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6 authors, including:

Josep Maria Padullés
National Institute of Physical Education (INEFC)

Albert Busquets Faciaben
University of Barcelona

Xavier Padullés

Carles Escalona-Marfil
Universitat Internacional de Catalunya

Article

Validity and Reliability of the Kinovea Program in Obtaining Angular and Distance Dimensions

Albert Puig-Diví [1,*], Josep Maria Padullés-Riu [2], Albert Busquets-Faciaben [2], Xavier Padullés-Chando [2]; Carles Escalona-Marfil [3] and Daniel Marcos-Ruiz [4]

[1] Blanquerna School of Health Sciences – Ramon Llull University, Barcelona, Spain
[2] National Institute of Physical Education of Catalonia INEFC, Barcelona, Spain; jpadulles@gencat.cat (J.M.P.-R.); albert.busquets@gencat.cat (A.B.-F.); x.padulles@gmail.com (X.P.-C.)
[3] School of Health Sciences – Central University of Catalonia, Vic, Spain; carlesescalona@gmail.com
[4] School of Health and Sport EUSES – University of Girona, Salt, Spain; dmarcos@euses.cat
* Correspondence: albertpd@blanquerna.url.edu; Tel.: +34-93-253-32-56

Abstract: Clinical rehabilitation and sports performance analysis both require the objectification of movement. Kinovea© is a free 2D motion analysis software that enables the establishment of kinematics parameters. This low-cost technology has been used in sports sciences, as well as clinical field and research work. Although it has been validated as a tool with which to assess time-related variables, this is not yet the case regarding angular and distance variables. The main objective of this study was to determine the validity and reliability of the Kinovea software in obtaining angular and distance data at different perspectives of 90°, 75°, 60° and 45°. For this purpose, a figure with 29 points was designed (in AutoCAD) and 24 frames analysed. Each frame was examined by three observers who each made two attempts. For each export data item, 20 angles and 20 distance variables were calculated, with intra- and inter-observer reliability also analysed. To evaluate Kinovea reliability and validity a multiple approach was applied involving the following analysis: -systematic error with a two-way ANOVA 2x4; -relative reliability with ICC and CV (95% confidence interval); -absolute reliability with Standard Error. The results thus obtained indicate that the Kinovea software is a valid and reliable tool that is able to measure accurately at distances up to 5 m from the object and at an angle range of 90°–45°. Nevertheless, for optimum results an angle of 90° is suggested.

Keywords: free software; human motion; Kinovea; low cost; reliability; validity; video analysis

1. Introduction

Clinical rehabilitation and sports performance analysis both require the objectification of movement in order to obtain quantifiable data and thus improve their results. New low-cost technologies applied to kinematic analysis have recently appeared, but must be validated prior to their wider adoption. For this purpose, movement can be analysed in a subjective manner using kinematics scales and objective methods.

1.1. Kinematics scales

In the field of clinical analysis, measurement scales are often used to quantify subject balance or gait kinematics. Such scales include the Tinetti test, the Unified Parkinson Disease Rating Scale (UPDRS) [1] and the Wisconsin Gait Scale (WGS) [2]. However, the information that these scales report depends partially on the level of experience of the observer, and hence a subjective component underlies their use. For this reason, mobile phones are often used to record data that are

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then compared and validated with other common tests, such as the 6-minute walk for gait analysis in patients with chronic obstructive pulmonary disease [3].

1.2. Clinical and sports technologies for motion analysis

Various tools can be used to record subject movement, including video cameras or smartphones that contain integrated accelerometers and cameras. In the field of modern biomechanics there is growing demand for two-dimensional (2D) software with which to analyse subject movement, as well as for the indirect calculation of centre of mass displacement [4] and gait analysis [5]. Some examples include Ubersense, now called Hudlthecnique [6], the MarkWiiR remote from Nintendo [7], the Microsoft Xbox One Kinect^{T} [8] and the Dartfish [9]. One such low-cost technology is Kinovea, which enables the analysis of angles and spatio-temporal parameters [10].

Kinovea is a free 2D motion analysis software under GPLv2 license, created in 2009 via the non-profit collaboration of several researchers, athletes, coaches and programmers from all over the world. It is widely available for download on the web [11]; the current official version is 0.8.15, although 0.8.24 has been used experimentally and the most recent update is 0.8.25 [12].

Kinovea allows the user to control temporal parameters and measure angles and distances frame by frame. These measurements can also be made from different perspectives, since the software carries out calibrations in non-perpendicular planes to the camera-object line analysed. As it is not a 3D program, Kinovea enables users to choose the plane on which to perform the dimensional analysis in 2D.

1.3. The application of Kinovea to sports

Kinovea has been used in three main fields: sports, clinical analysis and as a gold standard with which to compare the reliability of other new technologies.

[13] validated Kinovea-0.8.15 for the kinematic analysis of vertical movement through its automatic tracking point function. However, it is argued in [14] that kinematic analysis carried out using video recording can be impractical and costly compared to the use of contact mat and force platform for the measurement of vertical jump height.

[15] performed running gait analysis on a treadmill and concluded that Kinovea offers acceptable intra-observer reliability regarding photogrammetric visual identification within the same day, although this decreases when records are made within a 14-day interval.

[16] studied eight young high-performance artistic gymnasts in order to visualize their technique, error commission and performance, using visual observation, Kinovea and Physics Toolkit.

[17] used Kinovea for the biomechanical analysis of gymnastic jumping and acrobatic exercises, evaluating the launching body posture, multiplication of body posture, flight maximum height and concluding body posture of female acrobats [18].

[19] studied the kicking legs of seven futsal players during moderate-effort kicks. Kinovea was used to analyse the ankle condition during the pre- and post-impact phases, as well as the velocity of the ankle and foot prior to impact and the subsequent velocity of the kicked ball.

[20] analysed elite paddle tennis players during competition. Kinovea-0.8.15 was employed to study match parameters including total time, real time, rest time, work-to-rest-time, points, strokes for points, rally time, and rest rally time, as well as shot parameters including service, return, ground strokes, net strokes, and indirect strokes

[21] employed Kinovea-0.8.15 to analyse the long jump of Paralympic athletes during the London 2012 Paralympics. The authors concluded that the data obtained with Kinovea were reliable, valid and accurate, and that it had allowed the analysis of kinematic and temporal variables without disturbing the participants.

[22] evaluated the effects of physiological loading of the lumbar spine on 34 male cricket, hockey and basketball national team players, as a predictor of pain. Based on magnetic resonance imaging, intervertebral disc angles, the Farfan ratio, the lumbar body index, the compression deformity ratio, the biconcave deformity ratio and the anterior wedge deformity ratio, geometric variables were measured using Kinovea-0.8.15.

[23] measured the pedalling cycle of a national and international champion cyclist; hip, knee and ankle angles were analysed and compared using Kinovea and Matlab.

Finally, [24] measured the action-reaction times of 12 juvenile karate athletes in order to develop an assessment scale. A Canon SX260 240fps camera was used to record movements and Kinovea to obtain the time in milliseconds.

1.4. The application of Kinovea to clinics

Goniometers are single-degree angular measurement tools that are used widely in clinical joint assessment, including for physical therapy, sports medicine and performance, and musculoskeletal rehabilitation. However, goniometers are unsuitable for the detection of movements with multiple degrees of freedom, such as human walking and running gaits, since this requires multi-segmental and poly-articular functional mobility analysis. In contrast, video analysis enables motion to be followed dynamically.

[25] used Kinovea as a tool in the field of physiotherapy and rehabilitation to measure movement of the lower extremities, employing the angle and track path tools to analyse position, velocity and acceleration data. The authors concluded that Kinovea was successful in measuring both these parameters and poly-articular angular movements.

[26] assessed the intra-observer reliability of Kinovea for the analysis of knee and hip angulations, as well as for the identification of initial foot contact during running. The authors concluded that, in order to minimize measurement errors, attention should be paid to system setup

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prior to kinematic recording. Nevertheless, they also considered that the angular difference ratio obtained was sufficiently accurate to encourage the in-clinic use of Kinovea by physicians.

