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Automation of Measurements for Digital Posturography in a Standing Position: Software EPPA!

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Abstract. This paper introduces the development of the EPPA! Software, with its Spanish acronym, "Evaluación Posturográfica de Pie Automatizada," created using Matlab R2019a from Mathworks®.

EPPA! serves the following purposes:

a) To facilitate the objective evaluation of posture in a standing position through the standardization of 55 (fifty-five) variables (linear (±1 cm) and angular (±2°)), linked to anatomical indicators in digital posturographs in the standing position.
b) To provide access to intersegmental postural diagnoses based on regions, planes, and views, with respect to ideal reference lines and normality ranges.
c) To enable additional measurements of the evaluator's choice, beyond the standardized ones, tailored to the clinical case and the significance of specific anatomical regions or singularities of interest.

To validate the software, a comparison with the open-source software Kinovea © 0.9.5 was conducted using a pilot sample (n = 6) of older adult volunteers of both genders, who were referred for postural treatment due to diagnoses of orthopedic and/or traumatological musculoskeletal conditions. This study excluded individuals with neurological pathologies affecting motor control. The comparison was carried out by healthcare professionals with expertise in posturographic assessment. We found significant differences in the results of this comparison, with the Two One-Side Test (TOST) based on the normality of variable (linear and angular) in paired samples ($p < 0.05$).

Keywords: Human posture · Postural Evaluation · Posturography · Software design · Physical Therapy

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1 Introduction

1.1 Human Posture

According to the Posture Committee of the United States Academy of Surgery and Orthopaedics "posture is the refined skeletal alignment as a relative arrangement of body parts in a state of equilibrium that protects the supporting structures of the body against progressive injury or deformity" [1]. Posture is an important health indicator that contributes to:

1. The detection of a large number of disorders of the musculoskeletal system, generalised or regional pain syndromes, [2–5] the risk of falls and neck pain in older adults; [2, 6 –8]
2. the risk of musculoskeletal injuries in athletes, [9–12] or, alternatively, to their enhanced performance [13, 14]
3. ergonomic workstation design [15–17]

Posture, which result of genetics, height, weight, age, state of health, muscular conditioning [2, 14] and habits adopted throughout life, changes especially in stages of growth and development. In some cases, it is even associated with the pain that brings the patient to the physician's consultation [18–20].

From a biomechanical perspective, posture is "the positioning of one or more joints, maintained for a more or less prolonged period of time, by various means, with the possibility of re-establishing in time the most perfect physiological attitude", which is defined as that associated with the optimal posture for every individual, achieved with the minimum energy consumption [21]. In the human species, the upright standing posture corresponds to the position with the lowest energy expenditure [22, 23] and involves the entire muscular and osteoarticular system [24].

Postural stability is the ability to control the body's centre of mass in relation to the base of support. When disturbed, it could represent a major problem that could also involve consequences for the person's balance and stability [25]. Therefore, posture is related as an issue that affects the whole system and the surrounding environment, the position of the trunk relative to that of the limbs, and both as a whole in space [26]. The impairment of posture leads to aesthetic problems, pain syndromes and/or different degrees of disability [11, 27].

The definition of posture can be approached from different disciplinary areas. Therefore, its assessment and treatment may involve multi-trans and interdisciplinary viewpoints due to the multifactorial and individual nature of the variables involved [28, 29]

29] Multiple perspectives are possible, depending on the aspects that are considered relevant (environmental, socio-cultural, religious, psychological, affective-emotional, occupational, political, biological, neurological, biomechanical or physical).

In recent decades, various conceptual lines have proposed different therapies. The most relevant ones come from: a) global approaches to postural re-education, derived from mezierist concepts [27, 30, 31, 32, 33] and, b) clinical posturology [34–36]. They all involve different disciplines (kinesiology, physiotherapy or physical therapy, sports therapy, occupational therapy, orthopaedics and traumatology, neurology, neuro-orthopaedics, respiratory physiotherapy) [37] aimed at all levels of health care (prevention, re-education and/or rehabilitation), throughout the evolutionary stages.

1.2 Postural Assessment

Health professionals use postural assessment as part of the physical examination in daily clinical practice. In several countries of the world, postural assessment is one of the standardised examinations for admission to state or private institutions for children, athletes or workers. In our country the development of therapeutic methodologies that address the postural problem of people presents a growing development.

Even though there is broad consensus on the importance of postural assessment amongst health professionals, no agreement has been established on the evaluation and treatment of disorders related to postural control (indicators, procedures and optimal measurement methodology).

Different types of postural assessment have been reported: [13–38] visual observation [9], plumb-line method [11], goniometry, inclinometers and videos; photographic and digitisation method [39]; 3D analysis with reconstruction from retro-flective markers [40], radiographic method and 3D reconstruction by Rx [41], photogrammetric method [13], with use of optical sensors; Moire topography [42], biomechanical models using mathematical algorithms[43] based on theories of consistent approximations by Schwartz and Polak (1996), methods using force platform [44–46]; surface EMG [47]. There are different softwares validated by comparison with visual, goniometric and radiographic methods [48].

Although “clinical is sovereign”, visual inspection has been shown to be dependent on the experience of the assessor. It is subjective, qualitative, with relative specificity, sensitivity and reliability of the indicators used [39]. Qualitative diagnoses obtained by observational processes require standardised and validated instruments that provide quantitative data [2], with the greatest sensitivity, precision, systematisation and objectification in postural assessments. Therefore, visual observation is not sufficient and adequate for the assessment of posture, compared to the use of more objective methodologies such as clinical photography, photogrammetry or posturography [48–52].

The radiographic method concentrates on bone alignment and does not take into account the state of the rest of the structures of the musculoskeletal system. Although it provides local precision, when performed regionally, it presents variability in the taking of radiographic plates, is costly, harmful to health (ionising radiation), and not very sensitive to early postural alterations (minimal deviations) that present radiological evidence in more advanced stages.

The photogrammetric method combines the photographic method with the process of digitalising the images. The images are taken in the frontal and sagittal planes, with previous spatial references, providing quantifiable, reproducible and reliable data. The appropriate normalisation and standardisation of photogrammetry [53] allows reliable information to be obtained in the field of health.

All of the above leads to the need to add systematic procedures for the acquisition of quantitative data that allow objectification and precision [2–38] on what is considered to achieve postural “improvement”.

Digital posturography (or clinical photography) is used manually by many healthcare professionals by using of image processors for the acquisition of distances between anatomical points and angles [54]. Kinovea © (free and open access software) is one of the most widely used [56, 57].

