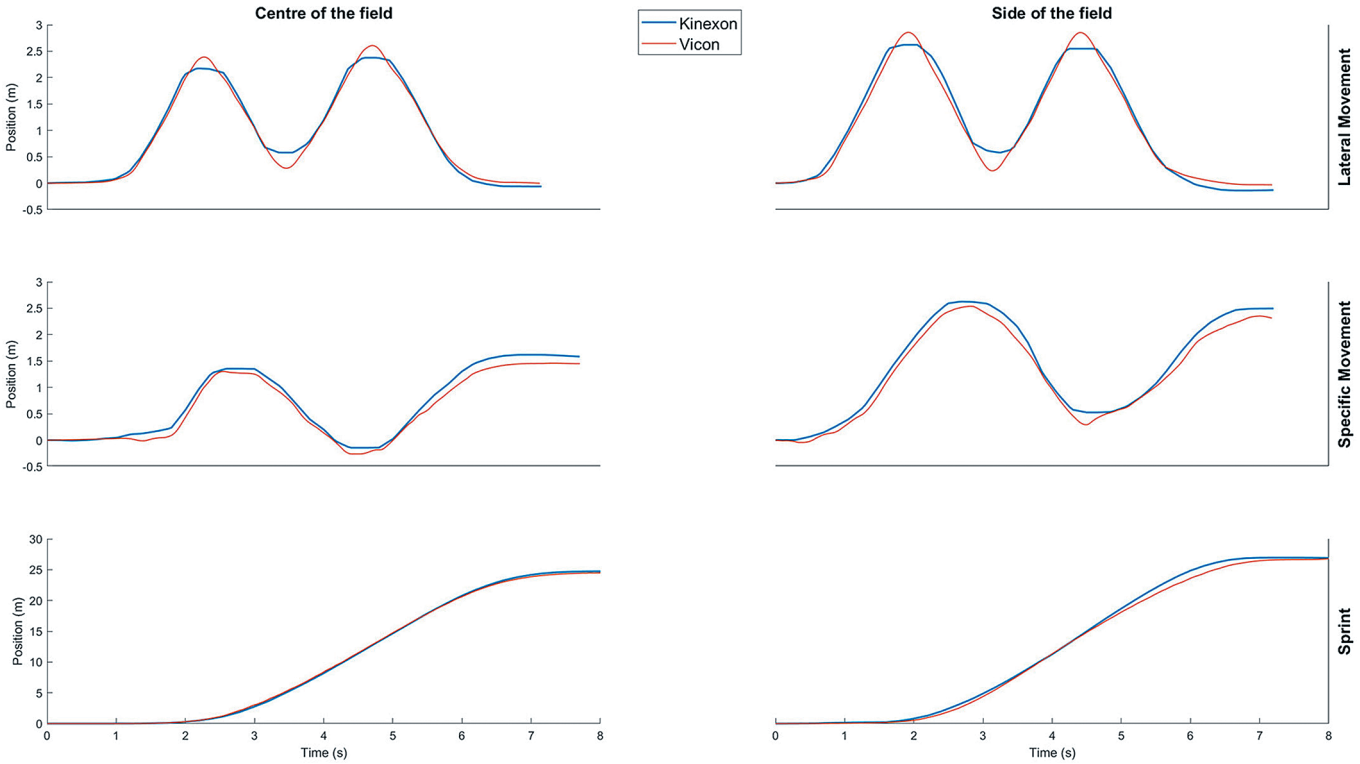

FIG. 2. Synchronized position data of the two systems (Kinexon and Vicon) both in the centre and on the side of the court, for each type of movement.

The data obtained from the three-dimensional marker position were used for further analysis. The loss of the marker signal was never longer than 25 successive images (i.e., 0.1 s) and automatically extrapolated with the Vicon 3D software using the marker position immediately before and after the loss.

