A VALIDITY STUDY COMPARING XSENS WITH VICON

Anne Benjaminse[1,2], Ruben Bolt[1], Alli Gokeler[1,3] and Bert Otten[1]

Department of Human Movement Sciences, University Medical Centre Groningen, University of Groningen, Netherlands[1]
Hanze University Groningen, School of Sports Studies, Groningen, Netherlands[2]
Department Exercise & Health, Faculty of Science Paderborn University, Paderborn, Germany[3]

Conducting on-field measurements is warranted to investigate and reduce real-world anterior cruciate ligament (ACL) injury risk. However, validation is first warranted to ensure how Xsens relates to Vicon. The purpose of this study was therefore to compare lower extremity kinematics from Xsens with Vicon. Ten recreational ball team sport athletes (5 females, 5 males) were included, who performed isolated and dynamic movements. Strong correlations were found for movement patterns (>0.7) for the isolated as well as the dynamics movements. However, absolute joint angles differ between both systems (ranging from 0.7º - 14.5º). This should be considered when using Xsens in an applied sport setting as drawing conclusions for being or not being at risk for ACL injury may depend on the system used. A major strength of this study is the inclusion of movements that are restricted to one plane and one joint as well as dynamic high-intensity movements resembling movements which occur in sports (e.g. change of direction). This analysis of methods of data collection leads to further advancement of knowledge the science of biomechanics in applied sports settings.

KEYWORDS: Xsens, IMU's, concurrent validity

INTRODUCTION: Despite intensive efforts put forward on prevention, the rate of anterior cruciate ligament (ACL) injuries has not reduced over the last years. After two decades, traditional prevention programs seem effective in short term, but have not decreased long-term injury incidence (Agel et al., 2016). This suggests an ineffective transfer from a (predictable) practice environment to an unpredictable and complex game environment. In a real-world situation, environmental factors such as position of opponents and teammates and the ball interact. The athlete needs to be able to pay attention to this, while performing optimal movements. To optimize ACL injury reduction in the field, there is an urgent need to train and test athletes in their own sport-specific context.

Wearable inertial measurement unit (IMU) systems, such as Xsens, allow measurement in such sport-specific settings (Blair et al., 2018). Xsens combines multiple inertial sensors (3D accelerometers, 3D gyroscopes and 3D magnetometers) fixed to body segments, to provide direct acceleration, angular velocity and magnetic-field measurements (Roetenberg et al., 2007, 2013). Through integration, 3D position and orientation of each segment can be obtained (Roetenberg et al., 2013). When combined with sensor fusion algorithms and a biomechanical model, full-body 3D kinematics can be obtained (Roetenberg et al., 2013; Takeda et al., 2009; Zhang et al., 2013).

On the other side, optoelectronic motion analysis systems (such as Vicon motion capture) are traditionally used in the laboratory and considered as the gold standard in biomechanical analysis to quantify the 3D characteristics of movement.

To transfer to sport-specific training and testing in relation to ACL injury prevention, validation is first warranted to ensure how Xsens relates to Vicon. Therefore, the aim of this research was to examine the concurrent agreement of Xsens for quantifying joint and segment kinematics with comparison to Vicon motion analysis.

METHODS: Ten recreational ball team sport athletes (5 females, mean age 22.4 ± 1.5 y, height 173.6 ± 4.6 cm, mass 66.5 ± 3.6 kg and 5 males, mean age 24.8 ± 1.4 y, height 182.5 ± 2.0 cm, mass 81.8 ± 5.4 kg) participated in this study and were measured on two testing days. Athletes wore a MVN Lycra suit (MVN Link BIOMECH full body, Xsens Technologies B.V., Enschede, the Netherlands), which is composed of 17 inertial sensors, a transmission pack (160 x 72 x 25 mm: 150 g) and battery (95 x 59 x 25 mm: 70 g), zipped into a compression suit. Each sensor (36 x 24 x 10 mm: 10 g) integrates a 3-D accelerometer (scale: ±160 m.s"2, noise: 0.003 m.s"2/pHz), 3D gyroscope (±2000 /s, 0. 05 /s/pHz) and 3D magnetometer (±1.9Gauss, 0.15 m Gauss/p Hz), internally sampling at 1000 Hz. The overall system update rate is 240 Hz. Sensors were placed following the manufacturers recommended placements; forefeet (dorsal side), shanks (medial surface of the tibias), thighs (lateral side above the knees), pelvis (middle of both the posterior superior iliac spines), shoulders (middle of the scapula spine), upper arms (lateral side above elbow), forearms (lateral side of wrist), hands (posterior side), sternum and the back of the head. To scale the Xsens biomechanical model, anthropometric measures were collected from each participant (cm); body height, arm span, shoulder width and height, foot and leg length, hip, knee and ankle height and hip width.