There is a wide range of software is available for postural assessment, including: All-bodyscan 3D, AlCimagem2000, Aplob, Appid, AutoCAD, BioPrint Biotonix [58], Corel Draw, Corporispro, DIPA: Digital Imaged-based Postural Assessment [20], Fisimetrix, ImageJ software, MATLAB, PAS/SAPo, Peak Motus motion analysis system, Physical physio, Physio easy, Posture print, Posturogram Fisiometer, OCRA: Occupational Repetitive Methods Checklist and RULA: Rapid Upper Limb Assessment [16], REBA: Rapid Whole Body Assessment and OWAS: Ovako Working Posture Analysis System [15]. In particular Alcimage and PAS/SAPo, have more inter and intra-examiner validation and comparison work with favourable results [2–52].

The papers can be grouped according to the body region assessed: cervical and shoulders [18], arm and trunk [17], spine [51], head, neck, shoulders and thorax [48], whole body [15–38], worker postures [16], or different variable postures. [20].

In addition to the variability of the populations and samples (schoolchildren, adolescents, adults and older adults), of the measurements and correlations established between different postural alignments in subjects with pain, with different lifestyles, radiological images, ranges of movement, it is impossible to carry out a meta-analysis to draw conclusions integrating all the studies.

Among the free (open source) software, the most widely used is Kinovea ©, which has achieved reliability, accuracy and validity of the results processing data on posture assessment [57]. In this work, it is used as a reference method for comparison with the software developed by EPPA! [56].

The advantages of the photogrammetric method could be summarised in that it is not exposed to harmful radiation, provides reliable, objective and reproducible data that might be stored and analysed at a later stage.

However, some disadvantages also have to be taken into account, such as the wide variety of available software, the fact that there is no standardisation of protocols, the difficulty of clinical follow-up, and the diversity of research criteria and lack of data in the field of collective health.

Notwithstanding the amount of research and software, the authors consulted continue to recommend further studies to determine methodology, imaging, measurements and greater inter and intra-examiner reliability [52–59].

Due the diversity of concepts about human posture, the individual character, the multifactorial and interdependent aspects involved in its alterations, it is necessary to consider complex interrelated variables for its approach [60].

The aim of the present work was to develop a software called EPPA! using Matlab R2019a [61] that allows:

a) automate postural measurements from digital posturographic processing,
b) access to intersegmental postural diagnostics by regions, planes and views, with respect to approximation with reference lines and normality ranges.

c) to provide freedom to the operator to mark additional parameters to the standardised points, lines and angles, according to the clinical case and the relevance of some region or anatomical singularity, to be deepened.

To analyse the performance of EPPA! software, the diagnostics and automatic measurements obtained with EPPA! were compared with the manual measurement methodology using the aforementioned Kinovea © software.

2 Materials and Methodology

2.1 Design and Objectives

The methodological design for the development of EPPA! was approached in two stages. The first stage was destined to:

a) The bibliographic review of: a) posture assessment protocols, b) clinical photographs, c) validation of indicators, d) digital posturography with (software that presented different degrees of automation, whether free or commercial access).
b) Development of software for the automation of digital posturography measurements and experimental implementation in a reference case (definitions of calculations, measurement processes, image capture and data export).
c) Application of the EPPA! software to a pilot sample and comparison of measurements obtained with the manual measurement procedure using the Kinovea © software, by the same expert evaluator.
d) Statistical treatment (paired samples and analysis of linear and angular variables) in the different posturographic views.

The specific objectives of this period were as follows:

1- To systematise and objectify the postural assessment through the marking of valid, reliable, sensitive and specific indicators (points, lines and angles), in the three dimensions of space, of the person in a standing position.
2- To standardise the taking of digital posturography in the standing position in order to automate the recording of the parameters evaluated (distances and/or angles with respect to the reference lines).
3- Develop the software: equations, calculations of linear and angular variables, comparison with vertical and horizontal references, generate tables for exporting data and analysed images. -Provide additional customised measurement options.
4- Quantify the measurements taken and interpret the results of the alterations and alignments detected.
5- Analyse the performance of the system, applying it to different subjects with the same expert evaluator.
6- Carry out the corresponding intra-evaluator-inter-subject validation statistics.
7- To compare the measurements obtained with the software under study and the method used with manual measurements.

The objectives of the second stage were as follows:

1. To train evaluator-researchers in the procedures for indicator location, standardised photographic shots and use of the EPPA! software.
2. To supervise the evaluation of each researcher using the software during the measurement of a new sample of evaluated persons.
3. Analyse the performance of the system inter and intra -raters, comparing inter and intra-subject measurements.
4. Validate the sensitivity, specificity, reliability and diagnostic consistency of the software with statistical methods.

2.2 Instruments and Procedures

In order to achieve systematisation, objectification and reproducibility throughout the process, the standardisation of the following procedures was taken into account:

Photographic: The professional camera used was Casio, model EX-FH25 (12Mpx), on a fixed tripod, with 3D calibration [2–62]. The distance from the camera lens to the subject was 3 m, according to the average distance (2.70 m $\pm$ 0.54 m) recommended by Petruccio et al. 2020. The height of the camera, from the ground, was in the range (01 m $\pm$ 0.21 m) corresponding to the height of the subject's navel, to minimise distortion due to perspective [48–51].

Digitisation of Images: The characteristics of the digital images were: 1600 (vertical) $\times$ 1200 pixels (horizontal), 72 dpi (horizontal and vertical), 24bpp, RGB colour model, the clinical photographs followed ethical protocols, in terms of respecting the intimacy and dignity of the patient; protecting the confidentiality of the data in the clinical history, anonymising or masking the face to guarantee patient privacy [63].

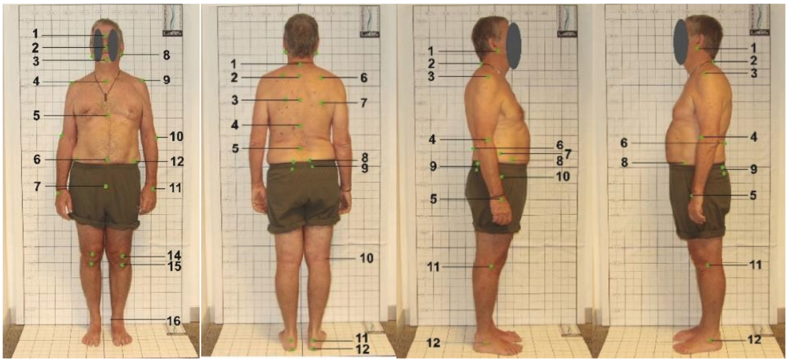
Environment: Privacy, comfortable temperature and adequate lighting for photography.

Clothing: Close-fitting clothing that allows optimal visibility of the body.

Reference grid: white background panel with a grid of 0.10 m on each side, 2 m high and 1 m wide, extending into the support base.

Reference Posture: Standing position with arms at the sides, gaze straight ahead, feet parallel to each side of the middle reference line. Due to the variability between subjects and to allow for reproducibility during the personalised monitoring of the assessments, the feet were separated until, at least, two points of contact were achieved on the medial side of both lower limbs (upper thighs, medial condyles of the knees, closest point between the two gastrocnemius muscles, medial side of the tibial malleoli, medial edge of the foot) [31].