[27] analysed the flexibility of the hamstring muscles by comparing the active extension of the knee and hip angle, using an inclinometer and video analysis with Kinovea-0.8.15. The authors supported the use of this program as a useful tool for health professionals who intend to measure hamstring flexibility in adolescents.

In the field of neurology, [12] used Kinovea-0.8.15 to assess the movement of six facial muscles through the program's "point tracking" function, and concluded that even without any prior training, the method was reliable for frontal muscle analysis.

Fatigue at work and ergonomics affect joint stress and that of the overall musculo-skeletal system. [28] used Kinovea to analyse the pronation-supination movements of a jeweller's forearm during the precision task of jewel assembly.

[29] used Kinovea-0.7.10-v2 for the frontal-plane analysis of the degree of occlusal-plane inclination in children with postural asymmetry. The occipital middle cervical-scapular waist angle was measured to two decimal places. The authors concluded that, in healthy children with postural asymmetry, there was a tendency toward a lower occlusal plane on side of the head inclination, apparently due to dent-alveolar growth factors.

[30] analysed 25 subjects to assess the relationship between foot posture (using the Foot Posture Index) and running kinematics on a treadmill, based on parameters including contact time, flight time, stride time, and stride frequency. They concluded that the foot posture index is not significantly associated with the kinematic parameters analysed.

[31] studied the forward head posture of the cervical segment by digitizing left and right sagittal plane photographs using Kinovea, measuring the angular craniovertebral and gaze variables.

1.5. Other applications of Kinovea

More recently, Kinovea-0.8.15 has been used as a reference system for the analysis of high-speed video, comparing the MarkWiiR system and the Wii-Remote of Nintendo [7].

Kinovea can also be employed with wide-angle cameras such as the GoPro. Whereas it was previously necessary to pre-process images to reduce distortion [32], the free program provided by GoPro-Studio-2.5.9.2658 solves this problem by reducing recording aberration.

1.6. AutoCAD as a tool for design and photogrammetric analysis

The 2D/3D program AutoCAD-2010 is commonly used in industrial design and architecture, and with scientific rigor in both the biomedical and engineering fields.

Several AutoCAD applications have been described as tools for application in clinical and sports sciences [33, 34, 35, 36].

1.7. Justification

The study of kinematics is required given the need to objectify human movement in various fields, including sports management analysis, clinical research, footwear, and orthopaedics [37].

One of the most rigorous and scientifically validated systems used in kinematic analysis is the three-dimensional (3D) motion analysis laboratory. According to [38], such systems provide very accurate data, but also involve technical difficulties in interpretation and set-up. [39] argues that 3D laboratories incorporate high-cost instrumentation and programs, thus largely limiting their use to research. Indeed, in [40] it is established that setting up a laboratory with 2D instrumentation and software costs approximately less than £700 (€950), with the authors expressing the need for the development of new low-cost technologies for the kinematic analysis of human gait. [41] hypothesised that many existing low-cost technologies exhibit a precision comparable to leading high-end reference systems.

Kinovea is an easy to use, portable and free tool that can be used in field situations; no previous experience is required to obtain accurate and reliable measurements. However, although it has been validated as a tool with which to assess time-related variables [10], to the authors' knowledge no analysis of validity has been made regarding distances and angles.

1.8. Objectives

The objective of this study was to determine the validity and reliability of the Kinovea program in obtaining kinematics data under different conditions of perspective.

2. Materials and Methods

The reliability and accuracy of Kinovea-0.8.24 were analysed to determine if it met validity criteria as a biomechanical metric measurement tool.

The procedure included eight steps, as described in the following numbered sections: 2.1. Design of a geometric figure; 2.2. Configuration and instrumentation of the recording space; 2.3. Image capture procedure; 2.4. Kinovea frame calibration; 2.5. Images digitisation; 2.6. Export of data to spreadsheet; 2.7. Data extraction and transformation; and 2.8. Statistical analysis.

2.1. Design of a geometric figure in AutoCAD-2010

First, a geometric figure was designed using the AutoCAD-2010 program. For this purpose a total of twenty-nine numbered markers were drawn, with four drawn at the ends of the geometric template. These latter markers formed an 800x555 mm rectangle to be used as a reference with which to calibrate the frame with Kinovea via the <<perspective grid >> command.

Based on the Helen Hayes protocol [8], twenty-five markers were drawn simulating a wire structure in the shape of a typical human lower extremity with lower limb bony anatomical prominences visible during different phases of the human gait. These markers were numbered to help to establish an order during the analysis process (Figure 1).

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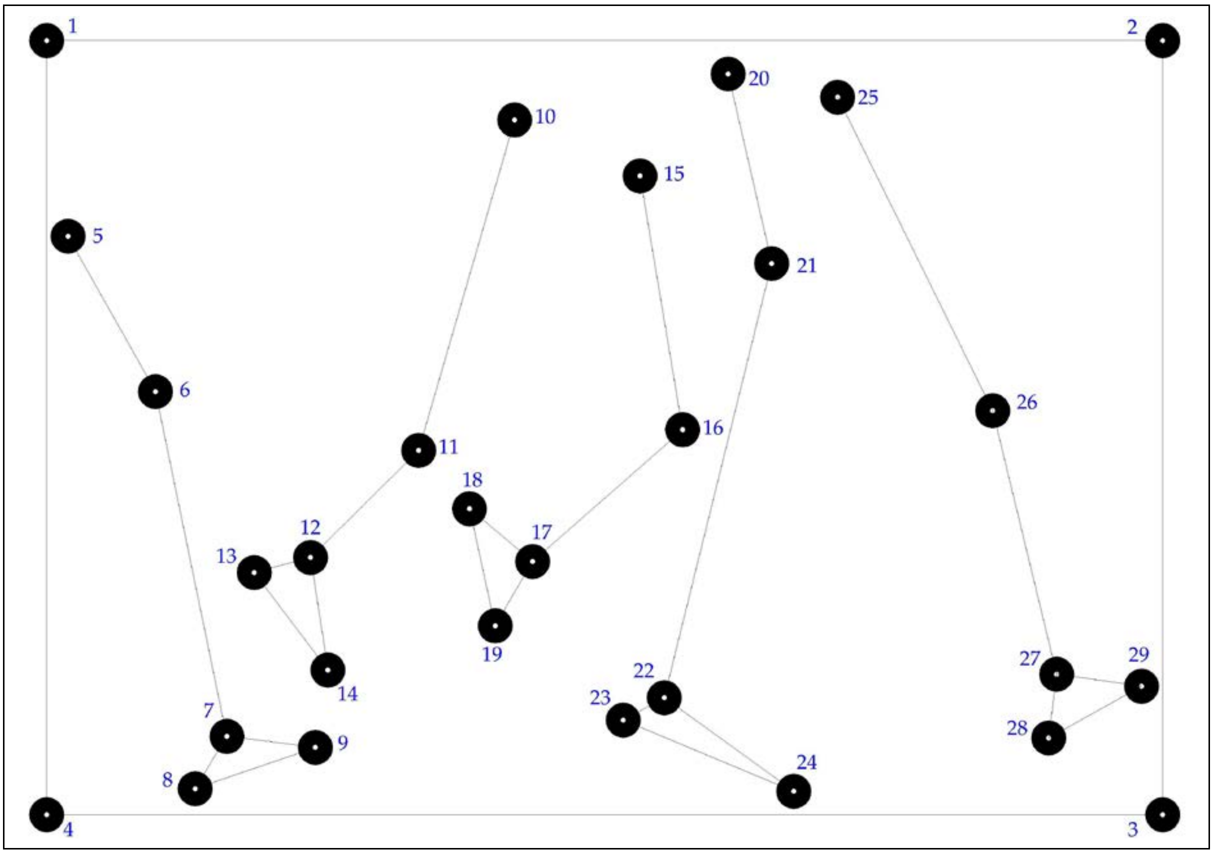


Figure 1. Geometric figure designed using the AutoCAD-2010 program.

