Validity and reliability of WIMU^{TM} inertial device for the assessment of joint´s angulations

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Abstract.

Measurement of the range of motion is fundamental in the physical examination and functional evaluation of different joints. WIMU^{TM} is an inertial device which allow to analyze join motion easily in real time.

The aim of this study was two-fold: i) to evaluate the validity of WIMU^{TM} for the measurement of different angles positions compared with a standard goniometer and a 2D video based motion analysis software; and ii) to evaluate the use of WIMU^{TM} for the assessment of angulations in a joint, specifically assessing the validity and reliability of WIMU^{TM} for the measurement of ankle dorsiflexion compared with a standard goniometer and Kinovea.The intraclass correlation coefficient and Pearson´s correlation coefficient (r) were performed to calculate the concurrent validity and Bland-Altman plots were performed to analyze agreement between measures. For the analysis of reliability both, relative and absolute indices were used.

Results showed an excellent validity and reliability of WIMU^{TM} for the assessment of angles positions and in its use for the assessment of ankle dorsiflexion.

The current findings conclude that WIMU^{TM} is a valid and reliable instrument to measure angles and joint´s motions. In resume, WIMU^{TM} provides a new alternative of clinical and sportive method of angles measurement.

Keywords: Inertial device, angle assessment, dorsiflexion.

Introduction

An accurate and reliable measurement of the range of motion (ROM) is fundamental in the physical examination and functional evaluation of different joints, as well as the monitoring and evaluation of training or rehabilitation programs. There are several instruments that have been used in the examination of ROM in different joints such as visual observation, goniometers, linear measures or inclinometers (Kolber & Hanney, 2012) even smartphones (Milanese et al., 2014). The gold standard in the joint analysis is the three-dimensional (3D) motion analysis, but these instruments are expensive in time and money, thus being not available to all professionals (Krause et al., 2015). For this reason, two-dimensional (2D) motion analysis is commonly used due to its lower cost. Universal goniometers are the most used in clinical practice because its low cost, accessibility, easy to use and portability (Milanese et al., 2014). On the contrary, a major drawback of the goniometers is that requires both hands from the user, increasing the risk of error in the measurement (Kolber & Hanney, 2012). Recently, the advances of technological applications for smartphones has increase the availability of a wide number of applications for measure ROM (Milanese et al., 2014). This based goniometry apps (2D) use different mechanism to calculate joint angles as DrGoniometer (Ferriero et al., 2013), Coach´s Eye (Krause et al., 2015) or Knee Goniometer App (KGA) (Milanese et al., 2014), being all of them reliable for its use in clinical and athletic activities.

Last years, wireless inertial measurement units have been used as motion capture devices. These devices are based on inertial/magnetic systems that are used as a wearable device allowing the measurement of the motions. Data of these devices could be sent to a computer in real time and be used to evaluate the movement and give immediate feedback (Meng, Shoepe, & Vejarano, 2016). The use of inertial measurement devices is increasing in research. However, its use in clinical practice is scarce, due their price compared with other instrument and the difficulty for the analysis and interpretation of their data by professionals not familiarized with their specific software.

WIMU™ is an inertial device that includes GPS technology and has been designed for control and monitoring of physical activity for performance, rehabilitation and research. WIMU™ can be used indoor and outdoor with the advantage of being easy to handle, small and lightweight. This inertial device consist of several sensors as accelerometers or gyroscopes, allowing WIMU™ to measure distance, speed and, specifically, angles. In addition, this device uses a specific software, QÜIKO™, for automatic analysis of the data generated in real time. This software have different algorithms that automatically calculate different measures and variables as angulations in a movement. In QÜIKO menu, the user only have to choose the variable to analyse and QÜIKO shows the results so it can be easily used by people not familiarized with the software to analyse data from inertial devices. Additionally, the last worldwide survey of fitness (Thompson, 2016) stated that wearable technology, which include GPS devices, will be a trend in next years in number one position, reinforcing the findings of previous surveys. The advances of this technology are unpredictable. For this reason, the validity and reliability of technology is necessary to adapt to the expected new users, facing the difficulties of the use and interpretation of reported data, as in WIMU™ and QÜIKO™.

