Erasmus+

Development of innovative training solutions in the field of functional evaluation aimed at updating of the curricula of health sciences schools

TEACH

MODULE BIOMECHANICS OF GAIT

Didactic Unit D: INSTRUMENTED ANALYSIS OF GAIT

D.1 Which gait biomechanical instrumented evaluation protocols exist?

Politechnika Śląska
IBV Instituto de Biomecánica de Valencia
Vniversitat de València
AMSE The Association of Medical Schools in Europe

D.1 Which gait biomechanical instruments evaluation protocols exist?

- Part 1 Photogrammetry
- Part 2 Accelerometers
- Part 3 Dynamometric platforms
- Part 4 Instrumented pressure insoles
- Keys ideas
- Bibliography

D.1 Which gait biomechanical instruments evaluation protocols exist?

Part 1. Photogrammetry and gait assessment.
Clinical approach

1. DEFINITION

Photogrammetry

Photogrammetry is the science of obtaining reliable information about the properties of surfaces and objects without physical contact with the objects, and of measuring and interpreting this information.

phot — **light**; *grama* — **draw**; *metrein* — **measure**

Video camera or Photo camera → **Images** → **Kinematic variables**

2. SYSTEM ELEMENTS

- Video **camera** system and spotlights or lighting system
- Image recording and processing system: **software**
- **Reference system**
- **Markers** and **accesories**