Concurrent validity was assessed by comparing kinematic data from a 8-camera system (Vantage V5 series with 8.5mm lens, Vicon Nexus, Oxford, UK), with a 100Hz sampling rate. Sixteen reflective markers (diameter: 14 mm) were attached to the outside of the Xsens suit according to the Vicon Plug-in-Gait model (Vicon Motion Systems, INC., Centennial, CO), using double-sided tape. Markers were placed on posterior heel, 2nd metatarsal head, lateral and medial malleoli, lateral and medial femoral epicondyles, tibia and thigh, anterior and posterior superior iliac spines. Five additional trunk markers on the sternum, clavicle, C7, T10 and right scapula were attached. To scale the Vicon biomechanical model, body height and mass, leg length, knee and ankle width were collected from each participant (mm).

Individual calibrations (T-pose for Vicon and N-pose and walking for Xsens) were performed. No magnetic disturbances were reported in the testing environment.

Raw motion analysis data were digitised in Nexus (v.2.7.1, Vicon, Oxford, UK) and Xsens MVN Analyze (v.2019.2.1) and processed in a customised software using MATLAB 9.6 (The MathWorks Inc., Natick, MA). Modelling procedures for the IMU data were based on the manufacturer’s recommendations. Sensor fusion for the IMU data were made using the manufactures proprietary algorithms (Xsens Kalman Filter) and filtered using the LXsolver (minimise soft tissue artefact) in MVN Biomech Studio. The Xsens biomechanical model was assigned to motion files in MATLAB and model-based calculations were computed using the Y-X-Z Cardan sequence, which corresponded to the ML-AP-Axial rotations computed in the motion analysis data (c-motion, 2016). Signs were added to match the conventions in Nexus.

The raw Xsens quaternion data were matched with the Vicon conventions as follows. Xsens joint quaternions were transferred to Euler angles in degrees through a rotation matrix. The Vicon Euler angle order of YXZ for hip, knee and ankle joints and their signs were taken as the convention. Data of both systems was synchronized and time matched through cross correlations of the joint angles with the highest amplitudes.

Cross correlation and offset was calculated for lower extremity variables (ankle dorsiflexion/ plantarflexion range of motion (ROM), knee flexion/extension ROM, hip flexion/extension ROM and hip abduction/adduction ROM). Basic test measurements were taken with isolated joint movements to get a better understanding of the performance of both systems. In addition, high speed, dynamic measurements including single leg landing, double leg landing and change of direction, were taken. Five trials were collected per movement. Average and standard deviations for correlations and offsets were calculated. Correlations range between -1 and 1, with 1 being perfectly correlated and -1 exactly the opposite and 0 having correlation. Offsets were in degrees joint angle.

RESULTS: Correlation and offset results are displayed in Table 1 and 2. In Figure 1 and 2, the movement patterns and amplitudes over time are presented. Results show that the movement patterns of Xsens and Vicon are strongly correlated, being greater than 0.7 for all variables. The offsets become larger when the amplitude of a certain joint motion becomes greater.

Table 1. Correlation and offset results comparing Vicon and Xsens during isolated movements.