Ankle dorsiflexion is commonly linked to several clinical conditions (Kleeblad, van Bemmel, Sierevelt, Zuiderbaan, & Vergroesen, 2016) and daily activities requires a minimum level of ankle dorsiflexion ROM such as walking or descending stairs (10°) and running (20° to 30°) (Calatayud et al., 2015). Based on its applicability in both, clinical conditions and sportive context, a test for the assessment of ankle dorsiflexion was chosen to analyze the agreement between WIMU™ measures and other commonly used devices as goniometer and 2D motion analysis. Therefore, the aim of this study was two-fold: i) to evaluate the validity of WIMU™ for the measurement of different angles positions compared with a standard goniometer and a 2D video based motion analysis software; and ii) to evaluate the use of WIMU™ for the assessment of angulations in a joint, specifically assessing the validity and reliability of WIMU™ for the measurement of ankle dorsiflexion compared with a standard goniometer and Kinovea. It was hypothesized that the WIMU™ device will display a high validity and reliability for measuring the different angulations and the ankle dorsiflexion test used in the study.

Method

Instruments

WIMU™ and two other different measurement systems were used to assess angles: a standard goniometer and a video-based motion software analysis.

WIMU™ (RealTrack Systems, Spain): this device comprises a great variety of sensors, such as two tri-axial accelerometers (2G and 8G), 3D gyroscope, 3D magnetometer, barometer and GPS. For the analysis of inclination angles, information of accelerometers, gyroscope and magnetometer is used to calculate unit quaternions, which is later transform to Euler angles. All information was obtained and analyzed using its specific software QÜIKO™.

Gollehon Extendable Goniometer (model 01135, Lafayette Instrument Co., USA): This goniometer has a dual scale of 0-180° and 180-0 with 1° increments, and has been used in previous studies to analyze the range of motion (Paulis, Horemans, Brouwer, & Stam, 2011).

Kinovea: This software is a free and open-source (GPL2) video player which allows to make motion analysis, including the calculation of angulations in real time, manually or using semiautomated tracking function. Reliability of this software in the analysis of range of motion has been reported as high in both inter and intra-rater assessment. Kinovea can be downloaded from http://www.kinovea.org/ .

Phase 1: validity of WIMU^{TM} for the measurement of different angles positions

Procedure.

In first place, the goniometer was fixed to a stable surface at 0° while the other arm of the goniometer was free. Secondly, the WIMU^{TM} was attached to the free arm of the goniometer. The inertial device was automatic calibrated in the moment it is turn on and simultaneously, a digital video camera (Sony EXILIM EX-ZR15, sampling frequency of 120 Hz) was aligned perpendicularly at the centre of the goniometer in a sagittal plane and a distance of 30 cm (Figure 1). Both devices were synchronized and after that, 88 aleatory angles measurements with a range value of 0-180 degrees were done using the Lafayette Gollehon goniometer as reference.

The video images were imported to Kinovea and the semiautomatic tracking function allowed the calculation of angles in each position, providing the information in real time. Information obtained by WIMU^{TM} was send to QÜIKO^{TM} software, which automatically computes the angles.

Phase 2: Validity and Reliability of WIMU^{TM} for the measurement of dorsiflexion ankle.

Participants: the participants in this study were 30 healthy male subjects (age=17.0±0.7; height= 1.7±0.1; weight= 66.2±8.4). All subjects were informed about the study procedures, giving their consent to participate before testing. The ethics committee of the university approved the study.

Procedure:

The assessment of dorsiflexion ankle was conducted using a standardized protocol. Prior to the test, subjects perform a warm-up based on eight to 10 minutes of jogging and static stretching, specifically of the lower-limbs (Bishop, 2003). All subjects were asked not to perform any intense physical activity 48 hours before the test. Ankle dorsiflexion was recorded with the knee straight, both hands resting on a wall and keeping the heel in contact with the floor (Kleeblad et al., 2016). The WIMU™ was placed on the calf muscle (Figure 1). The difference between de vertical angle (90°) and the measured angle was assessed as the dorsiflexion. Participants were asked to perform the test with one leg, three repetitions of each limb. Dorsiflexion ankle was assessed simultaneously using the WIMU™, the goniometer and Kinovea in order to check the agreement between these measures in this test. In order to analyze the reliability of the data, the evaluation were done twice with the same participants, with a period of 7 days.

Statistical analysis.