2.1. SYSTEM ELEMENTS: CAMERAS

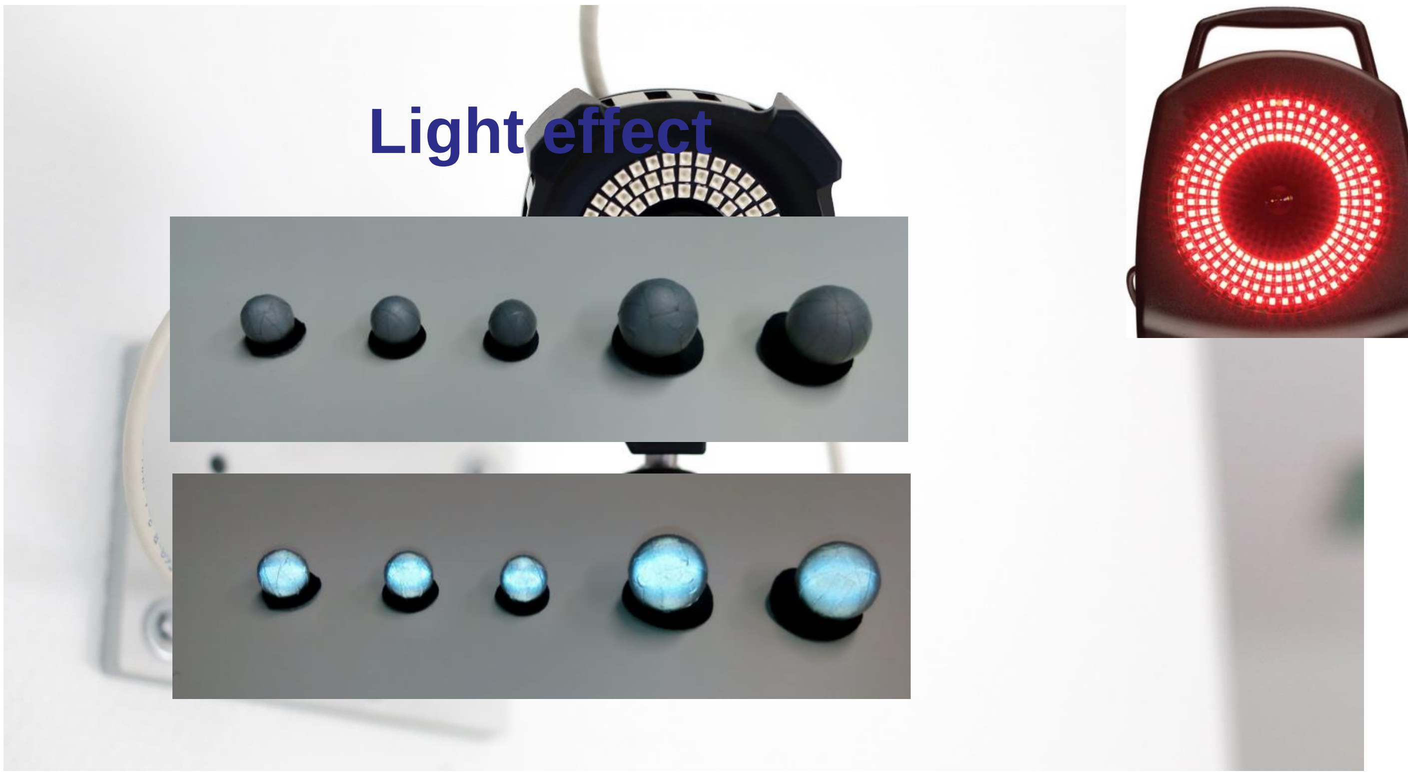
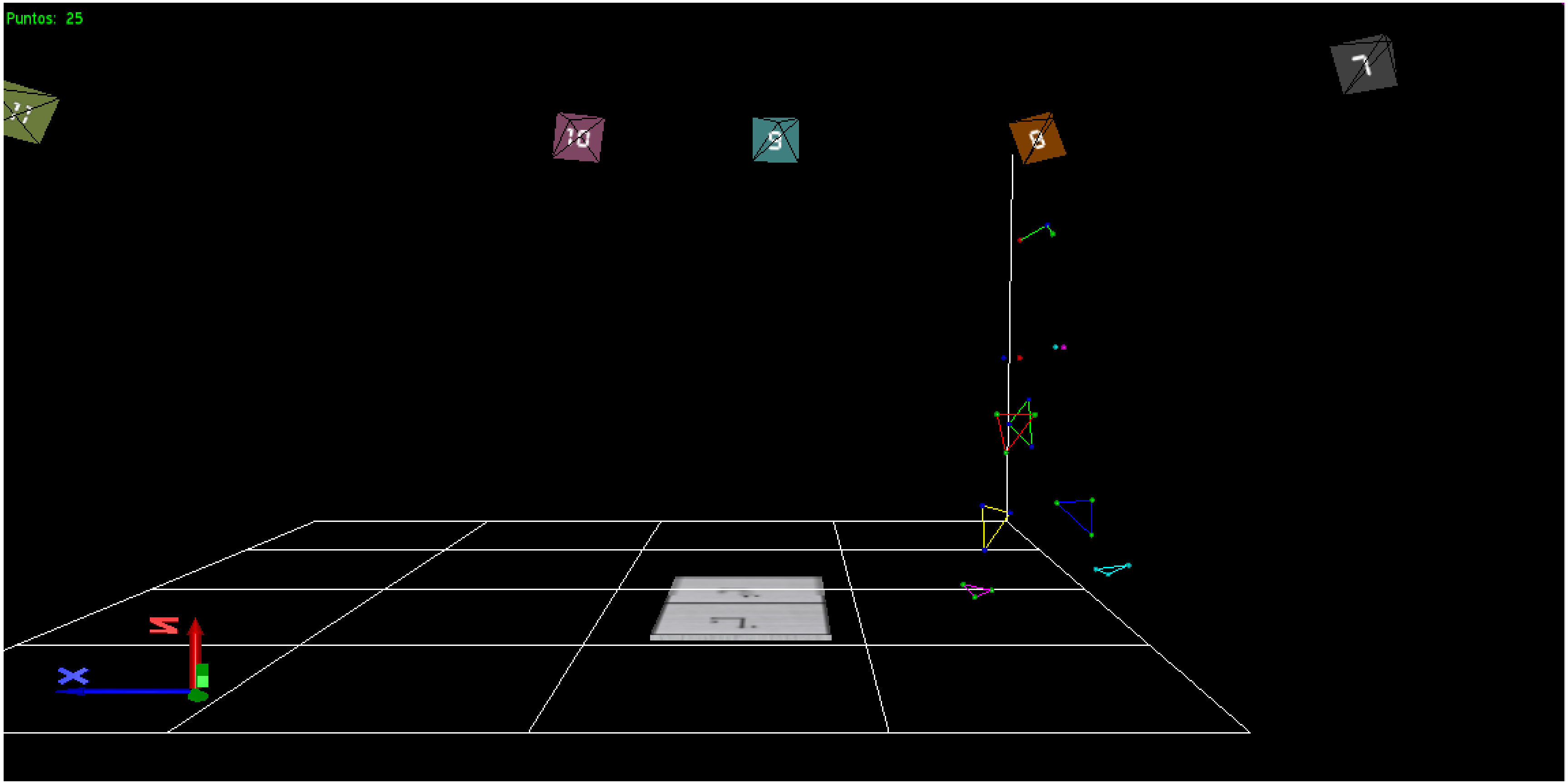
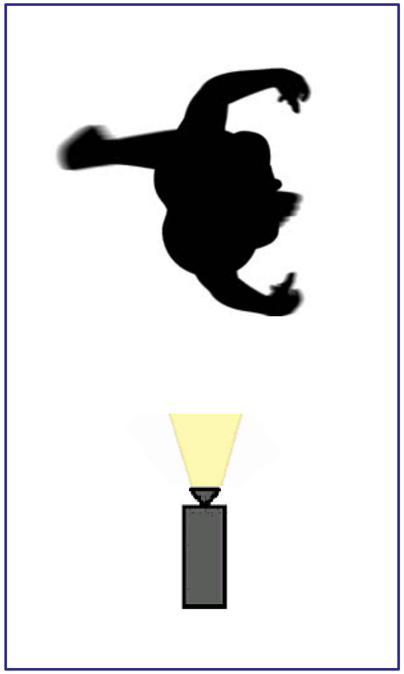