Anatomical Indicators (AI): The localisation of the anatomical points by means of palpatory, surface, projective and topographic anatomy was carried out by health professionals, experts in this technique (previously trained and qualified). Adhesive circular markers of 1 cm in diameter and green in colour were applied to the body surface of the subject under study. The centre of the marker is associated with the AI reported in the literature [2, 9, 11, 31, 36, 38, 64–74]. The location of the AIs is shown in Fig. 1 and the corresponding references in Table 1.



a) Anterior *b) Posterior* *c) Right profile* *d) Left profile*

Fig. 1. Location of the AI by views

Table 1. References corresponding to the AI, according to each view

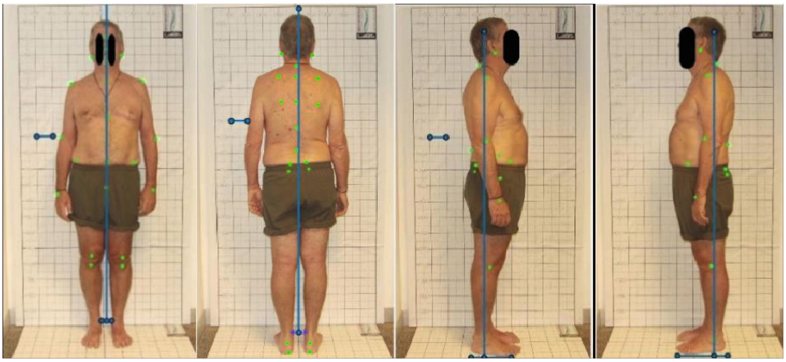
Front View	Posterior view	Profile view
1. Frontal eminence or glabella	1. Apex spinous C7	1. Earlobe (trago)
2. Anterior nasal spine	2. Apex spinous T3	2. Apex cervical curve
3. Mental protuberance	3. Apex spinous T7	3. Acromion lateral point
4. Suprasternal notch	4. Apex spinous T12	4. Elbow lateral epicondyle
5. Xiphoid process	5. Apex spinous L5	5. Third metacarpal base
6. Umbilicus	6. Junction point between spine sapulae and scapula medial border	6. Apex lumbar curve
7. Public symphysis	7. Scapular inferior angle	7. Iliac tubercle (hightest point of iliac rest)
8. Earlobe (trago)	8. Posterior superior iliac spine (PSIS)	8. Anterior superior iliac spine (ASIS)
9. Acromion lateral point	9. Posterior inferior iliac spine (PIIS) - 2 cm below PSIS	9. Posterior superior iliac spin (PSIS)
10. Elbow lateral epicondyle	10. Popliteal crease line (junction of lateral and medial condyle femur)	10. Greater trochanter (superior edge)
11. Third metacarpal base (III MtC base)	11. Achilles tendon insertion on calcaneal tuberosity	11. Lateral condyle femur
12. Anterior superior iliac spine (ASIS)	12. Calcaneus posterior aspect center	12. Fibular malleolus (anterior edge)

(*continued*)

Table 1. (*continued*)

Front View	Posterior view	Profile view
14. Patella center point		
15. Anterior tibial tubercle (TAT)		
16. Tibial malleoulus		

Reference Lines: The reference vertical line (RVL), perpendicular to the ground, in the anterior and posterior views, was defined as the straight line passing through the equidistant point between the vertices of the tibial malleolus. In the sagittal view (for both profiles) the vertical was drawn from the anterior edge of the fibular malleolus. The reference horizontal lines (RHL) were drawn parallel to the horizontal lines of the reference grid (parallel to the support surface) [23] (Fig. 2).



a) Anterior *b) Posterior* *c) Right profile* *d) Left profile*

Fig. 2. Grid calibration and automated marking of RVL in the four views

Direct Linear and Angular Measurements: Linear and angular measurements allow information on posture to be obtained and, by comparison, to record changes throughout the treatment process [13]. They refer to: - the distance (cm) between the reference points (AI) and the RVL or RHL; - the angles formed by the direction of the segment determined by two AIs and the RVL or RHL, as appropriate. The assignment of positive (+) or negative (-) signs follows the convention of O'Brien, Kuklo, Blanke, Lenke 2008. Direct magnitudes, per region and per reference plane, were assigned the value "0" when the deviation was less than 1 cm, or 2°, respectively, from the normal or neutral alignment. Some variables are composed of more than one measurement.

The definition of the variables from the linear and angular measurements, according to regions and views, are described in Tables 2, 3, 4.

Qualitative Postural Diagnostics (QPD): The integration of the set of magnitudes or angular and linear variables of the 4 views allows us to get different postural diagnoses by region and by plane (see last column of Tables 2, 3, 4). For this purpose, the data matrix of the variable "standing posture" was organised according to the intersegmental relationships of the four anatomical regions: (I) cervico-cephalic, (II) spine and trunk, (III) shoulder girdle and upper limbs, (IV) pelvic girdle and lower limbs. The degree of symmetry in the bilateral variables was also compared [59, 60].

2.3 Software Development

The MATLAB R2019a Graphical User Interface Development Environment (GUIDE) (mathworks.com/products/matlab.html) was used to develop the EPPA! software, implementing each window of the software as a user interface with buttons with their respective functions and specific menus for each view.

AI Capture Interface. An interface was developed to capture the coordinates (x-y) of the AIs and export the dataset as a matrix which was then used for the calculation of the different posturography parameters corresponding to the different views (anterior, posterior, left profile and right profile). Figure 3 shows the indicators acquired by the software in the four views.

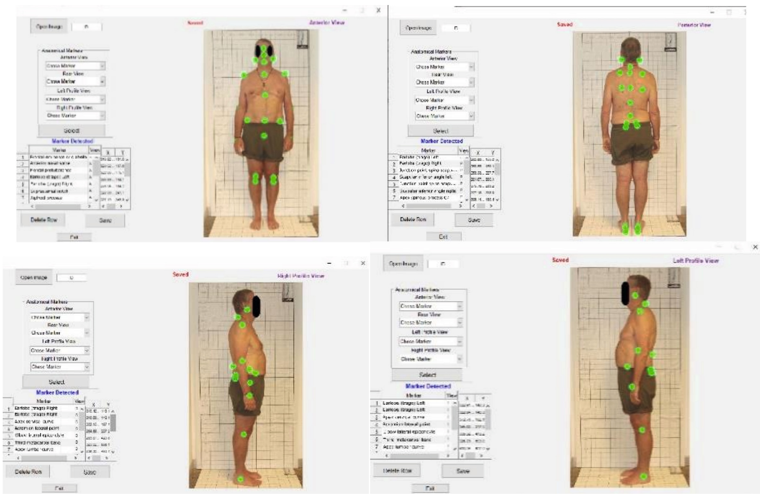


Fig. 3. EPPA! software screen with point capture in anterior, posterior and profile views.