Such markers' size, colour and geometry differ according to the literature. To measure kinematics during gait, a number of researchers have used planar, adhesive and flexible markers [40, 42]. In the present study, markers were drawn as black unfilled circles with a 25 mm outer diameter and a 2 mm inner diameter (i.e., solid white circles) in order to improve the precision of locating geometric centres in Kinovea (Figure 2).

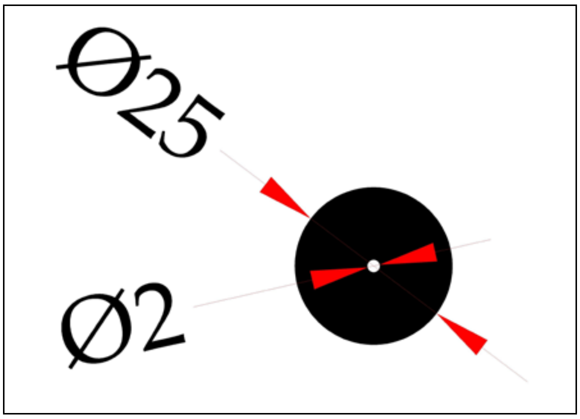


Figure 2. Marker shape and size (mm).

The geometric figure was dimensioned in AutoCAD-2010 to obtain numerical values of the x and y coordinates for each point, starting with marker number one as point 0.0 (Figure 3). These coordinates were used to create a spreadsheet containing trigonometric formulae that enabled the calculation of distances and angles from the coordinates exported from Kinovea. In addition, the distances between each pair of points were measured, as well as the angles between each segment

(Figure 4). These data were used to compare the two methods (coordinates and distances-angles) and to check the formulae.

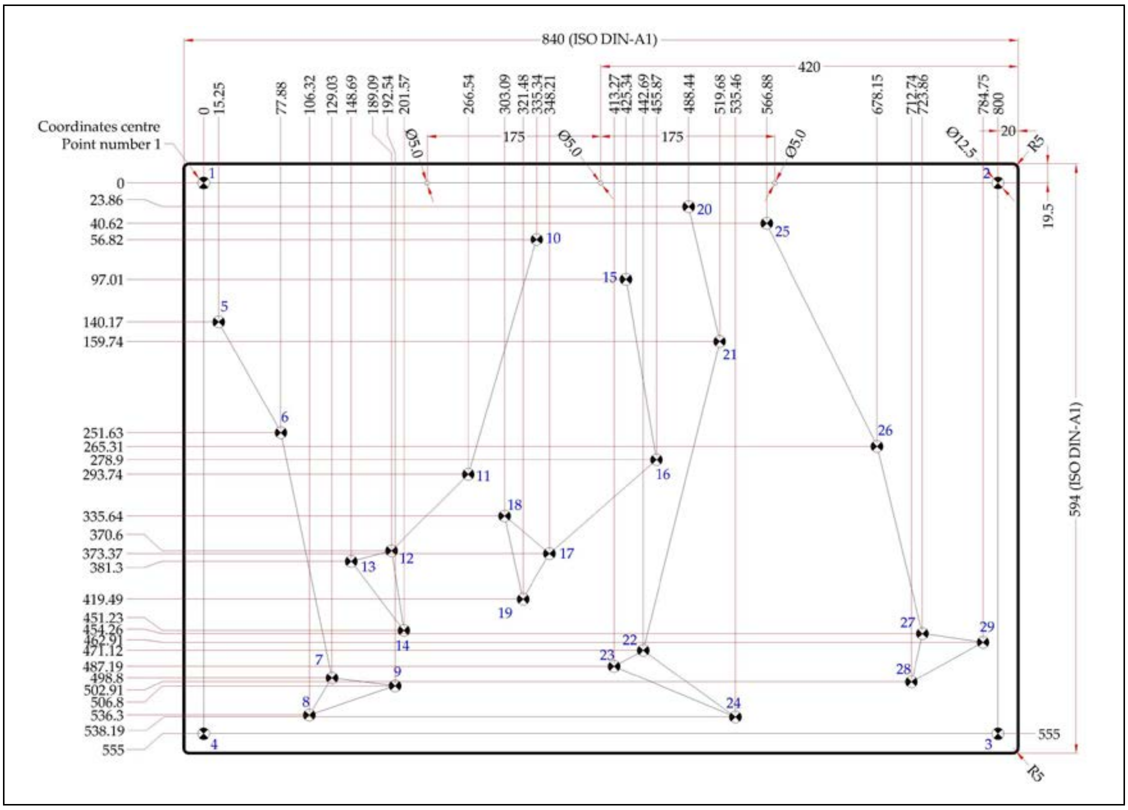


Figure 3. Two-dimensional coordinates (x-y axis) in AutoCAD-2010.

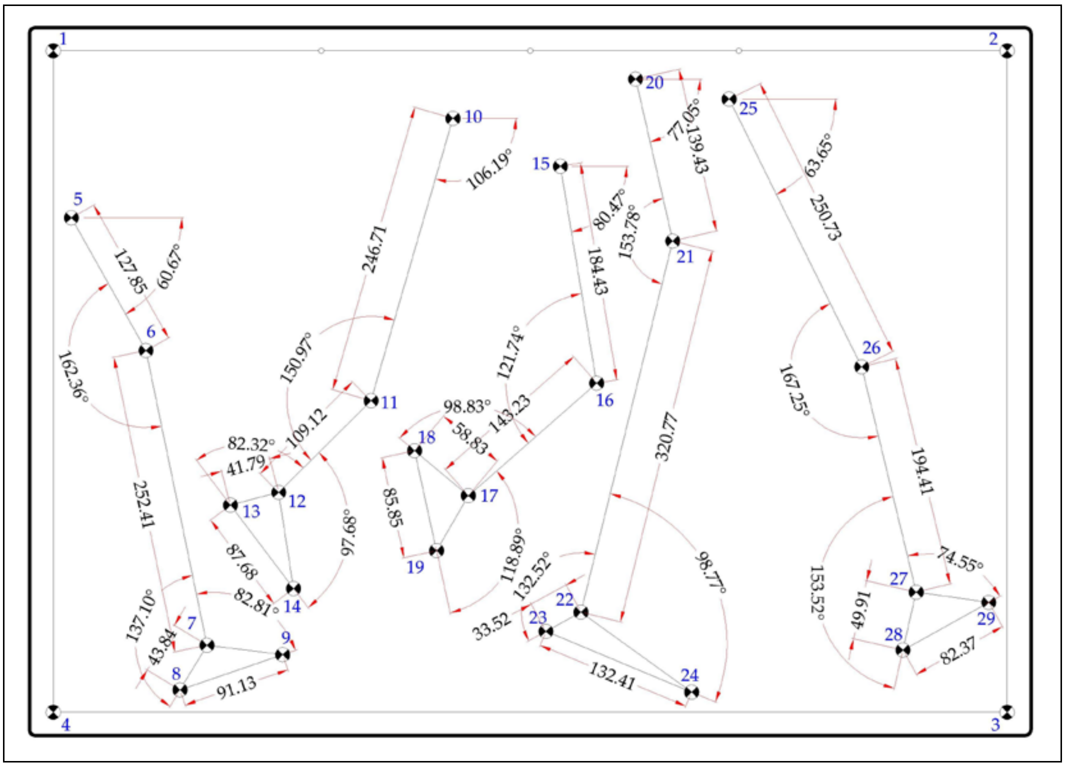


Figure 4. Distances and angles in AutoCAD-2010.

The geometric figure was then printed on ISO-DIN-A1 paper using an HP Design jet T120 plotter and stuck to a 10 mm thick cardboard base (Figure 5).