The average Vicon calibration errors (Image and World Error, respectively) for the two test sessions were 0.09 and 0.17 mm for data collected in the centre of the field, and 0.08 and 0.16 mm for those collected on the side of the field.

Data processing

Figure 2 illustrates, for one trial, the position signal obtained from both systems. The original datasets from Kinexon were oversampled from 20 to 250 Hz for subsequent fine synchronization with Vicon data. Signals from both systems were then filtered using a 3rd order zero phase shifting low pass Butterworth filter with a 10 Hz cut-off. Each pair of Kinexon and Vicon data sets for each movement repetition was manually synchronized to determine a common start and end. The distance travelled was then calculated as the sum of the instantaneous positions in the horizontal plane (x, y). Velocity and acceleration data were obtained by successive derivation and low pass filtering (10 Hz, 3rd order zero phase shifting Butterworth filter) of position data. Peaks in speed, acceleration and deceleration were calculated from the raw data and utilised for the analysis. They were respectively computed as the maximum mean speed, acceleration and deceleration over a 500 ms window [10, 15, 16].

Statistical analysis

The Hopkins spreadsheet [17] was used to compare the agreement between the two systems by linear regression. We compared the Kinexon system (practical) with the Vicon (criterion) while computing the mean and standardised bias, the Pearson correlation coefficient and the typical error of the estimate (TEE) expressed first as the absolute value, then normalized and as a coefficient of variation (CV), provided together with a 90% confidence interval. The following criteria were adopted to interpret the magnitude of the correlations: ≤ 0.01, trivial; > 0.1, small; > 0.3, moderate; > 0.5, large; > 0.7, very large; and > 0.9, almost perfect. Half the threshold of the modified Cohen scale was used to interpret the standardised TEE: > 0.01 (trivial) > 0.1 (small), > 0.3 (moderate), > 0.6 (large), > 1.0 (very large), and > 2.0 (extremely large) [17]. Regarding standardised bias interpretation, threshold values were the modified Cohen scale: 0.01 (trivial); > 0.2 (small); > 0.6 (moderate); > 1.2 (large); > 2.0 (very large); > 4.0 (extremely large) [17].

TABLE 1. Comparison of peak speed, peak acceleration, and peak deceleration between Kinexon and Vicon during three different locomotion activities performed in the centre of an indoor court.

	Movement	Mean ± SD Vicon	Mean ± SD Kinexon	Mean Bias ± CI	Standardised Bias ± CI	TEE ± CI	Standardised TEE ± CI	TEE as CV (%) ± CI	Pearson correlation (r) ± CI
Centre of the field									
Peak Speed ($m \cdot s^{-1}$)	Sprint	7.0 ± 0.4	7.2 ± 0.4	0.15 ± 0.01	0.38 ± 0.03	0.02 ± 0.01	0.06 ± 0.02	0.3 ± 0.1	1.00 ± 0.00
	Lateral	2.1 ± 0.1	2.0 ± 0.1	-0.09 ± 0.02	-1.14 ± 0.21	0.03 ± 0.01	0.44 ± 0.18	1.6 ± 0.4	0.92 ± 0.06
	Specific	2.6 ± 0.2	2.7 ± 0.2	0.12 ± 0.02	0.63 ± 0.10	0.05 ± 0.03	0.25 ± 0.11	1.9 ± 0.6	0.97 ± 0.03
Peak Acceleration ($m \cdot s^{-2}$)	Sprint	3.5 ± 0.3	3.6 ± 0.3	0.19 ± 0.02	0.60 ± 0.05	0.05 ± 0.01	0.15 ± 0.05	1.4 ± 0.3	0.99 ± 0.01
	Lateral	3.7 ± 0.1	3.6 ± 0.2	-0.14 ± 0.03	-1.10 ± 0.27	0.06 ± 0.01	0.48 ± 0.18	1.5 ± 0.4	0.90 ± 0.06
	Specific	3.7 ± 0.5	4.0 ± 0.4	0.27 ± 0.04	0.60 ± 0.09	0.10 ± 0.03	0.23 ± 0.10	2.8 ± 0.9	0.97 ± 0.02
Peak Deceleration ($m \cdot s^{-2}$)	Sprint	4.1 ± 0.6	4.4 ± 0.7	0.22 ± 0.04	0.39 ± 0.07	0.08 ± 0.02	0.14 ± 0.05	2.0 ± 0.5	0.99 ± 0.01
	Lateral	3.9 ± 0.1	3.7 ± 0.2	-0.14 ± 0.02	-0.99 ± 0.17	0.06 ± 0.01	0.44 ± 0.16	1.5 ± 0.4	0.92 ± 0.05
	Specific	2.5 ± 0.2	2.5 ± 0.1	0.00 ± 0.05	0.01 ± 0.34	0.12 ± 0.04	1.29 ± 1.26	5.0 ± 1.6	0.61 ± 0.26