Programming of the General Equations for All Views. Each view was developed using the principles of in-plane photogrammetry for the calculation of Euclidean distances between an AI and the RVL or RHL. The scale factor was taken in reference to the side of the grid: 10/Dpix (Dpix distance in pixels).

The angles were determined from the scalar product between the direction determined by the segment of interest, bounded by two AIs and the RHL or RVL, as appropriate. The intersection of the two lines corresponds to the highest indicator if the segment is horizontal and to the lowest indicator if the segment is vertical.

Programming Controls Common to All Views. The development of the screens for each view began with the implementation of the controls common to all of them: a) open image (uigetfile and imread command to access the image as a matrix), b) import markers, (the same command as "open image" to open the file, and access to the data with the load command); c) clean image, (eliminates all the measurements taken and leaves the image with only the reference lines drawn thanks to the imread command), d) exit, (close command to close the user interface).

The calculations of each view were defined by regions in order to achieve a better order of the data for their visualisation, export and subsequent analysis of the qualitative-quantitative diagnostics.

The presentation of the data was made in the form of a table with the following columns: Region, Variable, Measurement and Diagnosis. The menu was programmed so that the table can be exported to an Excel spreadsheet. Each view is presented in different spreadsheets, in the same file, for each subject.

Programming the Calculations for the Variables for Each View and Region. The next stage of programming was divided by each view according to the order: anterior, posterior, right and left profile The programming of the calculations is common to all views, but with the signs inverted according to convention.

For the anterior and posterior views, the reference lines were programmed by calculating the midpoint of the distance between the two tibial malleoli and tracing the RVL from that point, perpendicular to the RHL to the top of the image. In the lateral views, the functions zoom in the image, take points in coordinates and draw straight lines between two points on the floor grid, for the RHL. The RVL was drawn automatically in a direction normal to the RHL and crossing the fibular malleolus point.

The capture of the tangent lines to the occipital, dorsum and sacrum points was programmed. The zoom and coordinate point acquisition functions were used to automatically plot the line passing through the captured point and parallel to the RVL.

In all posturography measurements, if a parameter cannot be calculated because one of the AIs is hidden, "point not visible" is reported in the diagnostic column.

The calculations of the posturographic variables by regions of the anterior, posterior and profile views are presented in Table 2, 3 and 4, respectively.

Programming of Manual Measurements of the Evaluator's Choice. The possibility to include measurements outside those of the standard posturography is available in the "Manual Measurements" menu of each view.

The programming has a blank space for editing text and entering the name of the manual measurement to be performed. Three additional buttons have been incorporated for: measuring distances, angles to horizontal and angles to vertical, respectively (Fig. 4).

Data Export and Image Capture. Once the complete programming of the measurements in each view, including the additional manual measurements, was completed, the data from the interface display table was programmed to be exported to an Excel file.

Table 2. Frontal plane - Anterior view: AI - Linear and angular variables - QPD

Regions	Al	Linear and Angular Variables	Qualitative Postural Diagnostics
I	Frontal eminence or glabella Anterior nasal spine Mental protuberance	**Cephalic Rotation** Al to RVL Correspondence or Al to RVL Distance	Neutral cephalic alignment Rotation right (+) Rotation left (−)
	Earlobe (trago)	**Cephalic tilt** Angle at highest point-Straight Al with RHL	Neutral cephalic tilt Right titt (+) Left tilt (−)
II	Suprasternal notch Xiphoid process Umbilicus Pubic symphysis	**Truncal tilt** Angle at lowest point-Straight Al With RVL	Trunk alignment coronal balance neutral Unbalance right (+) Unbalance left (−)
	Suprasternal notch Xiphoid process Umbilicus Pubic symphysis	**Trunk Rotation** Al to WL correspondence or Al to RVL distance	Trunk rotation neutral Right rotation (+) eft rotation (−)
III	Acromion lateral point	**Shoulders Tilt** Angle Of vertex at highest point - Bilateral Al Straight with RHL	Shoulder alignment neutral Tilt right (+) Tilt left (−)
IV	ASIS	**Pelvic tilt** Vertex angle at highest point Bilateral Al Straight with RHL	Neutral pelvis alignment Pelvic tilt right (+) Pelvic tilt left (-)
	Medial condyle femur Closest point between both gastrocnemius muscles Tlbial malleolus	**Alignment Knee** Distance between each IA homologue	Normal knee alignment-Condyle-gastrocnemius-malleolus distances ≤ 1 Genu varus-Condyles-gastrocnemius distance > to malleolus distance Genu valgus-Malleolus distance > to condyles-gastrocnemius distance
	ASIS Patella center point TAT	**Angie Q knee** Angle vertex centre patella and straight lines to ASIS and TAT	Normal 15° > increased angle < decreased angle

Table 3. Frontal plane - Posterior view: AI - Linear and angular variables - QPD

Regions	AI	Linear and Angular Variables	Qualitative Postural Diagnostics
I	Earlobe (trago)	**Cephalic tilt** Angle at highest point-Straight Al with RHL	Neutral cephalic tilt Right tilt (+) Left tilt (-)
II	Apex spinous process C7 Apex spinous process T3 Apex spinous process T7 Apex spinous process T12 Apex spinous process L5	**Trunk tilt** Angle at highest point-Straight Al with RHL	Coronal balance neutral Unbalance right (+) Unbalance left (-)
III	Junction point between spine scapulae and scapula medial border Scapular inferior angle	**Scapular Alignment** AI distances with RVL bilateral comparative homologous points	Symmetrical distances upper/lower Normal = Lower 1 cm > upper Asymmetric distances upper/lower
IV	PSIS	**Pelvic tilt** Angle of vertex at highest point - Bilateral AI line with RHL	Neutral pelvis alignment Pelvic tilt right (+) Pelvic tilt left (-)
	Popliteal line midpointAchilles tendon insertion on calcaneal tuberosity Calcaneus posterior aspect center	**Calcaneal angle** Angle vertex at Achilles insertion point and straight lines to midpoint of popliteal lines and centre of posterior aspect of calcaneus	Calcaneus neutral alignment = 180° Angle (+) open to lateral Calcaneus valgus = pronated Angle (-) open medial Calcaneus varus = supinated

For this step, the xlswrite command was used, which generates a new file if it doesnot exist, with a name that includes the patient ID, and a spreadsheet for each view. An interface button was included to capture the image and save records of all measurements.

2.4 Comparison Between Automated Measurement Software EPPA! and Manual Measurements from the Most Widely Used Free

In order to contrast the results obtained with EPPA!, comparisons were made, in a pilot sample with the free software (Kinovea © 0.9.5). This software is the most widespread and widely used in the field of kinesiology, physical therapy, sports medicine and other areas that evaluate posture in daily clinical practice [56].