Figure 1. Smartcam from movement capture system kinescan/IBV

2.1. SYSTEM ELEMENTS: CAMERAS



2.1. SYSTEM ELEMENTS: CAMERAS



versus

Figure 2. Configuration of cameras for analysis in two-dimensions versus three-dimensions. Medicine Department Lab. University of Valencia

2.1. SYSTEM ELEMENTS: CAMERAS

Configurations for camera-based motion capture

Two-dimensional system

- One camera
- Coronal or sagittal plane movement
- Positioned orthogonally to capture

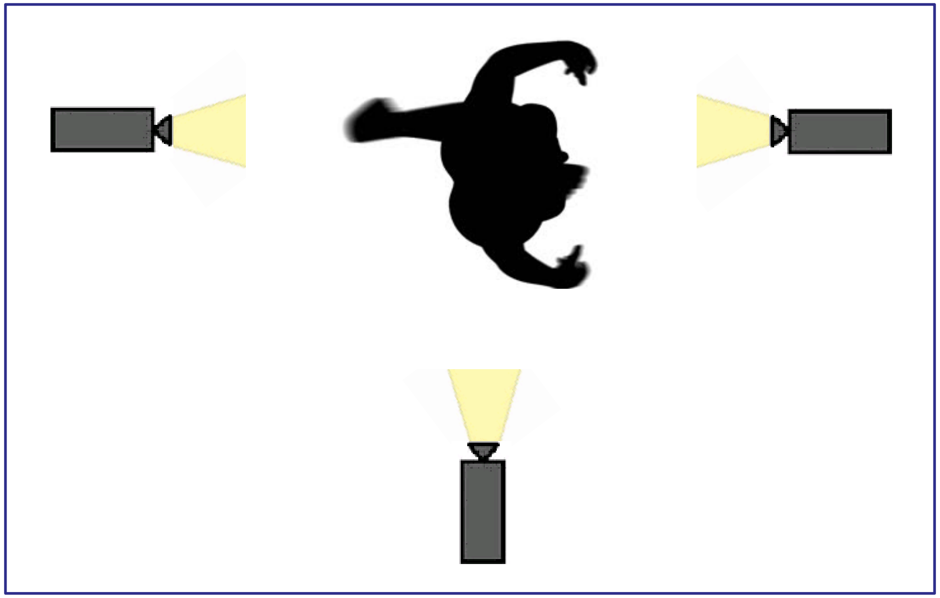


Figure 3. Two-dimensional video camera configuration

2.1. SYSTEM ELEMENTS: CAMERAS

Configurations for camera-based motion capture

Three-dimensional system

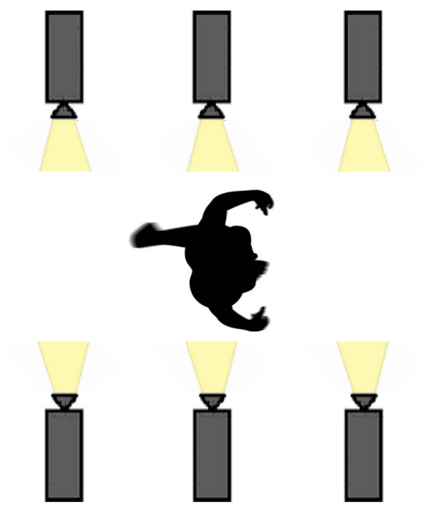


Figure 4. Linear camera configuration

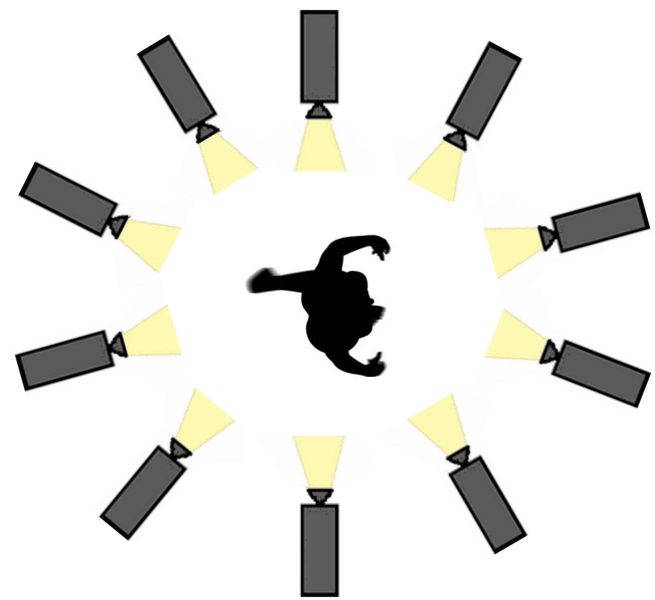


Figure 5. Umbrella camera configuration

2.1. SYSTEM ELEMENTS: CAMERAS

Recording frequencies per second with photogrammetry system			
Author	**Motor task**	**Frecuency**	**Sample**
Martin S. *et al*. 2014	Gait	75 Hz	Healthy participants
Jeremy J.B. et al. 2007	Gait	120 Hz	Normally active girls
Bisesti et al. 2015	Running	240 Hz	Healthy participants
Huchez et al. 2013	Gymnastics	250 Hz	Athletes
Inoue et al., 2014	Soccer	500 Hz	Athletes
Betzler et al. 2014	Golf	1000 Hz	Athletes

Table 1. Recording frequencies (Hz) with motion capture system.