Note: SD: Standard deviation, CI: 90% Confidence Interval, TEE: Typical Error of the Estimate, CV: Coefficient of Variation

TABLE 2. Comparison of peak speed, peak acceleration, and peak deceleration between Kinexon and Vicon during three different locomotion activities performed on the side of an indoor court.

	Movement	Mean ± SD Vicon	Mean ± SD Kinexon	Mean Bias ± CI	Standardised Bias ± CI	TEE ± CI	Standardised TEE ± CI	TEE as CV (%) ± CI	Pearson correlation (r) ± CI
Side of the field									
Peak Speed ($m \cdot s^{-1}$)	Sprint	7.1 ± 0.2	7.3 ± 0.2	0.17 ± 0.02	0.84 ± 0.08	0.05 ± 0.01	0.26 ± 0.09	0.7 ± 0.2	0.97 ± 0.02
	Lateral	1.9 ± 0.3	1.9 ± 0.3	-0.07 ± 0.01	-0.24 ± 0.05	0.04 ± 0.01	0.16 ± 0.06	2.1 ± 0.6	0.99 ± 0.01
	Specific	2.4 ± 0.1	2.6 ± 0.1	0.23 ± 0.02	2.85 ± 0.24	0.04 ± 0.01	0.47 ± 0.25	1.5 ± 0.5	0.91 ± 0.09
Peak Acceleration ($m \cdot s^{-2}$)	Sprint	4.4 ± 0.4	4.0 ± 0.3	-0.38 ± 0.15	-0.91 ± 0.35	0.39 ± 0.10	2.56 ± 21.15	9.4 ± 2.6	0.36 ± 0.30
	Lateral	3.2 ± 0.7	2.8 ± 0.9	-0.38 ± 0.06	-0.51 ± 0.09	0.08 ± 0.02	0.11 ± 0.04	2.7 ± 0.7	0.99 ± 0.00
	Specific	3.5 ± 0.2	3.7 ± 0.3	0.25 ± 0.05	1.10 ± 0.23	0.08 ± 0.02	0.34 ± 0.15	2.3 ± 0.7	0.95 ± 0.04
Peak Deceleration ($m \cdot s^{-2}$)	Sprint	3.2 ± 0.2	4.5 ± 0.3	1.24 ± 0.11	6.73 ± 0.61	0.18 ± 0.05	3.96 ± 3.81	5.7 ± 1.6	0.25 ± 0.33
	Lateral	3.4 ± 0.6	3.2 ± 0.6	-0.27 ± 0.03	-0.45 ± 0.04	0.06 ± 0.02	0.10 ± 0.04	1.9 ± 0.5	0.99 ± 0.00
	Specific	2.6 ± 0.5	2.4 ± 0.5	-0.16 ± 0.05	-0.33 ± 0.11	0.14 ± 0.04	0.29 ± 0.13	5.5 ± 1.7	0.96 ± 0.03