The sequence of the process, once the circular markers were applied to the anatomical landmarks and the standardised digital photograph was taken, the automated steps are

Table 4. Sagittal plane - Profile view: AI - Linear and angular variables – QPD

Regions	AI	Linear and Angular Variables	Qualitative Postural Diagnostics
I	Earlobe (trago)	**Alignment Cephalic** Correspondence with Sagittal WL (distance to RVL)	Sagittal cephalic alignment Head antepulsion (+) Head retropulsion (-)
	Vertical Tangent Occipital Vertical Tangent Dorsum	**Alignment Cephalic** Tangents aligned Occipital tangent to tangent Dorsum	Sagittal cephalic alignment Head antepulsion (+) Head retropulsion (-)
	Cervical curve apex	**Cervical lordosis** Distance to dorsum tangent	Normal cervical lordosis 3–6 cm >increased lordosis <decreased lordosis
II	Vertical Tangent Dorsum Vertical Tangent Sacrum	**Alignment Trunk** Tangents aligned Dorsum tangent to Sacrum tangent	Sagittal trunk alignment Anterior sagittal imbalance (+) Posterior sagittal imbalance (-)
	Lumbar curve apex	**Lumbar lordosis** Distance to sacral tangent	Normal lumbar lordosis 3–6 cm > increased lordosis < decreased lordosis
III	Acromion lateral point	**Shoulder Alignment** Al to RVL Correspondence or Al to RVL Distance	Sagittal alignment Shoulder Shoulder protraction (+) Shoulder retraction (-)
	Lateral acromion point Elbow lateral epicondyle III MtC base	**Elbow angle** Epicondyle vertex angle and straight lines to AI	Normal alignment Elbow 170°–180° Elbow flexion < 170°
IV	ASIS PSIS	**Pelvic sagittal tilt** Vertex angle at highest point - Straight line Al with RHL	Neutral Pelvic sagittal tilt Anterior Pelvic tilt (+) Posterior pelvic tilt (-)

(*continued*)

Table 4. (*continued*)

Regions	AI	Linear and Angular Variables	Qualitative Postural Diagnostics
	Iliac tubercle Greater trochanter	**Pelvis translation** AI to Sagittal RVL correspondence or AI to RVL distance	Neutral pelvic translation Pelvic antepulsion (+) Pelvic Retropulsion (-)
	Lateral condyle femur	**Knee Alignment** AI to sagittal RVL Correspondence or AI to RVL Distance	Sagittal knee alignment normal Genu flexus (+) AI in front of RVL Genu recurvatum (-)AI behind RVL
	Lateral condyle femur Lateral malleolus	**Tibia-foot angle** Malleolus vertex angle and straight lines to AI and RHL	Normal 90° > 90° ankle in extension < 90° ankle in flexion

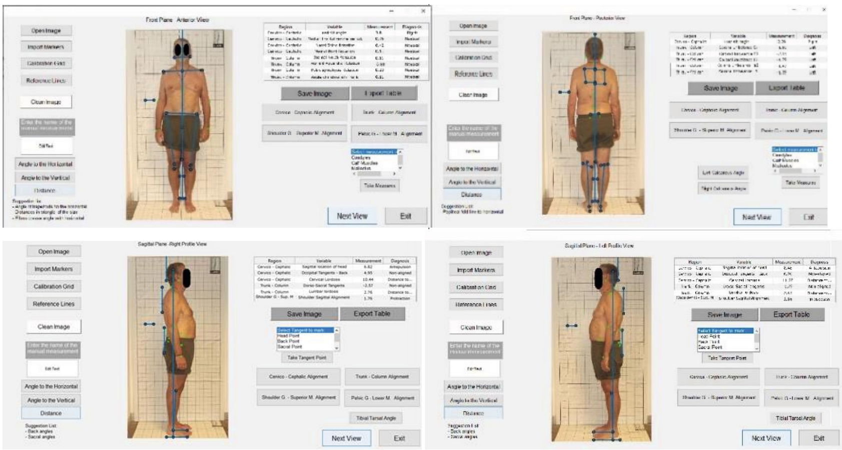


Fig. 4. Screenshot of the software with full measurements by views.

presented on the left of Table 5. For comparison with the measurements performed manually using open access software, Kinovea © 0.9.5, similar procedures were applied to the same posturographs of the aforementioned sample. The steps are presented in the right column of Table 5. For the comparison between both methods of measurements (manual and automated) the parameters of the same sample were standardised to the height of the subjects.

All variable measurements were transferred to Excel spreadsheets for statistical processing.

Table 5. Steps to compare the automatic procedure with the manual procedure.

EPPA! Steps	Kinovea @ 0.9.5 steps
Open Image in software	Calibrate photo with background grid (verticals and horizontals)
Grid calibration (pixel - cm equivalence)	Plotting coronal and sagittal reference verticals
Importing the markers	In sagittal views, in addition, draw the tangents: occipital, dorsum,sacrum
Marking die reference line and tangents	Calibrate distance 10 cm with 1 grid square background
Automatic execution of measurements per region, calculation of values, diagnostics and tables	Enlargement of images in each region and view, to pinpoint points to be measured
Capture the image with the measurements	Mark points, lines and angles of each of the variables (distances and angles) placing the cursor in the centre of the circle (AI) or midpoint of the thickness of the line, to register the measurement with the tools offered by Kinovea @
Data export in Excel tables	Capture Image and pass the data manually into the spreadsheet

The posturographies were performed in the framework of the UBACyT Project (2017–2019) Cod. 20620160100004BA, at LABIS- UCA, in 2018.

Table 6. Pilot sample population.

Average age (years)	71.33		68–79
Gender	Women = 4		Men = 2
Systematic physical activity	Yes = 3		NO = 3
History of falls	Yes = 3		NO = 3
Clinical pathology/s last year	HBP = 3		Diabetes = 1 COPD = 1
Trauma pathology/s in the last year (+ of 1 pathology subject)	Cervical pain = 4	Scoliosis = 2	Hip replacement = 1
	Lumbar pain = 4	HyperKyphosis = 2	Recurrent Patellar Dislocation = 1

The sample consisted of 6 (six) older adult subjects, volunteers of both sexes, aged over 65 years, referred for postural treatment for diagnoses of orthopaedic and/or traumatological musculoskeletal disorders, excluding neurological pathologies affecting motor control (See Table 6). All subjects gave their consent to perform the protocols designed.

2.5 Statistical Analysis

For the comparison of both methods, the TOST test (Two One-Side Test) was used, based on the normality of the variables (linear and angular). The pre-established maximum value (d) was 1 cm, and the p-value < 0.05. Since both methodologies were applied to each individual, with equal procedures and indicators, performed by the same evaluator, they were considered paired samples.