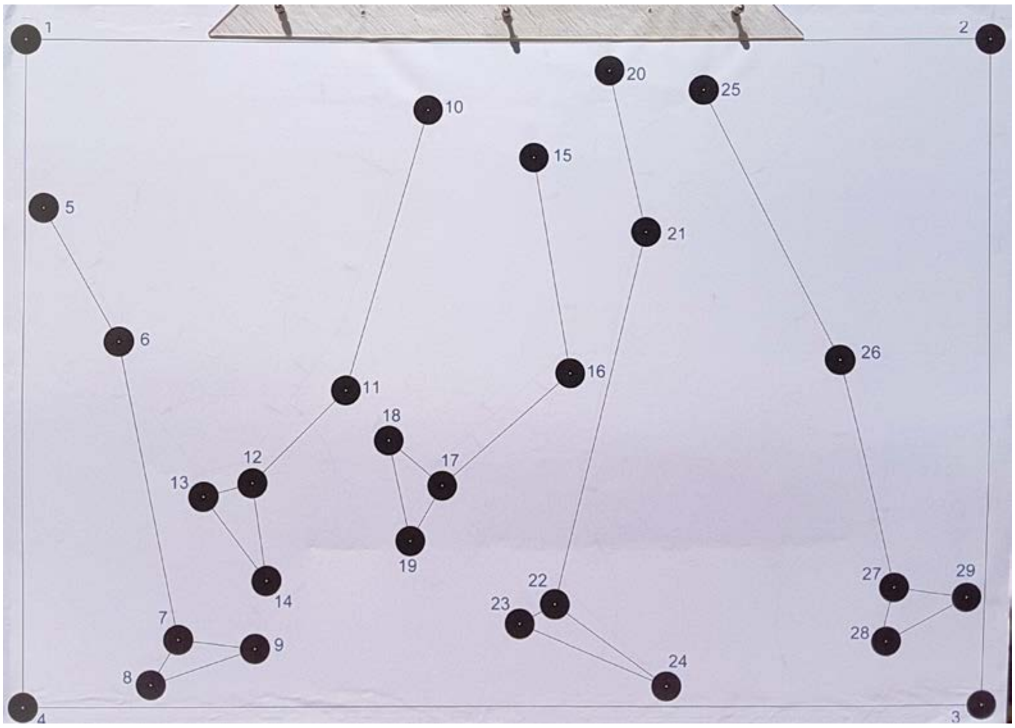


Figure 5. Printed figure on cardboard base.

To check the accuracy of the printing and to confirm that the printed figure was scaled 1:1, three randomly selected distances (10%) between the markers were verified using a calliper (Figure 6).

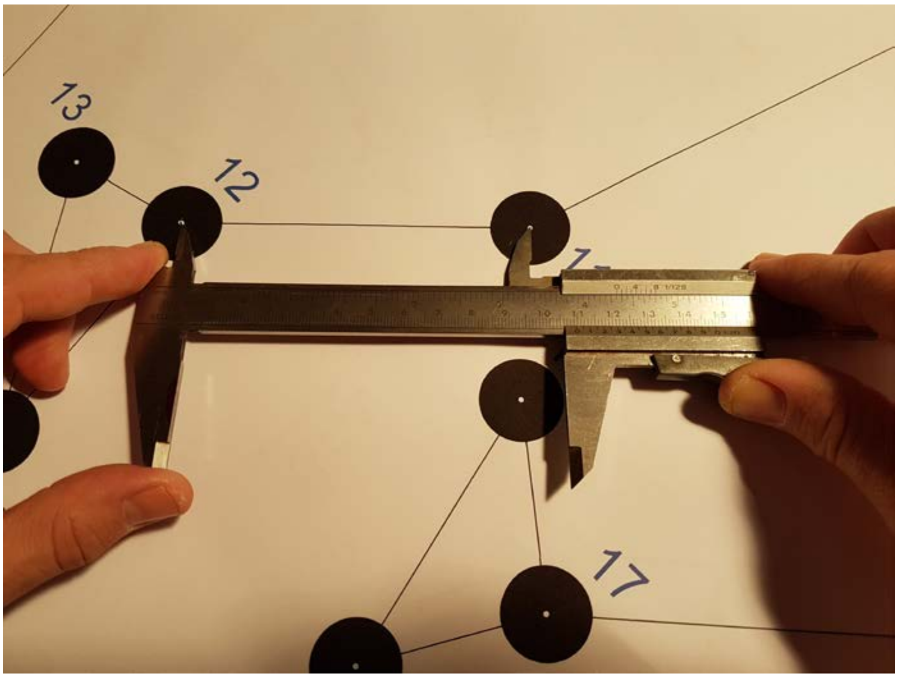


Figure 6. Verification of measurements with calliper.

2.2. Configuration and instrumentation of the recording space

The geometric figure was hung on a glass surface by means of a Ø115 mm Silverline suction cup, which incorporates a Ø4 mm rotation axis made of AISI-304 material on a self-lubricating nylon base to promote slippage (Figure 7).

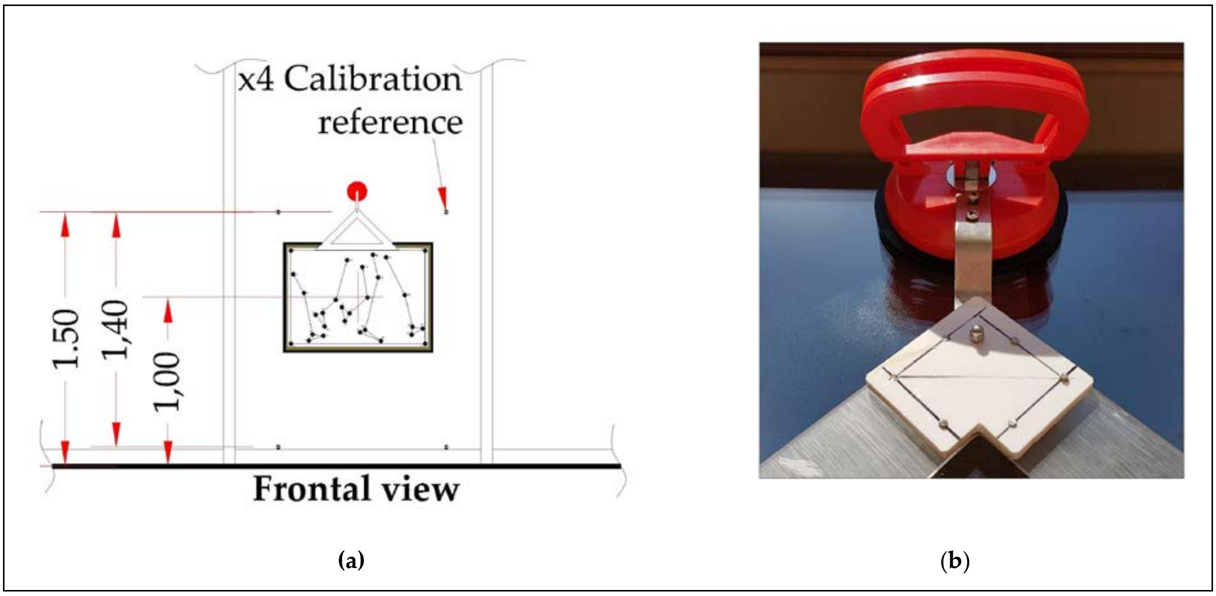


Figure 7. Capture area (**a**) and geometric figure hung on glass with suction cup (**b**).

The geometric figure was recorded using a CASIO Exilim EX-ZR700 high definition video camera with the following setup: resolution: 1280x720 pixels per inch; frequency: 30 Hz; focal length: 52 mm; sensitivity: ISO 400; aperture: 2.7; and shutter time: 1.80. The lens was located at a height of 0.68 m from the ground and 5 m from the centre of the recorded figure (Figure 8.).