A descriptive analysis with mean and standard deviation was carried out in first place in order to characterize the measurements obtained for all devices in both phases. Pearson´s correlation coefficient (r) was performed to calculate the concurrent validity and Bland-Altman plots (Bland & Altman, 1986) were performed to complete the validity analysis of WIMU™ with the representation of the degree of agreement between angles obtained using this device and both, goniometer and Kinovea software. The intraclass correlation coefficient (ICC) (2.1) was used for the analysis of validity of angles measured between the WIMU™ and Kinovea using the Goniometer as reference.

Relative reliability was estimated using the ICC 2.1 with 95% confidence intervals across the two test sessions (Shrout & J.L., 1979). ICC was interpreted according to Munro et al. as follows: moderate (0.50 to 0.69), high (0.70 to 0.89), and excellent (0.90 and above) (Munro, Visintainer, & Page, 1986). Absolute reliability was determined by calculating the Standard Error of Measurement (SEM) (SEM= SD $\sqrt{(1-ICC)}$); where SD is the mean SD of day 1 and day 2), and the Smallest Real Difference (SRD) (1.96 $\sqrt{2 \cdot SEM}$) (Weir, 2005).

The level of significance was established at $p < 0.05$. All of the analyses were performed using the software SPSS 21.0 for Windows (IBM Co., USA), except for the Bland-Altman plots, which were performed by using the software Graphpad Prism (Graphpad, Inc., USA).

Results

Table 1 shows means and standard deviations of the measures obtained by the WIMU™ using Kinovea and universal goniometer as reference, as well as ICC and Pearson´s r values for the validity analysis for both phase 1 and phase 2. Values for convergent validity were excellent for phases 1 and 2 (>0.95) for both, ICC and Pearson´s r indicating a perfect consistency between measures obtained by the three devices. Figure 2 showed the correlation between instruments. Bland-Altman plots showed all but five observations pair in the ± 1 SD range of the difference (Figure 3). Table 2 shows relative and absolute reliability of the ankle dorsiflexion test for WIMU™, Kinovea and goniometer measurement. The ICC values were excellent for the 3 devices (all of them >0.90) and WIMU™ showed the highest absolute reliability.

Discussion

The aim of this study was to evaluate the validity and reliability of WIMU™ for the measurement of different angles positions compared with a standard goniometer and a 2D video based motion analysis software. Results show the high values in concurrent validity and reliability that WIMU™ presents when it is compared with the goniometer and the Kinovea software, probed as a reliable and useful instrument for joint mobility measurement.

Results stated that WIMU™ reported very similar angles measurement compared with criterion methods.

Previous studies have used correlation coefficient to asses validity and reliability. However, this coefficient is unable to detect constant error, therefore, this analysis cannot state the validity of an instrument (Magnúsdóttir & Karlsson, 2014). Bland-Altman plots provide accurate information about the agreement between measures (Bland & Altman, 1986). In our analysis, Bland-Altman plots show that most of the measurement are close to the mean of the differences with both instruments, goniometer and Kinovea, stating a high level of agreement. Additionally, the ICCs and correlation coefficient shows a perfect agreement between measures (1.00).

In this study we provide both, relative and absolute indices of reliability and both indices showed a good reliability for ankle dorsiflexion when it is measured using anyone of the device used (WIMU™, a goniometer or the 2D video-analysis with Kinovea) although WIMU™ present a little better absolute reliability index. The SEM was included since this value is very important in the correct clinical interpretation of test result. The SEM is used to indicate the amount of measurement noise, which is unlikely to be of clinical significance. The SEM percentages in the present study suggest that differences of less than 0.64% should be considered measurement noise in ankle dorsiflexion assessed by WIMU™. Whether a post-treatment difference that lies between the SEM and SRD represents a genuine change is less certain (McKenna, Cunningham, & Straker, 2004). The SRD percentages in the present study suggest that for ankle dorsiflexion assessed by WIMU™, a change of 5.81% is necessary.