2.2. SYSTEM ELEMENTS: SOFTWRE

Images recording

Images processing

Figure 6. Motion capture system software available in the market

2.3. SYSTEM ELEMENTS: REFERENCE SYSTEM

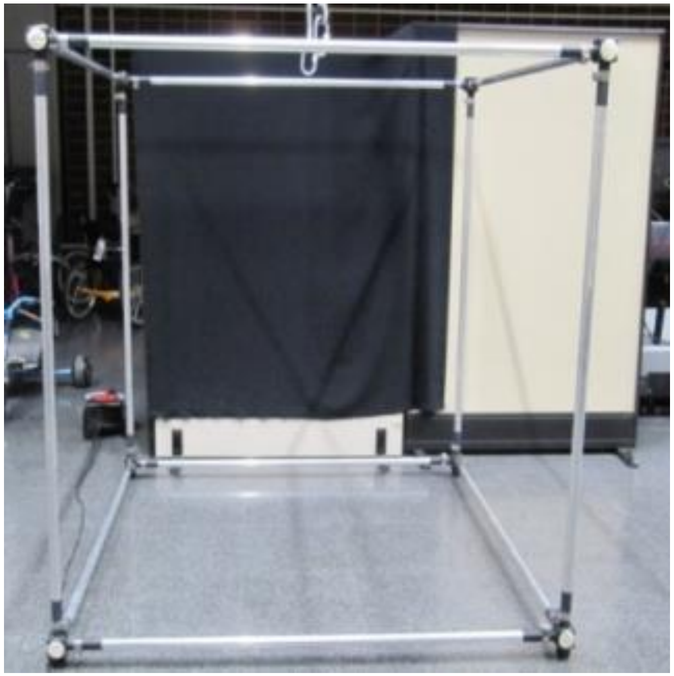
Global coordinate system (GCS)

STATIC CALIBRATION

DYNAMIC CALIBRATION

2.3. SYSTEM ELEMENTS: REFERENCE SYSTEM

Static calibration



Two-dimension

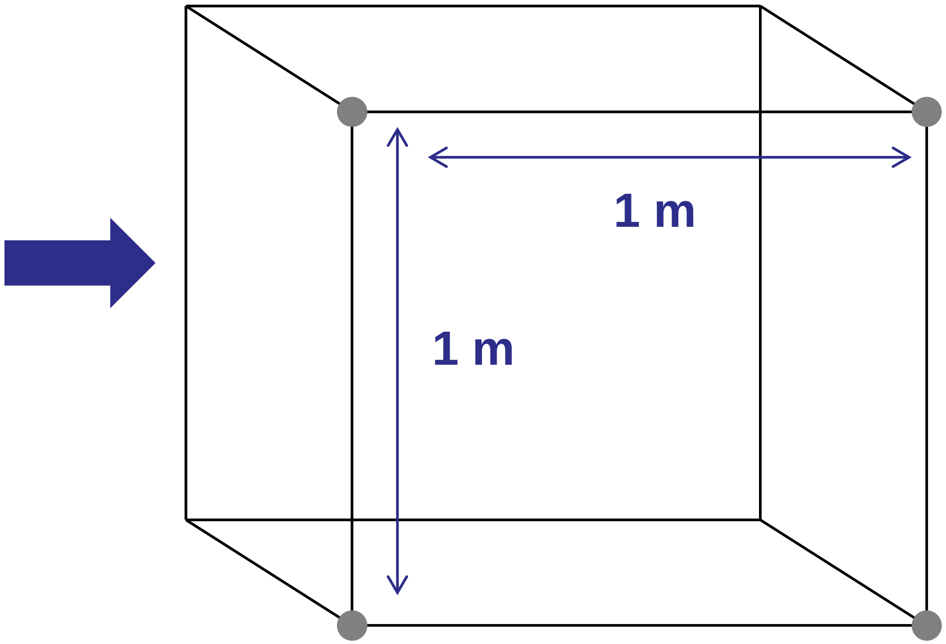
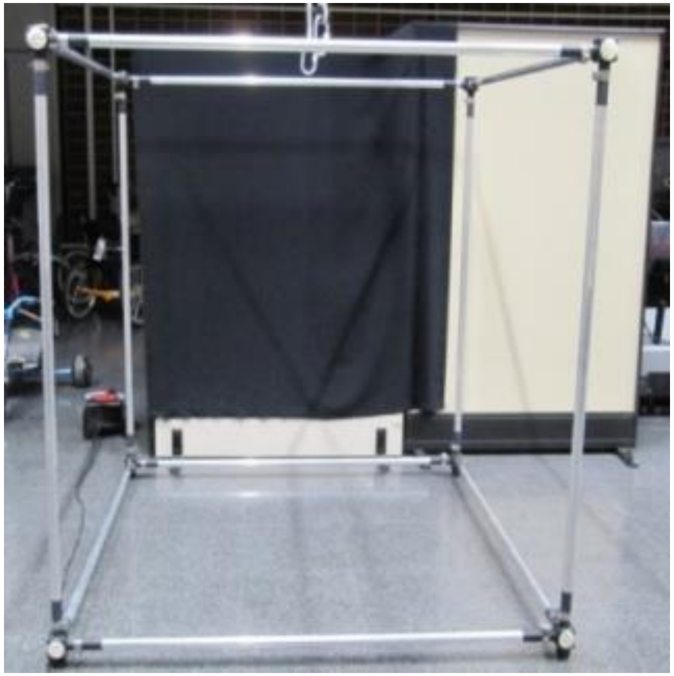