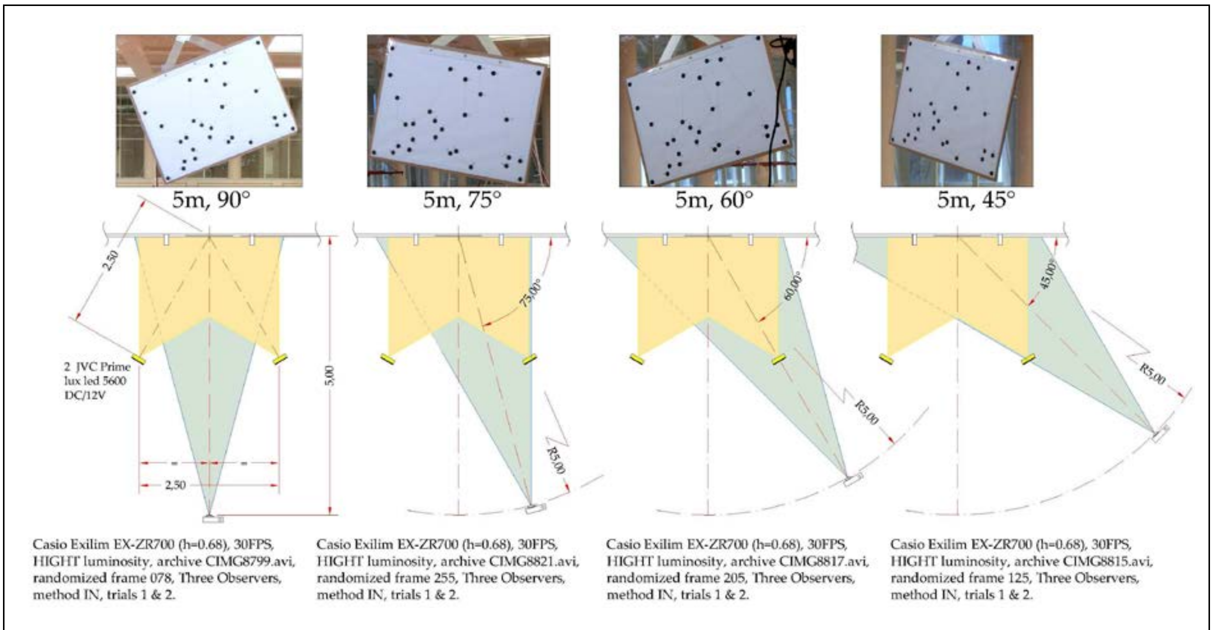


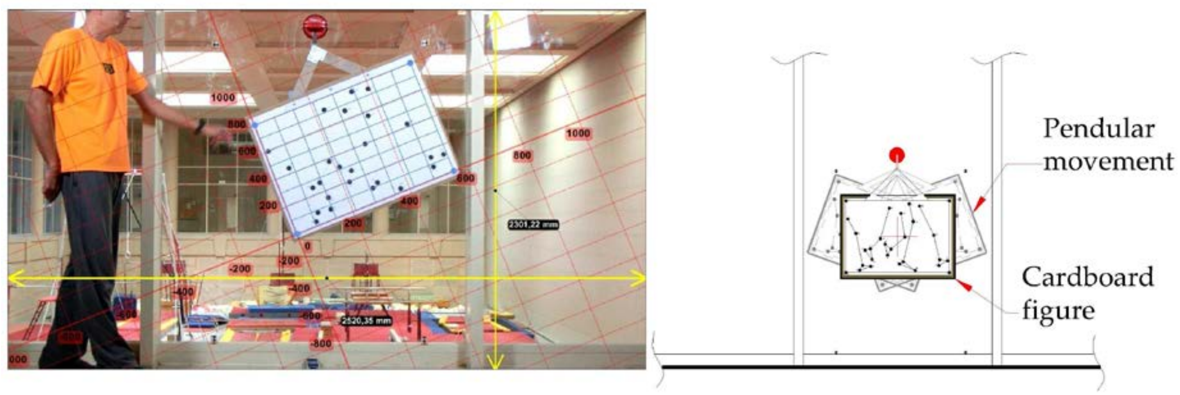
Figure 8. Recording area setup.

In order to precisely place the instrumentation, distances were measured with a BOSCH PR 15 laser distance measurer, with the camera placed perpendicular to the ground using a 40 cm magnetic bubble level (STANLEY ANTICHOC). Capture area illumination was achieved with two JVC Prime DC / 12V non-flickering LED lights.

The total recording area was 2.52x2.30 m (2520.35x2301.22 mm). Recordings were carried out from 4 different perspectives between the geometric figure and the camera: orthogonal (90°), 75°, 60°, and 45°; the same set-up was used for each of the four perspectives.

2.3. *Image capture procedure*

After the figure was pulled to one side by one researcher, recording commenced and the figure was released, causing a pendular movement (Figure 9). After a few seconds, when the figure had ceased moving, recording was stopped. This procedure was repeated from each of the four perspectives.



(a) (b)

Figure 9. Capture area **(a)** and pendular movement of the geometric figure **(b)**.

One frame of the video files obtained from each perspective was randomly selected and analysed using Kinovea.

2.4. *Kinovea frame calibration*

Each frame was analysed twice by each of three observers. For this purpose, three computers with the Kinovea program installed were used, including one desktop computer with a screen resolution and size of 1440x900 pixels and 48.37 cm (19.04 inches), respectively, and two notebooks with a screen resolution and size of 1366x768 pixels and 46.19 cm (18.18 inches), respectively. The entire image calibration and digitisation process was completed using a Logitech M305 wireless mouse.

The four selected frames were calibrated based on perspective via the <<perspective grid>> command, setting the corners of the grid at reference markers 1-4.

To improve the accuracy of grid placement, a 600% zoom was carried out and the grid ends placed on the geometric centre of the markers via the <<scroll>> command.

Finally, the geometric reference system was calibrated based on the known dimensions between points 1, 2, 3 and 4 via the <<calibration>> command (Figure 10).

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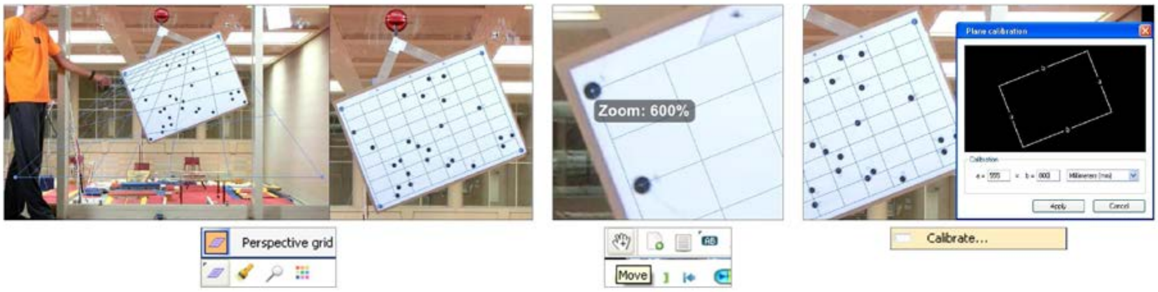
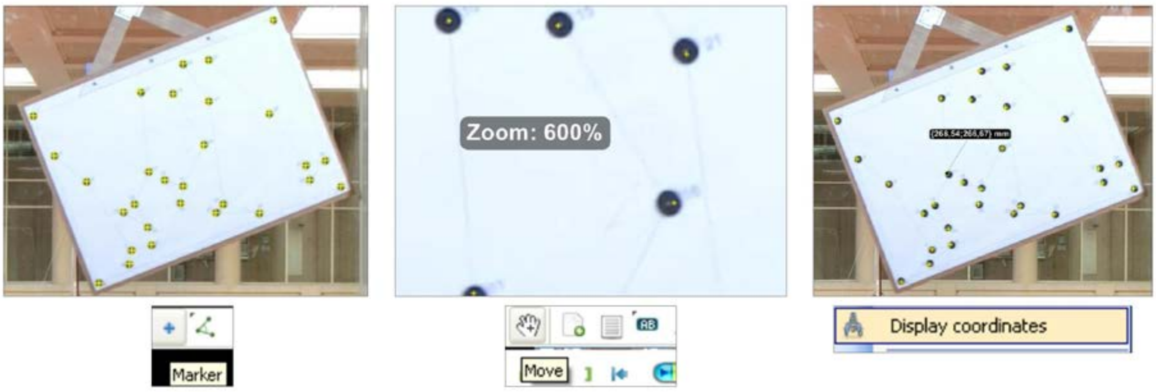


(a) (b) (c)

Figure 10. Perspective grid **(a)**, grid point placement **(b)**, and frame calibration **(c).**

2.5. *Image digitisation*

For each of the four selected frames, the twenty-nine points were digitised on the geometric figure via the <<markers>> command. To improve digitisation accuracy, the points were re-centred on the geometric centre of the markers via the <<move>> command at an increased zoom (600%), with the coordinates of each point then displayed via the <<display coordinates>> command (Figure 11).