Note: SD: Standard deviation, CI: 90% Confidence Interval, TEE: Typical Error of the Estimate, CV: Coefficient of Variation

RESULTS

Table 1 presents mean and standard deviation of peak speed, peak acceleration and peak deceleration in the centre of the playing field during sprints, lateral and handball-specific movements, as well as the respective bias, TEE and correlations between values obtained from practical (Kinexon) and criterion (Vicon) systems. Standardised biases were small to moderate for all variable for all movements and trivial for deceleration during the specific movement. The standardised TEEs were small to moderate for all variables during all movements, except for peak deceleration during specific movement, which was only very large. The magnitude of the correlations was almost perfect for all analyses except for peak deceleration during specific movements, which was only large.

Table 2 presents the results from the data recorded on the side of the field. Standardised biases were also small to moderate for all variables (peaks in speed, acceleration, and deceleration) during lateral movement. During specific movements biases were small to moderate only for acceleration and deceleration peaks and large for peak speed. During the sprint, standardised biases were extremely large for peak deceleration and moderate for peak speed and acceleration. Standardised TEEs were small to moderate for all variables for lateral and specific movements and for peak speed during sprints. They were very large for peak acceleration and deceleration during sprints. In the same way, the magnitude of the correlations was almost perfect for all variables during lateral and specific movements and for peak speed in sprints. The correlation was only small for acceleration and deceleration during sprint.

DISCUSSION

The purpose of this study was to assess the concurrent validity of the Kinexon LPS UWB based system in comparison to the Vicon motion capture system during sprints, lateral movements, and handball-specific drills. The present results suggest that the LPS Kinexon validity may be considered as acceptable to assess indoor locomotor movements. The magnitude of the correlations between the two systems was almost perfect (> 0.90) for all variables during all types of movements, except in three particular cases: i) peak decelerations during specific movements in the centre of the field, ii) peak accelerations during linear sprints on the side of the field and iii) peak decelerations during linear sprints on the side of the field.

As shown in Table 1, in the centre of the playing field, the standardised TEEs of peak speed and peak acceleration for sprints, lateral and specific drills were trivial to moderate (CV 0.3 ± 0.1 to 2.8 ± 0.9%). These results were similar to or even better than both those reported by Serpiello et al. (2017) for LPS (CV < 3.5%) and Scott et al. (2016) for GPS (peak speed CV: 5.4 to 20.6%). Regarding

peak deceleration in both linear sprints and lateral movements, standardised TEEs were also small to moderate (1.5 ± 0.4 and 2.0 ± 0.5%). Those results were better than those obtained by Serpiello et al. (2017) (CV > 10%). For peak deceleration during specific movements, however, the standardised TEE was very large (5.0 ± 1.6%). There were also almost perfect correlations of the data between the two systems (r > 0.9) during both multidirectional (specific movements) and unidirectional movements (sprints and lateral movements), except for peak decelerations during specific movements (r: 0.61 ± 0.26). In comparison with the results obtained in the various GPS or LPS validity studies [5, 7, 9], the Kinexon system seems to be more effective for measuring peak speed, accelerations and decelerations during handball-specific movements. It also seems more effective at measuring high acceleration and deceleration peaks during sprints performed in the centre of the playing field (CV < 5%) than the other positioning system already tested (CV > 5%) [7, 18].