	Correlation (mean ± SD)	Offset (Euler in °) (mean ± SD)
Ankle (dorsiflexion/plantarflexion)	0.995 ± 0.002	2.2 ± 2.6
Knee (flexion/extension)	0.996 ± 0.002	8.5 ± 4.6
Hip (flexion/extension)	0.991 ± 0.008	4.5 ± 2.2
Hip (abduction/adduction)	0.993 ± 0.008	4.6 ± 1.4

Table 2. Correlation and offset results comparing Vicon and Xsens during one of the dynamic movements, change of direction

	Correlation (mean ± SD)			Offset (Euler in º) (mean ± SD)		
	single leg landing	double leg landing	change of direction	single leg landing	double leg landing	change of direction
Ankle (dorsiflexion/ plantarflexion)	0.910 ± 0.129	0.963 ± 0.085	0.867 ± 0.144	1.6 ± 4.6	0.7 ± 4.1	0.9 ± 5.7
Knee (flexion/ extension)	0.972 ± 0.042	0.999 ± 0.029	0.977 ± 0.027	6.5 ± 8.3	5.8 ± 6.6	7.6 ± 7.6
Hip (flexion/ extension)	0.958 ± 0.058	0.987 ± 0.024	0.965 ± 0.048	-14.4 ± 7.6	-14.5 ± 9.5	-9.6 ± 9.8
Hip (abduction/ adduction)	0.858 ± 0.185	0.955 ± 0.084	0.749 ± 0.269	1.1 ± 4.9	2.4 ± 4.5	3.0 ± 5.6

Figure 1. Vicon (solid line) and Xsens (dotted line) comparisons of representative single isolated trial. Red = flexion/extension, green = abduction/adduction, blue = rotation. Y-axis: Euler angles in degrees. X-axis in milliseconds.

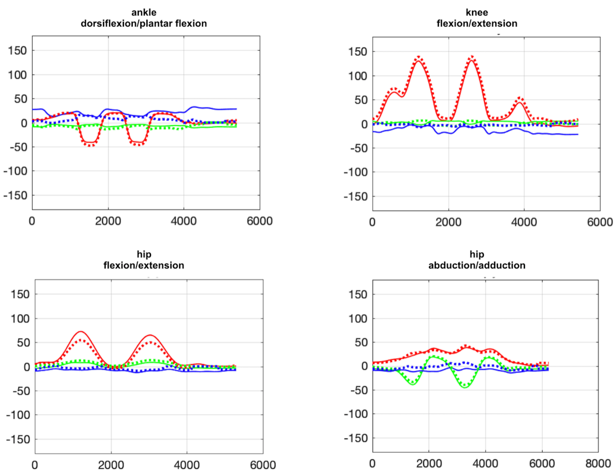
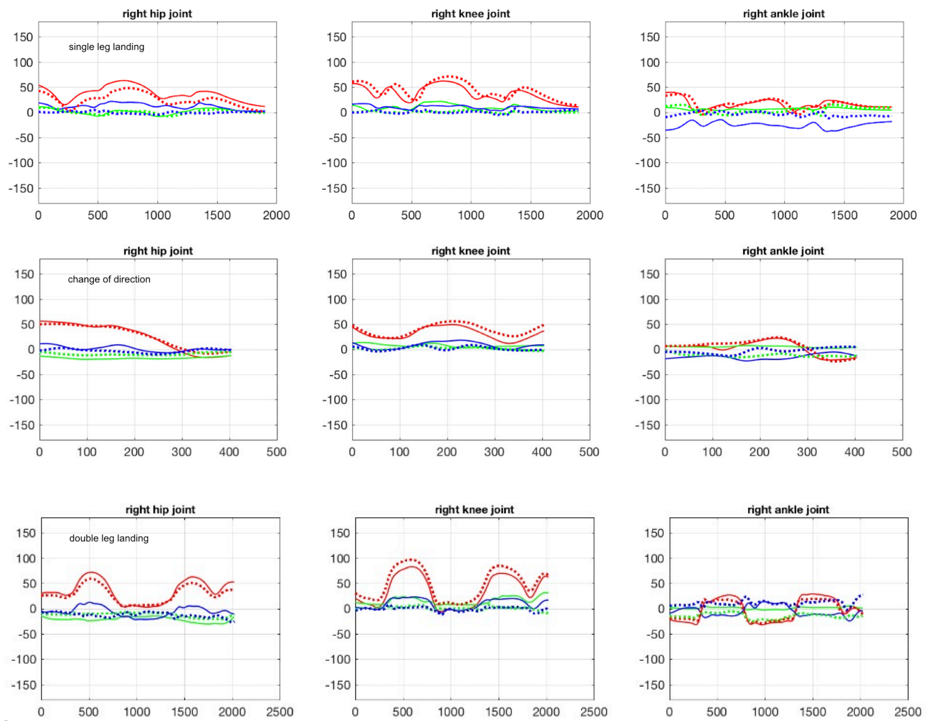