3 Results

Figure 5 shows the result of the automated processing with the EPPA! software of the four views of them six subjects of the pilot sample, and Fig. 6 shows some of the measurements made with the Kinovea ©.

From the measurements presented in Tables 2, 3, 4, 55 (fifty-five) variables were compared, between the four views:

– in anterior view 15 (fifteen) variables: 9 (nine) linear and 6 (six) angular;
– n posterior view 16 (sixteen) variables: 12 (twelve) linear and 4 (four) angular;
– in both profile views - right and left-, 12 (twelve) variables (each): 9 (nine) linear and 3 (three) angular.

The hypothesis of equivalence was tested at a significance level of 5% (p-value $<$ 0.05). From the comparison of the linear variables, equivalences were observed in all the variables in the anterior view, posterior and both profiles, and only one variable (lumbar lordosis) in one profile was not significant. As for the angular variables, the hypothesis of equivalence was proved for all angle measurement variables. Equivalence was only absent for one calcaneal angle, in posterior view, and the Q angles of both knees, in front view. Figures 7, 8, 9, 10 and 11 present the comparisons for anterior, posterior and profile views, grouped by linear and angular variables, respectively.

All distance and angle variables, in the anterior view, were significant with p-value $<$ 0.05. Only the variables, region IV corresponding to Right Q-Angle (p-value = 0.1801) and Left Q-Angle (p-value = 0.0667), were non-significant.

All distance variables in the posterior view were significant (p-value < 0.05). In region IV, only the angular variable corresponding to the Right Calcaneal Angle (p-value = 0.7834) was not significant.

Among all the distance and angle variables analysed in both profiles, only one of the nine variables was not significant (p-value < 0.05) in the right profile, in region II, the "lumbar lordosis" variable with a p-value = 0.1249.

The rest of the distance and angle variables in both profiles were significant (p-value < 0.05).

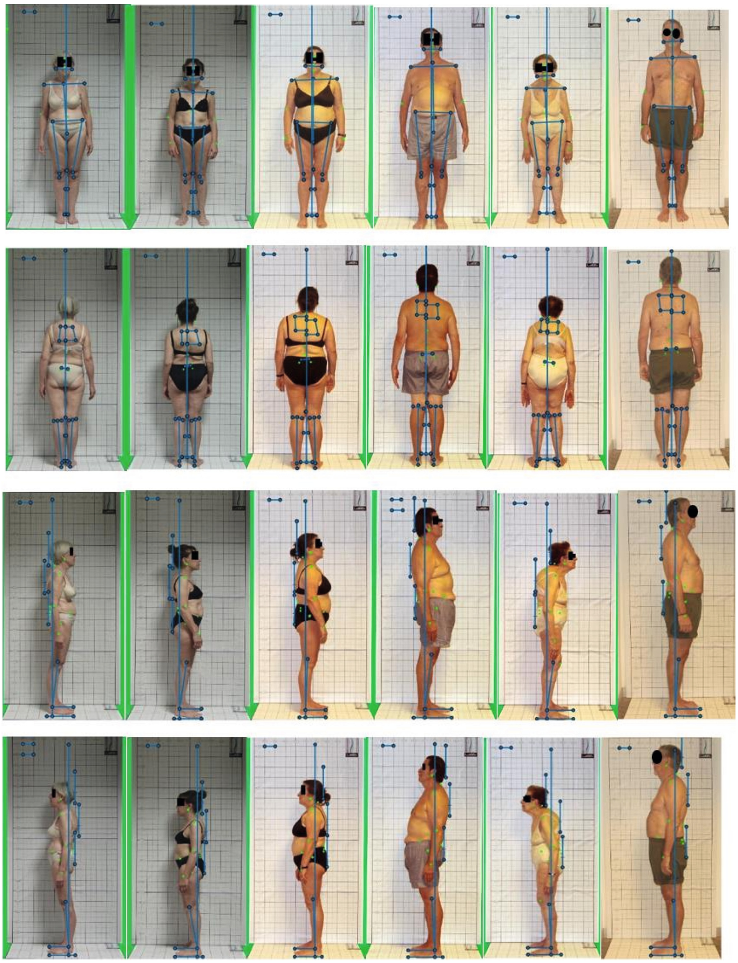


Fig. 5. Automated processing applying EPPA! Software.

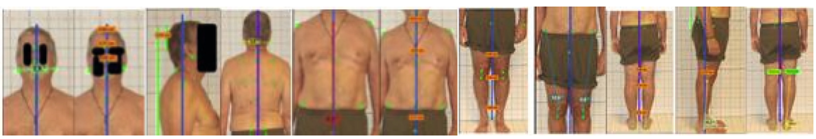


Fig. 6. Measurements with Kinovea © software

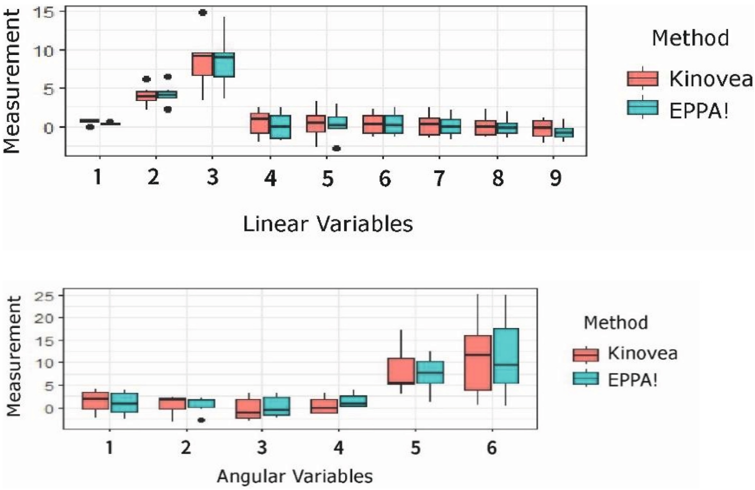


Fig. 7. Comparison of the measurements between the results of the anterior view: a) linear variables: 1- condyle distance; 2- Gastrocnemius distance; 3- Malleolus distance; 4- Xiphoid process rotation; 5- Frontal eminence rotation; 6- Suprasternal notch rotation; 7- Ante- rior Nasal spine rotation; 8- Mental protuberance point rotation; 9- Pubic symphysis rotation. b) Angular variables: 1- Cephalic Tilt Angle; 2- Shoulder Tilt Angle; 3- Pelvis Tilt Angle; 4- Trunk Tilt Angle; 5- Right Q- Angle; 6- Left Q- Angle.