Figure 7. Rigid cubic structure for static space calibration in two-dimensional analysis

2.3. SYSTEM ELEMENTS: REFERENCE SYSTEM

Static calibration



Three-dimension

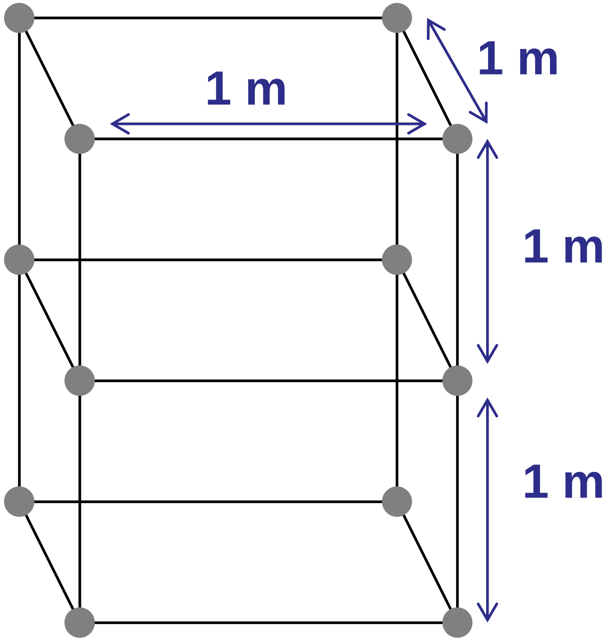
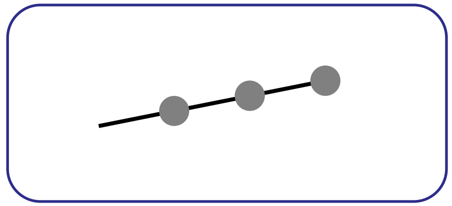


Figure 8. Rigid cubic structure for static space calibration in three-dimensional analysis