Figure 2. Vicon (solid line) and Xsens (dotted line) comparisons of representative dynamic trials. Red = flexion/extension, green = abduction/adduction, blue = rotation. Y-axis: Euler angles in degrees. X-axis in milliseconds.



DISCUSSION: The purpose of this research was to examine the cross correlation and offsets of Xsens (Xsens MVN system) in comparison to Vicon motion analysis by quantifying joint and segment kinematics. Both systems have their own quality in different conditions (laboratory versus field), it is thus important to know agreements and differences respectively. It is innovative that we systematically observed and analysed 3D joint angles per isolated joint movement. In general, it can be stated that both systems show strong agreement for the total amplitude. This is in line with others, finding good to excellent intraclass correlation coefficients (ICC) for hip, knee and ankle ROM, depending on the task (Al-Amri, 2018).

However, the absolute angles are different between Xsens and Vicon. It is therefore very important to understand the calibration method used. Xsens takes the positions of all joints and axes in the N-pose as 0º, opposed to Vicon taking the real joint angles in the T-pose, leading to different absolute angles for Xsens compared to Vicon. Caution should be taken with directly comparing data from these two systems. The 0º-levels of Xsens do not depend on markerplacement and calibration.

Additionally, this insight is important for sport professionals when testing on the field using Xsens, as these difference may exceed clinical relevant differences. The Xsens system is a very valid method to use for measuring lower extremity kinematics while performing movements resembling on-field movements. However, users should be careful with the interpretation of the absolute angles as it has practical consequences using one or the other system. With Xsens providing other absolute angles than Vicon, one may over- or underrate injury risk. Furthermore, measurement accuracy for Vicon will have been affected by the fact that markers were placed on the lycra suit instead of directly on the skin. Our complete future data analysis will include the trunk, lower extremity Y (abduction/adduction) and the Z (rotation) axes.

CONCLUSION: This study identified the cross correlations and offsets between joint angles during movements as measured by the Xsens and Vicon motion capture systems. Although strong correlations were found, absolute joint angles differ between both systems. It should be clear that drawing conclusions may depend on the system used. This analysis of methods of data collection leads to further advancement of knowledge the science of biomechanics in applied sports settings.

REFERENCES:

Agel J., Rockwood T., Klossner D. (2016). Collegiate ACL injury rates across sports: national collegiate athletic association injury surveillance system. Data Update (2004-2005 Through 2012-2013). *Clin J Sport Med,* 26, 518–523.

Blair S., Duthie G., Robertson S., Hopkins W., Ball K. (2018). Concurrent validation of an inertial measurement system to quantify kicking biomechanics in four football codes. *J Biomech,* 73, 24-32.

Al-Amri M, Nicholas K, Button K, Sparkes V, Sheeran L, Davies JL. (2018). Inertial measurement units for clinical movement analysis: reliability and concurrent validity. *Sensors (Basel),* 28.

Roetenberg, D., Luinge, H., Slycke, P., (2007). Ambulatory position and orientation tracking fusing magnetic and inertial sensing. *IEEE Trans. Biomed. Eng*. 54, 883-890.

Roetenberg, D., Luinge, H, Slycke, P., 2013. Xsens MVN: Full 6DOF human motion tracking using miniature inertial sensors (Technical paper). Xsens Technologies B.V. Enschede, http://www.xsens.com.

Takeda, R., Tadano, S., Natorigawa, A., Todoh, M., Yoshinari, S., (2009). Gait posture using wearable acceleration and gyro sensors. *J. Biomech.,* 42, 2486–2494.

Zhang, J.J., Novak, A.C., Brouwer, B., Li, Q., (2013). Concurrent validation of Xsens MVN measurement of lower limb joint angular kinematics. *Physiol. Measure.* 34, 63-69.