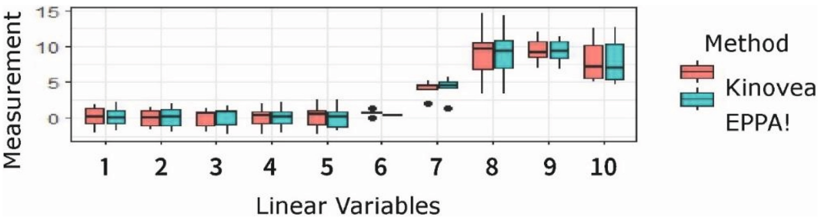


Fig. 8. Comparison of the measurements between the results of the posterior view: a) linear variables: 1-Trunk tilt- C7 coronal unbalance; 2- Trunk tilt-L5 coronal unbalance; 3- Trunk tilt-T12 coronal unbalance; 4- Trunk tilt-T3 coronal unbalance; 5- Trunk tilt-T7 coronal unbalance; 6- Condyle distance; 7- Gastrocnemius distance; 8- Malleolus distance; 9- Right Internal point scapula spine; 10- Left Internal point scapula spine.

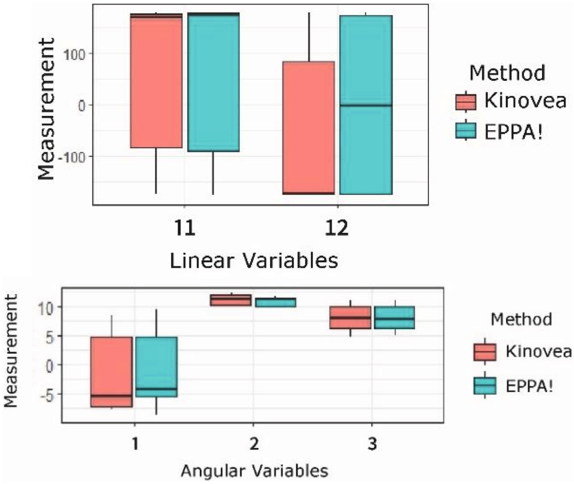


Fig. 9. Comparison of the measurements between the results of the posterior view: b) 11- Scapular Inferior angle Right; 12- Scapular Inferior angle Left. c) Angular variables: 1- Right Calcaneal Angle; 2- Left Calcaneal Angle; 3- Pelvic Tilt Angle.

4 Discussion

Owing to the fact that the human posture is individual, it is not possible to determine a standard or normal posture (in terms of measures of central tendency in statistics) [28], but rather that which, compared with the ideal posture, has the smallest deviations and involves the least energy expenditure [21].

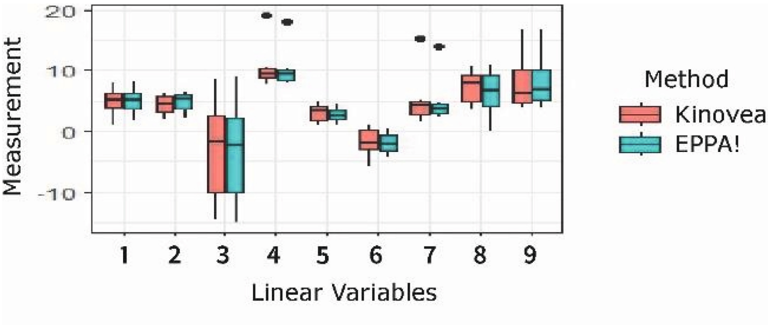
In carrying out this work, aspects related to the location of the markers, the selection of which are the most sensitive and specific, and the verbal instructions given to the subject at the moment of the 4 photographs can be discussed.

In our case (model of reaction forces from the floor), the patient is given clear and standardised instructions regarding the position of the feet on the support plate and in front of the grid, so that this position is repeatable and progress in the treatment can be measured quantitatively and objectively, respecting the variability in the base of support as explained in Sect. 2.2.)

In this aspect, there are works that do not take this variability into account and state that subjects should maintain a comfortable posture and should not be forced into a "correct" posture as this would lead to a distortion in the results of the assessment. It is evident that this procedure is of doubtful reproducibility over time and makes it impossible to compare with other related studies.

Some studies that use whole-body photogrammetry [2], by not specifying instructions for the standing position of the subjects, mean that the support base could be very wide. This could lead to minimising compensations or postural alterations and thus lose diagnostic sensitivity.

The success of the methodology (precision, sensitivity, accuracy, specificity, diagnostic consistency) depends on the expertise of the examiner responsible for the correct



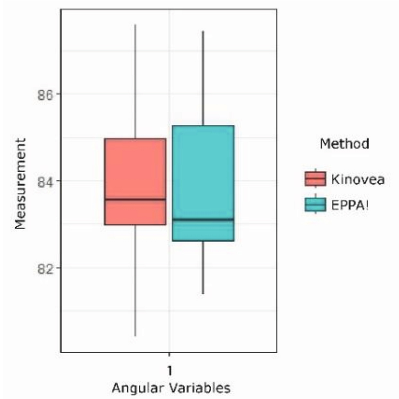
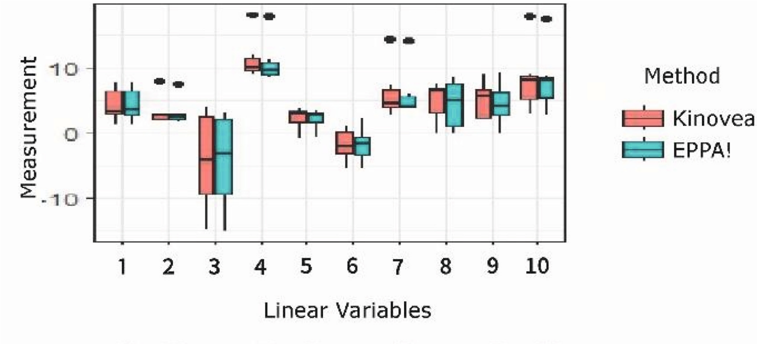


Fig. 10. Comparison of the measurements between the results of the right profile view: a) linear variables: 1- Sagittal shoulder alignment; 2- Sagittal knee alignment; 3- Pelvic Sagittal tilt; 4- Cervical lordosis; 5- Lumbar lordosis; 6- Trunk alignment-Dorsum Sacrum Tangents; 7- Cephalic alignment-Occipital Dorsum Tangents; 8- Pelvic translation (Trochanter point); 9- Cephalic alignment earlobe point) b) angular variables: 1- Tibia-foot angle.

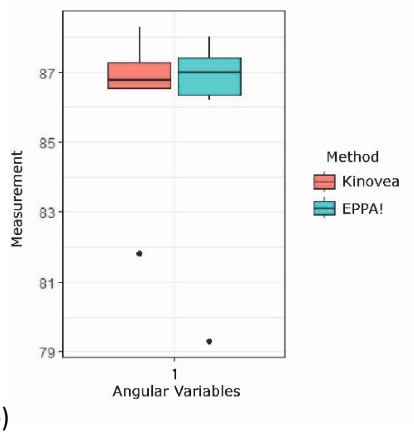
location of the anatomical markers (AI). Prior training and qualification of the professionals is necessary. This is the starting point before any automation of measurements in any software. Then, the authors discuss those procedures where the markers are placed directly on the photograph, without having been applied on the body surface by semiology or direct palpation [2].