The increase in new instruments and methods to measure angles (joint mobility) for its use in evaluation for rehabilitation or performance in sport has made that several studies have examined the validity and reliability of this methods. Other studies have stated that new apps in smartphones are valid and reliable with worst values of those found here. Knee Goniometer App, has shown ICCs values for validity similar of WIMU^{TM} (>.98). Coach´s eye has been stated as an alternative instrument to asses joint mobility with ICCs lower than 0.9 (Krause et al., 2015); DrG has values of intra and inter-rater reliability > 0.86 (Otter et al., 2015); Clinometer reported inter-rater reliability of 0.65 (Werner et al., 2013). Other method, as photography based goniometry has shown values of test-retest reliability of 0.93 to 0.99 (Blonna, Zarkadas, Fitzsimmons, & O'Driscoll, 2012) or Kinovea, with intra and inter-rater reliability ICCs from 0.87 to 0.97 (El-Raheem, Kamel, & Ali, 2015).

When compared WIMU^{TM} with previous methods (with goniometer as criterion reference), the inertial device had greater reliability, which may be due to several factors. 2D and 3D analysis systems use different markers or reference lines to measure the angle. This procedures can lead to variation from subject to subject or from session to session (Della Croce, Leardini, Chiari, & Cappozzo, 2005). In this study, when compare results of the phase 1 with phase 2, it can observed that phase 2 is less, although despicable, valid and reliable due to the fact that WIMU^{TM} have to be placed in the leg. Also, 2D devices has the drawback of its dependence of a correct plane of the camera for its accuracy (Magnúsdóttir & Karlsson, 2014). WIMU^{TM} do not need human interaction, only the colocation of the device in the body, and QÜIKO automatically shows the angle, which is calculated by the transformation of unit quaternions to Euler angles. Independently of the instrument used, errors associated in the measurement can be associated with the tool, the tester or the ROM (Piriyaprasarth & Morris, 2007). In fact, it has been reported higher SEM in novice clinicians in the use of goniometers, whereas experienced clinicians have reported higher SEMs in the use of KGA app (Milanese et al., 2014).

Limitations. Nevertheless, measurement in human movements could be easily identified, considering that, thanks to QÜIKO, maximum and minimum angles appears automatically in the software. However, results point out that WIMU^{TM} have a perfect consistency in angles measurement. Further studies are necessary to assess the validity of this device in real sports movements, postural evaluation or different clinical conditions.

Conclusion

The current findings conclude that WIMU^{TM} is a valid and reliable instrument to measure angles position and could be used for the assessment of joint´s ROMs. WIMU^{TM}. Additionally, due to its software give the information about angles in real time, it could be used to monitoring rehabilitation or training exercises providing immediate feedback.

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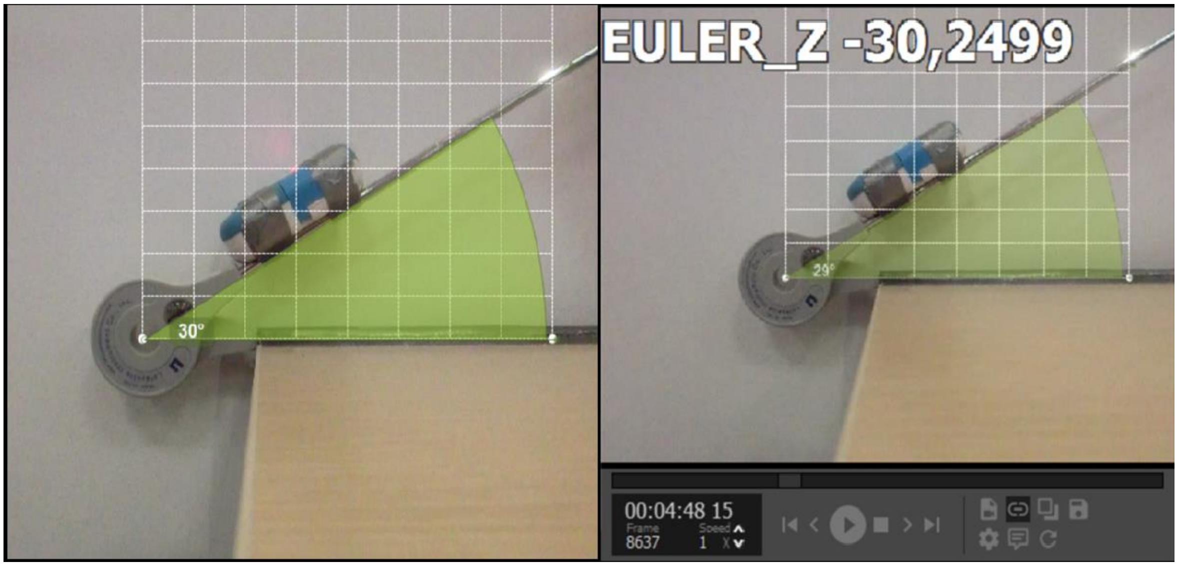
Figure title and legends.