2.3. SYSTEM ELEMENTS: REFERENCE SYSTEM

Dynamic calibration



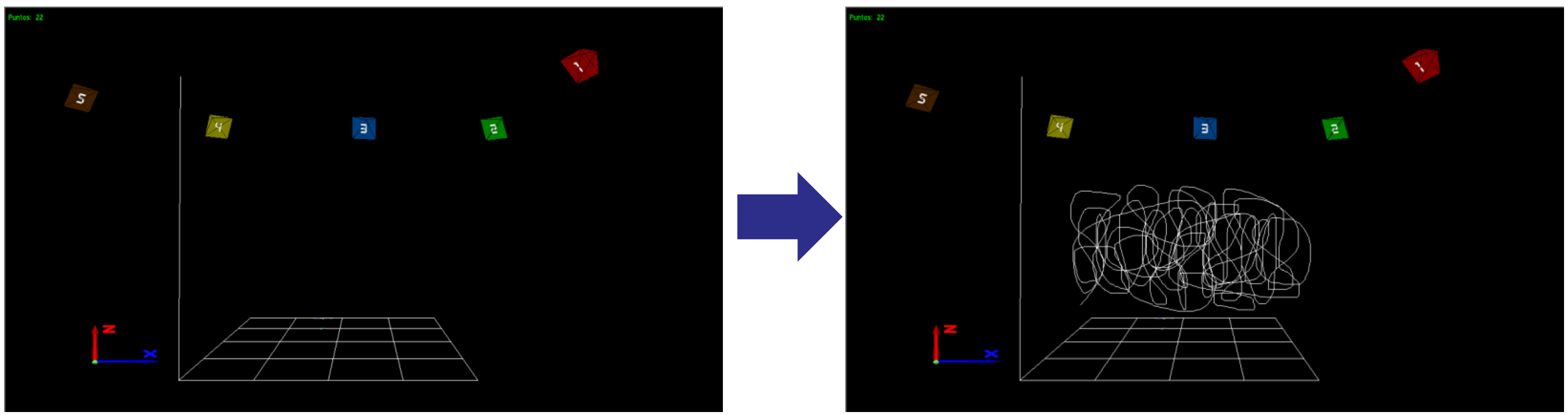


Figure 9. Dynamic space calibration with a wand and tracking cloud

2.4. SYSTEM ELEMENTS: MARKERS AND ACCESORIES

Markers

- Passive markers

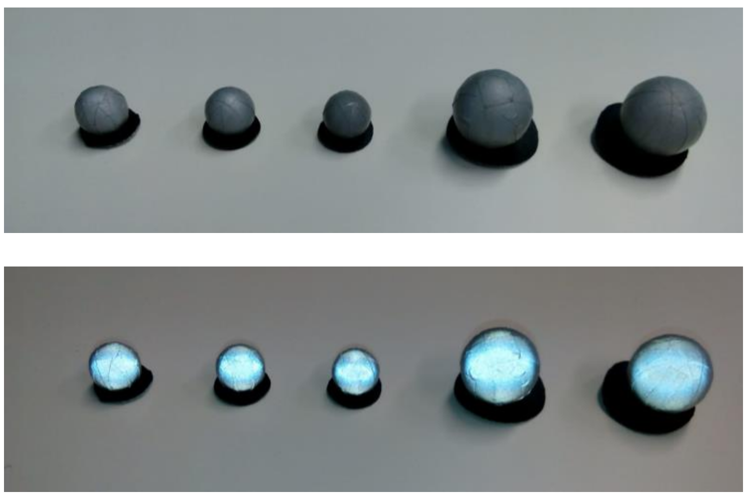


Figure 10. Passive individual markers

Scotchlite reflective material

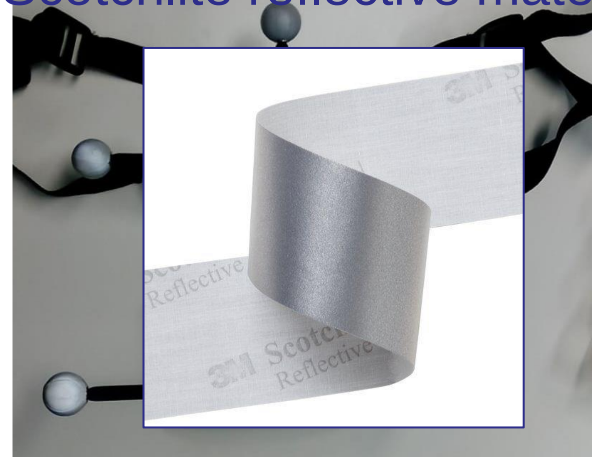


Figure 11. Passive cluster markers

2.4. SYSTEM ELEMENTS: MARKERS AND ACCESORIES

Markers and other materials

- Active markers

Figure 12: Active markers
(Image from J. Richards et al. 2018)

- Other materials

Figure 13: Double-contact adhesive

3.1. MOVEMENT DEFINITION AND BIOMECHANICAL MODEL

What we want to measure?

Figure 14. Configuration for ankle movement analysis. From A. Ali and T. Gevers. 2011

versus

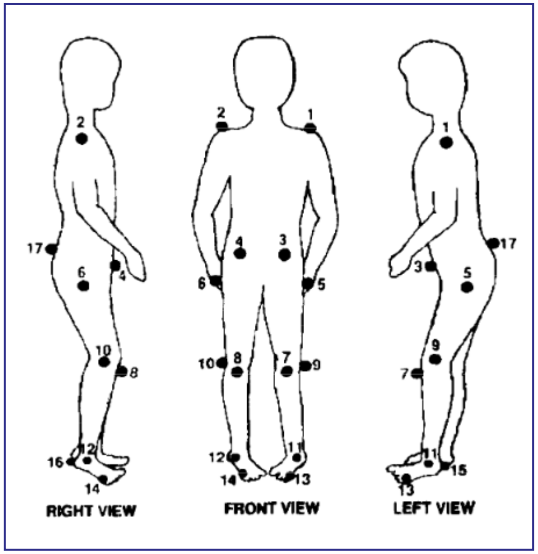


Figure 15.Configuration for lower limb gait analysis. From Eng H. Lee et al. 1992

3.1. MOVEMENT DEFINITION AND BIOMECHANICAL MODEL

Configurations of biomechanical model for gait analysis

➢ Simple marker set

- Head of the fifth metatarsal
- Lateral malleolus
- Lateral condyle of the femur
- Greater trochanter
- Anterior superior iliac spine
- Acromion process
- Lateral condyle of the humerus
- Styloid process at the wrist

It is not possible to measure axial rotation

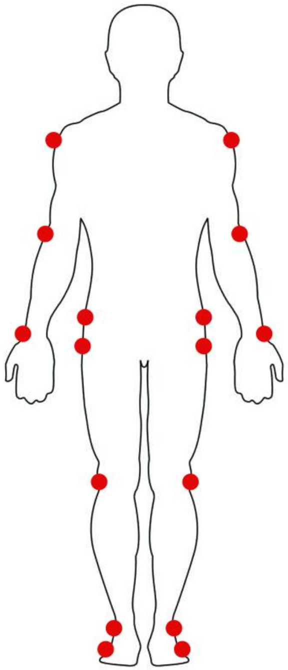


Figure 16. Simple marker set configuration

3.1. MOVEMENT DEFINITION AND BIOMECHANICAL MODEL

Configurations of biomechanical model for gait analysis

➢ Vaughan Marker set

- Head of the fifth metatarsal
- Lateral malleoli
- Heel
- Tibial tuberosity
- Femoral epicondyle
- Greater trochanter
- Anterior superior iliac spine
- Sacrum