(a) (b) (c)

Figure 11. Placement of points on markers **(a)**, point re-centring **(b),** and display of coordinates **(c).**

2.6. *Export data to spreadsheet*

Once the points had been placed and their coordinates displayed, they were exported using the command <<Export to spreadsheet>> (Figure 12.).

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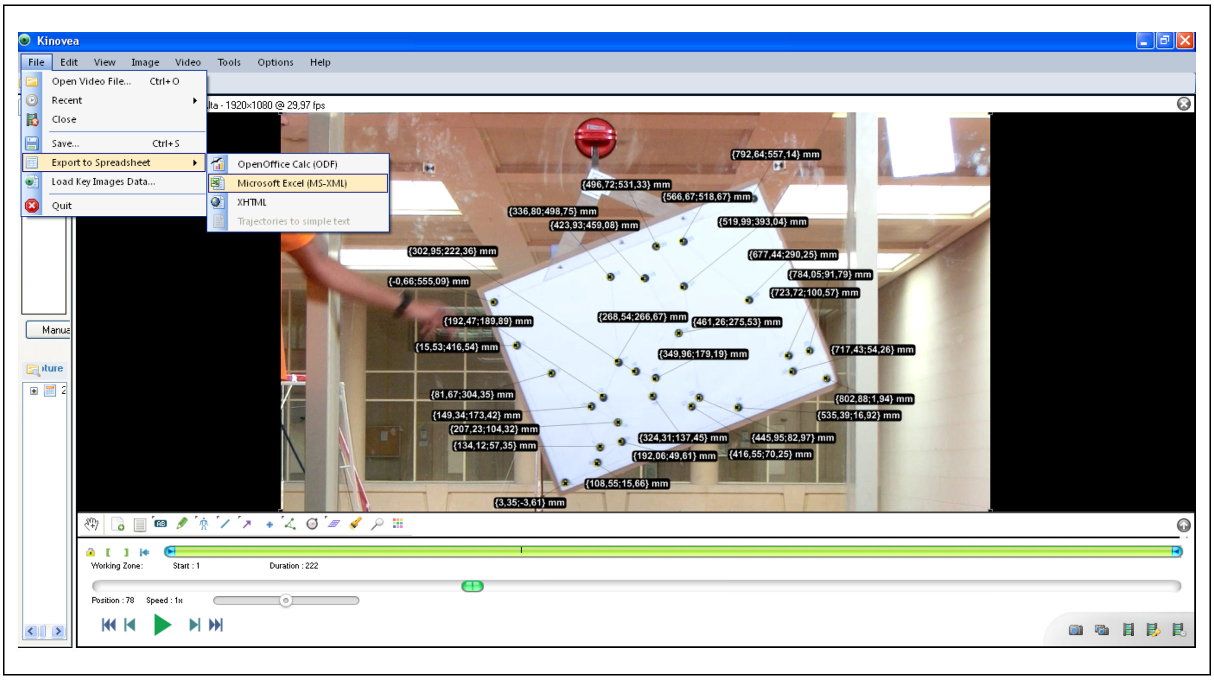
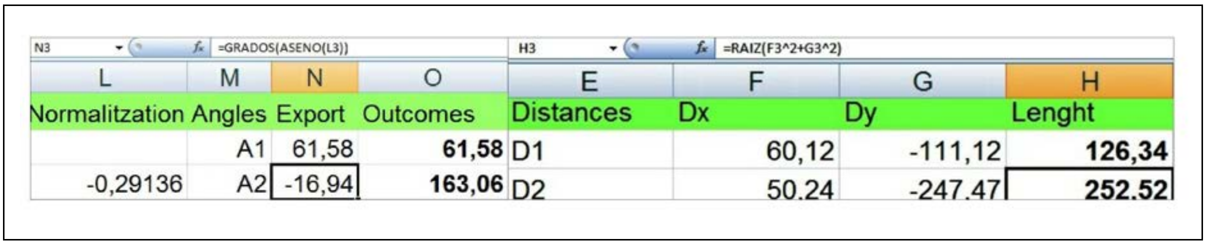


Figure 12. Displayed coordinates and export to spreadsheet.

2.7. Data extraction and transformation

The exported data were pasted into a spreadsheet containing trigonometric formulae that enabled the calculation of 20 angles and 20 distances between the points based on their x-y coordinates (Figure 4, Figure 13).



N3	=GRADOS(ASENO(L3))			H3	=RAIZ(F3^2+G3^2)		
L	M	N	O	E	F	G	H
Normalitzation	Angles	Export	Outcomes	Distances	Dx	Dy	Lenght
	A1	61,58	61,58	D1	60,12	-111,12	126,34
-0,29136	A2	-16,94	163,06	D2	50.24	-247.47	252.52

Figure 13. Trigonometric template in spreadsheet.

2.8. Data analysis

The entire analysis procedure in Kinovea was carried out for each the four perspectives (90°, 75°, 60°, and 45°) by the three observers. Each observer conducted two trials or attempts on non-consecutive days, resulting in a total of 24 frames being analysed. Intra- and inter-observer reliability were calculated, and statistical analysis performed using Microsoft Excel-2007 and PASW Statistics 18.0.

The Shapiro-Wilks test was administered to determine data normality, and the heteroscedasticity of the variables was calculated using Pearson's correlations between the average of the two trials and the absolute difference between the two trials. When normality and / or heteroscedasticity were not fulfilled, transformations were applied.

In order to evaluate the reliability and validity of the use of Kinovea from each of the four perspectives, and following the proposal made by several earlier authors [43, 44, 45, 46, 47, 48], a

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multiple approach was applied involving tests of systematic error and relative and absolute reliability.

Systematic error (SE) between the two attempts and four different perspectives was calculated for each observer via a two-way ANOVA [2 (Trial) x 4 (Perspective)]. When the assumption of sphericity was not fulfilled, the Greenhouse-Geisser correction was applied. In the event of a significant effect, post-hoc analysis was carried out with the Bonferroni correction. A low SE and good reliability can be inferred when there are no significant differences between attempts and/or planes.

Relative reliability reports consistency when making several attempts. Here relative reliability was assessed via the Intraclass Correlation Index (ICC) and the Coefficient of Variance (CV). CV was calculated by dividing the standard deviation (SD) by the mean (M) and is expressed as a percentage (%), with a good relative reliability defined by low CV values (close to 0) and high ICC values (≥0.80). The range of values within the specific probability including "true" reliability was calculated using the 95% confidence interval (CI) of CV and ICC.

Absolute reliability was examined using the Standard Error of Measurement (SEM), which expresses the variation between attempts, and the Minimum Detectable Change (MDC), which expresses the minimum change that must occur to be considered as a true change. The MDC percentage (MDC%) was also calculated to facilitate comparison between measurements.

Finally, data validity was tested using different Pearson correlations between the values of the coordinates obtained in the Kinovea software and the real coordinates (i.e., gold standard).

3. Results

3.1. Numeric data – tables

The mean and standard deviation of the coordinates obtained after digitization are displayed in Table 1. Data on both axes (transformed when necessary) showed a normal distribution, with the low correlation between the average of the two trials and the absolute value of the difference between the trials indicating low levels of heteroscedasticity.

Table 1. Mean (M) and standard deviation (SD) calculated for each perspective, and the absolute differences between the two trials. Heteroscedasticity assessment is presented as the correlation between the mean of the two trials and their absolute difference.