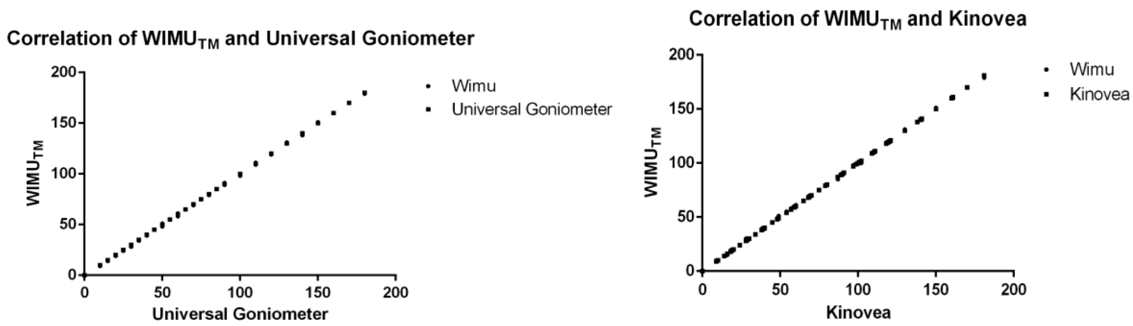
Figure 1.



Title:

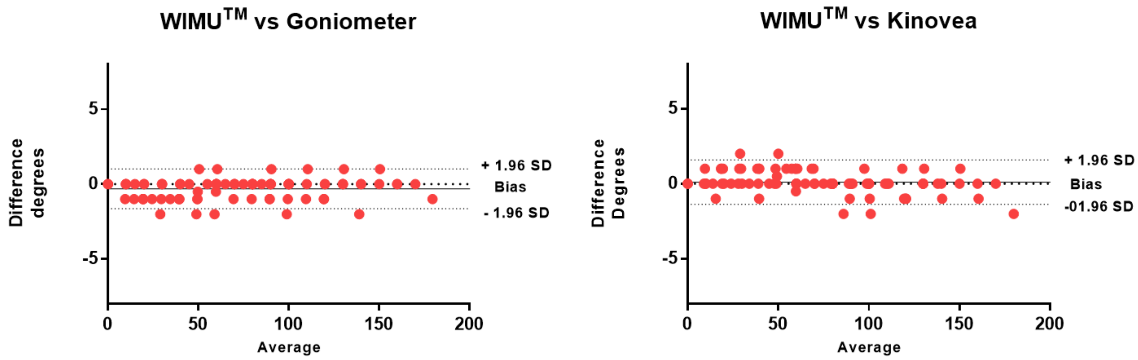
Legend: In the left image it can be observed the inertial Devise attached to the goniometer, the position of the camera and the automatic tacking function of the Kinovea calculating the angle. In the right side, QÜIKO software automatically calculating the same angle.

Figure 2:



Legend: Agreement between Universal Goniometer (UG), Kinovea software and WIMU^{TM} measurements based on the measurement of different angles (n = 88).

Figure 3.



Legend: Bland-Altman 95% Limits of Agreement Between the WIMU™ device and universal goniometer (left panel) and the Kinovea (right panel).

Table 1. Descriptive Statistics, intraclass correlation coefficients (ICC) and correlation coefficient of the angles obtained by WIMU™ and Kinovea using a goniometer as reference

	WIMU™	Goniometer	ICC	IC 95%	Pearson´s r
Angles (°)	73.84 ±43.76	74.14 ±43.64	1.00	1.00- 1.00	1.00*
		Kinovea			
		73.73 ±44.02	1.00	1.00-1.00	1.00*

*p<0.001

Table 2. Test-retest reliability of the angles adquired by WIMU™ and Kinovea using a goniometer as reference

	Mean1 ± SD	Mean2 ± SD	P of t-test	ICC	IC 95%
WIMU™	73,84 ±43,76	73,83 ±43,77	.905	1*	1-1
Kinovea	73,73 ±44,02	73,76 ±43,98	.765	1*	1-1

*p<0.001