Functional reference of the foot

Pelvic Tilt

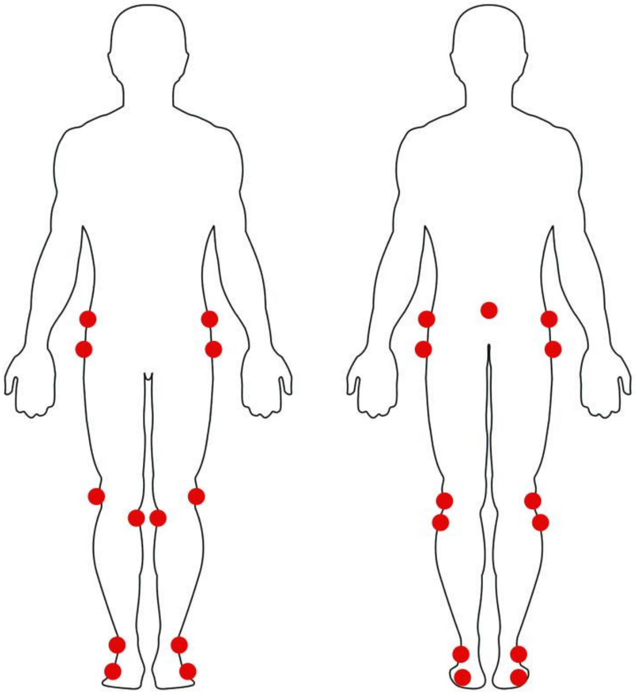


Figure 17. Vaughan marker set configuration

3.1. MOVEMENT DEFINITION AND BIOMECHANICAL MODEL

Configurations of biomechanical model for gait analysis

➢ Helen Hayes Marker set

- Head of the second metatarsal
- Lateral malleoli
- Heel
- Tibial wand
- Femoral epicondyle
- Femoral wand
- Greater trochanter
- Anterior superior iliac spine
- Sacrum

Tibial and femoral wands for femoral and tibial rotations.

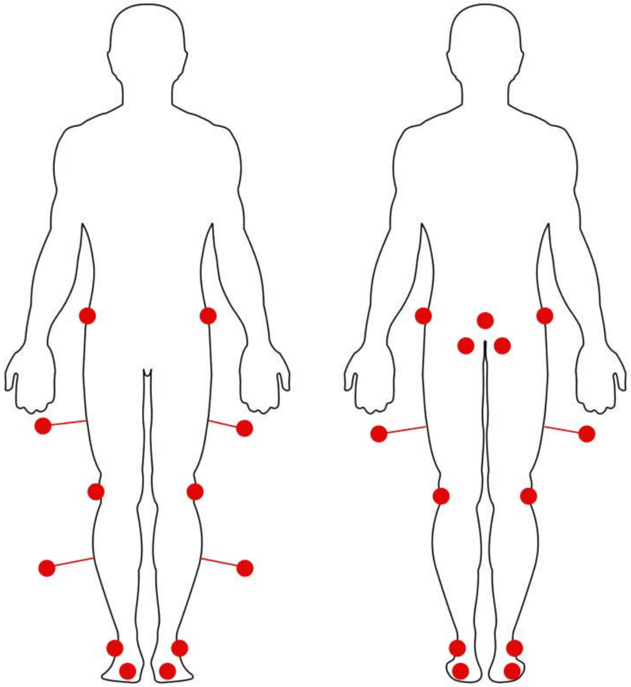


Figure 18. Helen Hayes marker set configuration

3.1. MOVEMENT DEFINITION AND BIOMECHANICAL MODEL

Configurations of biomechanical model for gait analysis

➢ The Calibrate Anatomical System Technique Marker set (CAST)

- Standardize the description of the pelvis and lower limb
- Six-degrees of freedom
  - Three linear or translational movements
  - Three rotation or angular movements
- Two types of markers: anatomical and segment

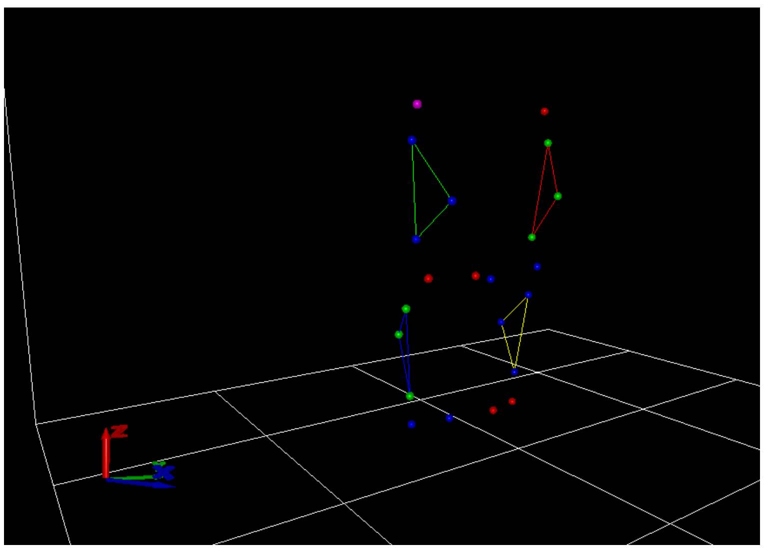
3.1. MOVEMENT DEFINITION AND BIOMECHANICAL MODEL