		Trial 1 (mm)		**Trial 2 (mm)**		**Diff Trial 1-Trial 2 (mm)**			
		M	**SD**	**M**	**SD**	**M**	**SD**	**rTrial1-Trial2**	**pTrial1-Trial2**
Coordinates in x-axis	*Observer 1*								
	45 deg	373.07	252.74	372.03	252.40	1.17	0.63	0.360	0.029

	60 deg	376.36	252.20	376.08	246.83	0.96	0.60	-0.046	0.407
	75 deg	375.12	252.27	375.28	251.71	0.66	0.56	-0.456	0.006
	90 deg	376.61	251.82	379.83	251.59	3.30	1.77	-0.169	0.191
	Observer 2								
	45 deg	373.57	252.72	373.20	252.46	0.53	0.50	0.260	0.086
	60 deg	376.85	252.27	377.27	252.21	0.55	0.42	0.288	0.065
	75 deg	376.01	252.20	376.04	252.11	0.37	0.30	-0.040	0.419
	90 deg	380.00	251.67	380.22	251.46	0.50	0.32	-0.191	0.160
	Observer 3								
	45 deg	371.77	252.91	379.52	251.49	7.79	4.10	-0.357	0.029
	60 deg	376.61	251.82	376.21	252.19	0.77	0.88	0.186	0.166
	75 deg	375.25	252.07	375.80	252.17	0.60	0.38	0.171	0.187
	90 deg	379.35	251.52	379.52	251.49	0.63	0.44	0.154	0.212
Coordinates in y-axis	*Observer 1*								
	45 deg [a]	226.53	187.73	227.03	187.26	0.95	0.78	-0.041	0.416
	60 deg [a]	228.33	187.58	228.47	183.41	0.81	0.60	-0.059	0.380
	75 deg [a]	227.30	187.40	227.62	188.00	0.85	0.68	0.121	0.266
	90 deg [a]	228.15	187.58	228.00	187.18	0.81	0.65	0.089	0.323
	Observer 2								
	45 deg [a]	226.34	186.79	226.49	187.74	0.51	0.35	0.121	0.266
	60 deg [a]	228.20	185.99	228.21	187.74	0.41	0.32	-0.238	0.107
	75 deg [a]	227.59	185.54	227.56	187.56	0.34	0.21	0.121	0.265
	90 deg [a]	227.63	187.54	227.19	187.90	0.83	0.48	-0.386	0.019
	Observer 3								
	45 deg [a]	226.59	187.78	227.84	187.45	1.28	0.90	-0.253	0.093
	60 deg [a]	228.15	187.58	228.44	187.39	0.64	0.56	-0.544	0.001
	75 deg [a]	226.98	187.28	227.10	187.50	0.40	0.38	-0.083	0.335
	90 deg [a]	227.48	187.79	227.84	187.49	0.77	0.50	0.016	0.468

[a] data square-root transformed to assess correlation after normality test failure

The systematic error (SE) produced by the different observers was evaluated via ANOVA [2 (Trial) x 4 (Perspective)]. On the x-axis, an interaction (Trial x Perspective) was observed for the three observers, with a main effect on Trial for observers 1 and 3 (Table 2). Post-hoc analyses showed that the coordinates recorded from a 45° perspective differed between attempts for all observers.

Intrarater analysis revealed significant differences between the two trials conducted by observer 1 from a 90° perspective and those conducted by observer 2 from a 60° perspective. The main effect found on Trial for observers 1 and 3 indicated differences between the attempts.

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On the y-axis, an interaction (Trial x Perspective) was recorded in the trials conducted by observers 2 and 3, and a main effect on Trial for observers 1 and 3. Post-hoc analyses revealed significant differences between trials for observers 2 and 3 from a 90° perspective, but only for observer 3 from a 45° perspective.

The trials conducted by observers 1 and 3 were overall significantly different, with the sizes of the effect of the different interactions and the simple effects moderate or large (Table 2).

Table 2. Two-way ANOVA RM comparing trials and perspectives conducted by the same observer

		F	df	p	η^2p	Power	Post-hoc
Coordinates in x-axis	*Observer 1*						
	Trial x Perspective	61.540	3.112	0.001	0.622	1.00	45°: T1 > T2; 90°: T1 < T2
	Perspective	0.003	3.112	1.000	0.000	0.05	-
	Trial	18.621	1.112	0.001	0.143	0.99	T1 > T2
	Observer 2						
	Trial x Perspective	9.474	3.112	0.001	0.202	1.00	45°: T1 >T2; 60°: T1 < T2
	Perspective	0.004	3.112	1.000	0.000	0.05	-
	Trial	0.925	1.112	0.338	0.008	0.16	-
	Observer 3						
	Trial x Perspective	87.859	3.112	0.001	0.702	1.00	45°: T1 < T2
	Perspective	0.002	3.112	1.000	0.000	0.05	-
	Trial	97.290	1.112	0.001	0.465	1.00	T1 < T2
Coordinates in y-axis	*Observer 1*						
	Trial x Perspective	1.996	3.112	0.119	0.051	0.50	-
	Perspective	0.000	3.112	1.000	0.000	0.05	-
	Trial	4.407	1.112	0.038	0.038	0.55	T1 < T2
	Observer 2						
	Trial x Perspective	4.788	3.112	0.004	0.114	0.89	90°: T1 > T2
	Perspective	0.000	3.112	1.000	0.000	0.05	-
	Trial	1.788	1.112	0.184	0.016	0.26	-
	Observer 3						
	Trial x Perspective	11.861	3.112	0.001	0.241	1.00	45°: T1 < T2; 90°: T1 < T2
	Perspective	0.000	3.112	1.000	0.000	0.05	-
	Trial	46.680	1.112	0.001	0.294	1.00	T1 < T2

The obtained relative reliability (ICC and CV) and absolute reliability (SEM and MDC) values are displayed in Table 3. Trials conducted from all perspectives by all observers presented very high values of ICC, indicating the reliability of the different observers. The ICC confidence interval (95%) of between 0.99 and 1 also provided greater data robustness.

Standardisation of errors based on CV (%) revealed considerable dispersion of values, especially on the y-axis. The differences found between trials when digitizing the same marker affected the CV mean for the same perspective. Values of absolute reliability (SEM and MDC) were low, being at or very close to 0 (Table 3), indicating low error for the different perspectives and observers.

Table 3. Inter-trial reliability of the three observers for each perspective

		Mean	SD	Typical Error	ICC (95%CI)	SEM	CV (95% CI)	MDC	MDC (%)
Coordinates in x-axis	*Observer 1*								
	45 deg	372.55	250.34	0.82	1.00 (1.00-1.00)	0.00	10.34 (10.05 - 10.65)	0.00	0.00
	60 deg	376.22	250.26	0.68	1.00 (1.00-1.00)	0.00	-6.21 (-6.46 - (-5.97)	0.00	0.00
	75 deg	375.19	249.77	0.47	1.00 (1.00-1.00)	0.00	NaN	0.00	0.00
	90 deg	378.22	249.5	2.36	1.00 (1.00-1.00)	0.00	-0.04 (-0.89 - (-0.82)	0.00	0.00
	Observer 2								
	45 deg	373.39	250.36	0.37	1.00 (1.00-1.00)	0.00	3.95 (3.81 - 4.08)	0.00	0.00
	60 deg	377.06	250.02	0.39	1.00 (1.00-1.00)	0.00	5.84 (5.70 - 5.99)	0.00	0.00
	75 deg	376.02	249.93	0.26	1.00 (1.00-1.00)	0.00	13.23 (13.14 - 13.32)	0.00	0.00
	90 deg	380.16	249.35	0.35	1.00 (1.00-1.00)	0.00	NaN	0.00	0.00
	Observer 3								
	45 deg	375.64	250.01	5.51	1.00 (1.00-1.00)	0.00	-15.68 (-17.68 - (-13.67)	0.00	0.00
	60 deg	376.41	249.79	0.54	1.00 (1.00-1.00)	0.00	-15.11 (-15.30 - (-14.91)	0.00	0.00
	75 deg	375.53	249.90	0.42	1.00 (1.00-1.00)	0.00	5.42 (5.27 - 5.58)	0.00	0.00
	90 deg	379.43	249.29	0.45	1.00 (1.00-1.00)	0.00	-8.25 (-8.41 - (-8.09)	0.00	0.00
Coordinates in y-axis	*Observer 1*								
	45 deg	226.78	185.84	0.67	1.00 (1.00-1.00)	0.00	7.57 (7.33 - 7.82)	0.00	0.00
	60 deg	228.40	185,72	0,57	1.00 (1.00-1.00)	0,00	-160.18 (-160.39 - (-159.98)	0,00	0,00
	75 deg	227,46	186,05	0,60	1.00	0,00	-149.87 (-150.09 -	0,00	0,00