As shown in Table 2, on the side of the playing field, peak speed standardised TEEs were small to moderate regardless of the type of movement (0.7 ± 0.2 to 2.1 ± 0.6%); in contrast however, standardised TEEs for peak accelerations and decelerations were small to moderate for lateral and handball-specific movements (1.9 ± 0.5 to 5.5 ± 0.7%). During the sprint, extremely large standardised TEEs could be found for peak accelerations and decelerations (5.4 ± 2.6 to 9.4 ± 2.6%). The large TEE reported and the measurements errors of the Kinexon system on the side of the playing field mirrored the poor correlations observed in terms of peak accelerations and decelerations during linear sprint (r: 0.36 ± 0.30 and 0.25 ± 0.33). This measurement error may be due to the method used to obtain the acceleration signal, which was derived twice from the position signal. However, deriving the signal likely multiplies the possible measurement errors. For this reason, even if speed measurement was very precise (r: 0.97 ± 0.02, standardised TEE: 0.26 ± 0.09), it still contained some errors that were likely increased by the derivation process. This problem did not occur in the centre of the playing field since the agreement was almost perfect for sprinting speed (r: 1.00 ± 0.00, standardised TEE: 0.06 ± 0.02); the measurement error was too small to affect the correlation after derivation. Moreover, the standardised bias was greater on the side of the field (0.84 ± 0.08) than in the centre of the field (0.38 ± 0.03). These results were similar to or even better than those presented by Luteberget et al. [8] when examining the ClearSky system on the side of the field. The current results demonstrated that when the distance between the receiver tag and the antennas is not homogeneous, the accuracy of acceleration and deceleration measurements decreases. GPS validity studies also showed an overall inability to correctly measure accelerations and decelerations on the side of the playing field in a stadium covered with a roof, but this was more likely here due to a limited number of connected satellites [19].

The Kinexon system seems to be more accurate than GPS, which is generally less reliable for measuring multidirectional movements (CV > 10%) than unidirectional movement (CV < 5%), and for measuring peak acceleration and deceleration in sprints (CV > 5%) [18, 20]. In comparison to the ClearSky system examined by Luteberget et al. [8], the Kinexon system is likely more accurate to measure peak speed anywhere on the field (r: 0.91–1.00 versus 0.37–0.98 and standardised TEE: 0.06–0.47 versus 0.19–2.54). Everywhere on the field, Kinexon measurement of peak speed and acceleration is likely as effective as the LPS system examined by Serpiello et al. [7], and better for measuring peak decelerations. Moreover, our results demonstrated that changes of direction, including handball-specific movements, were correctly detected and measured by the Kinexon system for all variables in all conditions in comparison to Vicon (CV: 0.3–2.8%), with the exception of peak deceleration in the centre of the field (CV: 5.0%). These results were better than those observed by Serpiello et al. [7] for LPS (CV: 2.1–5.3%) and by Vickery et al. (2014) for GPS (CV: 20.0%) during successive 45° and 90° change of direction and random movements including change of direction.

Limitations

The results of the present study reflect the specific configuration of the UWB-based LPS Kinexon in our indoor stadium (i.e., Coubertin Indoor Stadium, Paris). In fact, the effect of the position of the antennas in the stadium is important, particularly when distances between the field of play and the walls are small. It seems that when the heterogeneity in the distance between the receiver tag and some of the antennas is too great (i.e., very close to the tag for some antennas, very far for others), the quality of peak acceleration and deceleration measurement is impaired.

This study did not investigate the validity of the Kinexon system near the penalty spot even though some players spend more time near this position than anywhere else on the playing field. However, for medio-lateral side-to-side and specific movement, our results did not show a significant difference between the centre and the side of the playing field. In consequence, it could be assumed that the validity would have been similar in this specific spot in comparison to the one calculated for the two tested areas.

Practical applications

This study demonstrated that 20 Hz LPS Kinexon units can measure the fundamental handball movement demands in terms of peak speed, peak acceleration and peak deceleration with an acceptable level of error, especially in the centre of the field. Practitioners may however need to treat some of the data with more care, such as peak accelerations and decelerations of wing players, which were shown to have a lower level of precision.

CONCLUSIONS

To conclude, the UWB-based Kinexon system has an acceptable validity compared with the Vicon to assess handball-specific locomotor patterns. Care should however be taken when monitoring accelerations and decelerations on the side of the playing field during linear sprints (e.g., wingers' counterstrike).

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