Although photogrammetry is a methodology frequently used in scientific work for posture assessment, the mathematical procedures involved are very varied [51]. Petruccio's literature review in 2020 on photogrammetry studies recommends further studies to achieve greater inter- and intra-examiner reliability.

The relevance of the present work is considered to emphasise the need and importance of developing automated software to objectify the evaluation of the subject's standing posture, respecting the individuality of each person without losing reproducibility over time in successive comparable measurements and making it possible to select points, lines and angles, according to the criteria of the expert evaluator for other measurements in addition to those standardised by the software.



a)



b)

Fig. 11. Comparison of the measurements between the results of the left profile view: a) linear variables: 1- Sagittal shoulder alignment; 2- Sagittal knee alignment; 3- Pelvic Sagittal tilt; 4- Cervical lordosis; 5- Lumbar lordosis; 6- Trunk alignment- Dorsum Sacrum Tangents; 7- Cephalic alignment-Occipital Dorsum Tangents; 8- Pelvic translation (Iliac point); 9- Pelvic translation (Trochanter point); 10- Cephalic alignment (earlobe point) b) angular variables: 1- Tibia- foot angle;

The principles of photogrammetry are used for the calculation of distances and angles by Abarca Reyes (2019), however, a notable difference between that author and the EPPA! software was that the programming of the angle functions used by this author was not able predict the sign of the angles calculated by the software. It is important to note the conventions regarding deviations from reference lines: positive signs when they are to the right and in front of the person, and negative signs when they are to the left and behind [63]. In response to this, the angle calculation procedures in EPPA! apply the scalar product [75], between a vector consisting of the points of interest and another vector with vertex at the same reference point and direction parallel to the RVL or RHL; as appropriate.

The highest point in the image is chosen as the vertex for the angles with respect to the horizontal and the lowest for those taken with respect to the vertical, detecting it with a programming line of a conditional (if-then function). This choice is considered to facilitate the angle analysis.

Refering to the comparison of EPPA! with other software available on the market, we can mention BioPrint [76]. This software uses artificial intelligence to compare the patient's posture against its database. The database includes more than 1,000 elite athletes and has more than one million analyses performed, thanks to 100 million data collected in more than thirty countries. It is questioned whether it is relevant to compare subjects with pathologies or older adults posturally with elite athletes, and, above all, that averages and standard deviations do not reveal anything about the correct alignment but rather the frequency or ¨normality in statistical terms of each diagnostic value.

In contrast to this approach, EPPA! is concerned with the evaluation of individual balance conditions. The posture of each person is not compared with a database, but the deviations from the reference line are diagnosed, considering the posture as an individual, personal and dynamic behaviour, i.e. the one that gets closer to the ideal posture, with the lowest energy consumption [9–21].

In relation to the comparisons made of EPPA! with the use of Kinovea ©, it was found that, in the second one, the handling of the measurements is executed with greater complexity, as it depends on the manual marking of all the reference lines, distances and angles.

In EPPA!, once the AI are entered, most of the segments and calculations are performed automatically through a menu of buttons by regions and by views, which makes it much faster and friendlier to use, minimising errors, subjectivity and time.

According to Puig Divi (2019), Kinovea © has been validated as a measurement tool in health sciences and sport and can be used as a reference method to compare new technologies based on spatio-temporal analysis, providing reliability and validity to measure distances and angles from different perspectives based on a coordinate system.

Coincidentally with Abarca Reyes (2019), when the measurements were compared with the Kinovea © software, it is observed that in the procedures of the latter there may be some difficulty in locating the centres of the markers using the digital pointer, generating a certain lack of accuracy, along with the time involved in the marking and measurements of each photograph.

From the statistical comparison made between EPPA! and Kinovea ©, it can be seen that there is a lack of equivalence in variables measuring lumbar lordosis in profile, in a calcaneal angle, in posterior view and in anterior view, in Q angles of both knees. From this, possible sources of error were analysed. The three possible errors were considered:

a) software measurement error: the maximum diameter of the adhesive circles used as markers is 1 cm. Then, the software cursor will be centred on the centre of it (having a measurement error of 0.5 cm). Even anticipating extreme error due to human eye and/or mouse manipulation, marker deformation, or by placing the cursor at the boundary of the marker circumference (instead of at the centre), the maximum cursor location error, and thus maximum software measurement error, would be $\pm$ 1 cm;
b) grid calibration error. This error can be minimised during the calibration of the photo in the software, since the cross of the software cursor can be made to coincide with

the intersection of the grid lines, for example at the level of the person's navel (where the dispersion of the focus is smaller) and the 10 cm y line can be drawn,

c) error in the diagnosis of postural assessment: during the quantitative process when generating the tables with measurements by regions and by views, $\pm$ 1 cm in linear variables and $\pm$ 2° in angular variables is taken as a neutral range.

The limitations of this work include the fact that the comparative statistics were carried out with a very small sample (n = 6), as a pilot test, and that posturographies already taken in previous research were applied, due to the impossibility of including new patients in the immediate post-pandemic period. This is why a new stage of intra and inter-evaluator validation is proposed with a larger sample size and in different lines of research (athletes, older adults, scoliosis, others).

5 Conclusions

It is considered that all the objectives established for this development were achieved.

- The literature review allowed us to update our knowledge of the different methodologies used in posture assessment and, in particular, those using different software. It also provided a solid and robust basis for the posture assessment protocol to standardise the taking of digital posturography, the validation of indicators and measurement processes, managing to systematise and objectify the postural assessment through the marking of valid, reliable, sensitive and specific indicators (points, lines and angles), in the three dimensions of space, with the person in a standing position, automating the recording of the parameters assessed (distances and/or angles with respect to the reference lines).
- Software EPPA! was developed for the automation of digital posturography measurements and implemented in a pilot sample on an experimental basis, concluding with the capture of the image, the export of quali-quantitative data and arriving at intersegmental postural diagnoses by regions, planes and views.
- It was possible to test the measurement options chosen by the assessor, marking points, distances and angles that are required according to the clinical case and the relevance of some region or particularity of the person, providing suggestions for accessory measurements in each view.
- The performance of the software was analysed by comparing each variable with measurements processed using free and open access software, and the paired samples hypothesis was confirmed with the equivalence test statistics. All diagnoses were coincident, only three measurements (one linear and two angular) did not show significant differences.

It is considered that this work provides a concrete digital tool to standardise and systematise postural evaluations with a qualitative-quantitative methodology through digital posturography that will allow access to a more precise postural diagnosis and a systematic follow-up of the therapeutic results.

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Sciences, Pontificia Universidad Católica Argentina. Interest´s conflicts weren‘t reported for this study.

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