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				(1.00-1.00)		(-149.65)		
90 deg	228,08	185,73	0,57	1.00 (1.00-1.00)	0,00	-0.40 (-0.60 - (-0.19))	0,00	0,00
Observer 2								
45 deg	226.41	186.11	0.36	1.00 (1.00-1.00)	0.00	138.83 (130.70 - 138.96)	0.00	0.00
60 deg	228.20	185.99	0.28	1.00 (1.00-1.00)	0.00	-47.50 (-47.61 - (-47.40)	0.00	0.00
75 deg	227.58	185.89	0.24	1.00 (1.00-1.00)	0.00	2.28 (2.19 -2.37)	0.00	0.00
90 deg	227.41	186.06	0.59	1.00 (1.00-1.00)	0.00	NaN	0.00	0.00
Observer 3								
45 deg	227.21	185.98	0.91	1.00 (1.00-1.00)	0.00	8.64 (8.63 - 8.97)	0.00	0.00
60 deg	228.29	185.83	0.54	1.00 (1.00-1.00)	0.00	-0.10 (-0.26 - 0.07)	0.00	0.00
75 deg	227.04	185.74	0.28	1.00 (1.00-1.00)	0.00	2.75 (2.65 - 2.85)	0.00	0.00
90 deg	227.67	185.98	0.54	1.00 (1.00-1.00)	0.00	2.90 (2.70 - 3.09)	0.00	0.00

In terms of data validity, Pearson coefficient values were very high regarding the correlation between observer and actual data (Table 4). The smallest typical error of the estimate (TEE) was always found for trials conducted from a 90° perspective, while the highest overall value was recorded from a 45° perspective. Nevertheless, the low TEE values demonstrate the overall validity of the data obtained using Kinovea.

Table 4. Correlation values among perspectives for each observer and for all observers pooled

		Observer 1			**Observer 2**			**Observer 3**			**Observers pooled**		
		r	p	TEE	r	p	TEE	r	p	TEE	r	p	TEE
Coordinates in x-axis	45 deg vs Real coordinates	1.00	0.001	3.671	1.00	0.001	3.595	1.00	0.001	1.979	1.00	0.001	3.043
	60 deg vs Real coordinates	1.00	0.001	1.637	1.00	0.001	1.751	1.00	0.001	1.608	1.00	0.001	1.626
	75 deg vs Real coordinates	1.00	0.001	2.25	1.00	0.001	2.020	1.00	0.001	2.242	1.00	0.001	2.157
	90 deg vs	1.00	0.001	1.182	1.00	0.001	1.145	1.00	0.001	1.083	1.00	0.001	1.042

	Real coordinates											
Coordinates in y-axis	45 deg vs Real coordinates	1.00	0.001	1.026	1.00	0.001	0.998	1.00	0.001	0.697	1.00	0.001	0.847
	60 deg vs Real coordinates	1.00	0.001	0.948	1.00	0.001	0.778	1.00	0.001	0.764	1.00	0.001	0.741
	75 deg vs Real coordinates	1.00	0.001	0.777	1.00	0.001	0.675	1.00	0.001	0.749	1.00	0.001	0.664
	90 deg vs Real coordinates	1.00	0.001	0.873	1.00	0.001	0.736	1.00	0.001	0.576	1.00	0.001	0.585

TEE= typical error of the estimate

3.2. Interpretation

The results of the reliability tests (SEM, MDC, ICC, and CV) support the precision of the protocol. SE values were small for both attempts and perspectives.

The validity assessment was then repeated, producing a result of ICC = 1. One reason for this is that SEM and MDC were calculated from ICC; these two measures are thus linked, which provides great reliability when expressed to two decimal places.

Data validity can be considered acceptable for all planes (perspectives), with a correlation value of 1 (ICC = 1) obtained for all three observers.

The digitized values of the 29 x-axis coordinates were used to calculate an average of the set of values obtained by means of ANOVA. Slight numerical differences in the values of the paired trials were detected, as well as in the mixture or combination of the attempts made from different perspectives by observer 1. However, no significant differences were recorded in TEE values.

In summary, the obtained statistics show that the numerical difference between attempts one and two were mathematically very small.

4. Discussion

As previously stated in the literature review, Kinovea is widely used for human motion analysis in both sports and clinical sciences. Furthermore, it has also been validated as a time measurement tool [10], and as such is used as a reference method with which to compare new technologies based on temporal space analysis. However, to the best of this author's knowledge, the present study is the first to assess the reliability and validity of Kinovea in measuring distances and angles from different perspectives based on a coordinate system.

Although there are other videographic analysis programs available, such as Dartfish, which has been used previously for scientific research [49, 50], the latter does not allow the correction of perspective and cannot be considered a 'low cost' tool, since it is not free as Kinovea is.

The present study has also paid special attention to the data digitisation protocol employed, which must be controlled so as to avoid potential biases when taking repeated measurements. We propose the use of black circular markers with a smaller white circle in the centre, in an attempt to increase the repeatability of this step, as well as a 600% zoom view to set the marker centres.

To assess the validity and reliability of Kinovea, an 800x555 mm geometric figure was constructed, with 29 points simulating a lower limb in different positions of the gait cycle. The figure was suspended and pushed to create a pendular movement, which was recorded with a video camera located at a distance of 5 m and using a 2.52x2.30 m recording area. Four frames were selected, one from each perspective, and digitized in Kinovea. Three observers each made two attempts to digitize the images into coordinates; these coordinates were then exported to a spreadsheet to be transformed into angles and distances.

The reliability of Kinovea coordinate digitisation has been assessed previously by other authors. The inter-intraobserver reliability found in the present study is slightly higher than that reported elsewhere, including the ICC value of >0.79 reported in [13], the ICC value of 0.997 obtained in [10], and the Kappa index value >0.80 reported in [15]. Furthermore, the Pearson correlation coefficients obtained in the present study indicate very high correlation between data.

The results show that Kinovea is reliable when measuring in the perspective range from 90° to 45° and at a 5 m distance from the registered object. However, the differences found between the four tested perspectives suggest that Kinovea is best employed at 90° rather than 45°.

Nevertheless, according to the reliability tests performed in this study (SEM, MDC, ICC and CV), Kinovea can be considered reliable when employed at any of the four perspectives analysed. In addition, SE values were small for both attempts and perspectives.

The validity tests confirmed that the obtained results are acceptable for all perspectives, with a correlation value of 1 (ICC = 1) recorded for all three observers. One possible explanation for this is that SEM and MDC were calculated from ICC; these measures are thus linked, which provides great reliability at two decimal places.

In fact, the measurement accuracy typically required from a clinical or sports science point of view is not as high as that reported in this paper; whereas all measurements were here made at the millimetre scale, in clinical practice an accuracy down to the centimetre may be assumed [40].

5. Conclusions and future work

The results of this study suggest that Kinovea is a valid, precise and reliable (both inter- and intrarater) program with which to obtain data from coordinates. Biomechanical measurements can be obtained under rigorous digitisation, suitable for use in the scientific, clinical and sporting fields.

In summary, Kinovea is a free, reliable tool that produces valid data, providing an acceptable level of accuracy in angular and linear measurements obtained via digitisation of x- and y-axis coordinates.

Future research should involve an assessment of the reliability and validity of Kinovea as a 2D tool for gait analysis, the use of a 3D system as a gold standard, as well as the development of a standard 2D laboratory set-up for clinical and sports science research.

Supplementary Materials: A summary of the procedure can be seen in the video accessed via the following link: https://drive.google.com/open?id=0BzhpXyL0tZoCdjBPbW5FelozVGc

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