The Calibrate Anatomical System Technique Marker set (CAST)

- Anatomical markers
  - Used for calibration of the model
  - Located lateral and media to the joints
  - Joints instrumented: proximal and distal to the each segment
  - Global coordinates system → Local coordinates system

Local coordinates system (LCS)

Global coordinates system (GCS)



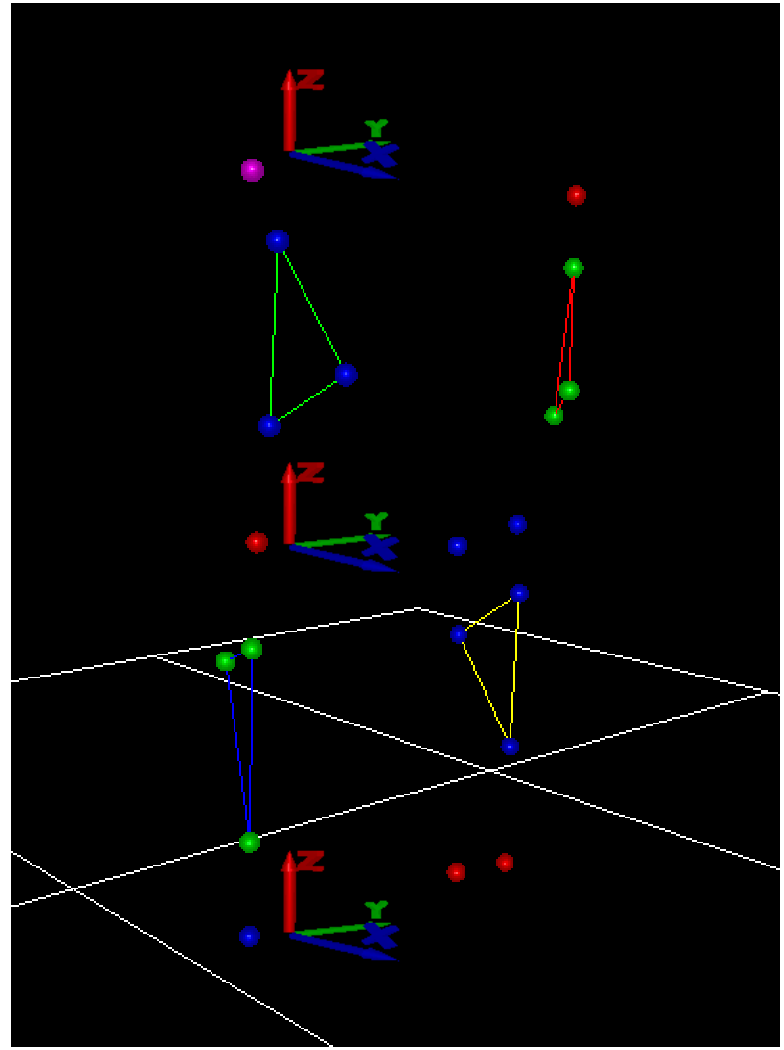


Figure 19. Global coordinates system versus Local coordinates system

3.1. MOVEMENT DEFINITION AND BIOMECHANICAL MODEL

The Calibrate Anatomical System Technique Marker set (CAST)

- Anatomical markers

Foot segment
- Metatarsal head
- Ankle malleolli

Tibial segment
- Ankle malleolli
- Femoral Condyles

Femoral segment
- Femoral Condyles
- Greater trochanter

Pelvis segment
- Posterior superior iliac
- Anterior superior iliac

3.1. MOVEMENT DEFINITION AND BIOMECHANICAL MODEL

The Calibrate Anatomical System Technique Marker set (CAST)

- Segment markers
  - They can be located arbitrarily in the segment
  - Easily tracked
  - Non-collinear
  - At least three markers in each segment

3.2. DATA CAPTURE

1º

Static calibration scene

2º

Gait trial Scene

3.2. DATA CAPTURE

What is important during the recording of the gait?

- Enough space to make several strides
- Gait performance without interference of model instrumentation
- Makers must be visible throughout the measurement record
- Standardized instruction

3.3. DIGITIZING OF THE MEASURES

Digitizing or tracking is the process of identifying points on the body using markers or a visual impression of the joint centres. There are two methods of digitizing: manual and automatic.

Manual digitizing	Automatic digitizing

3.4. OBTAINING THE RESULTS

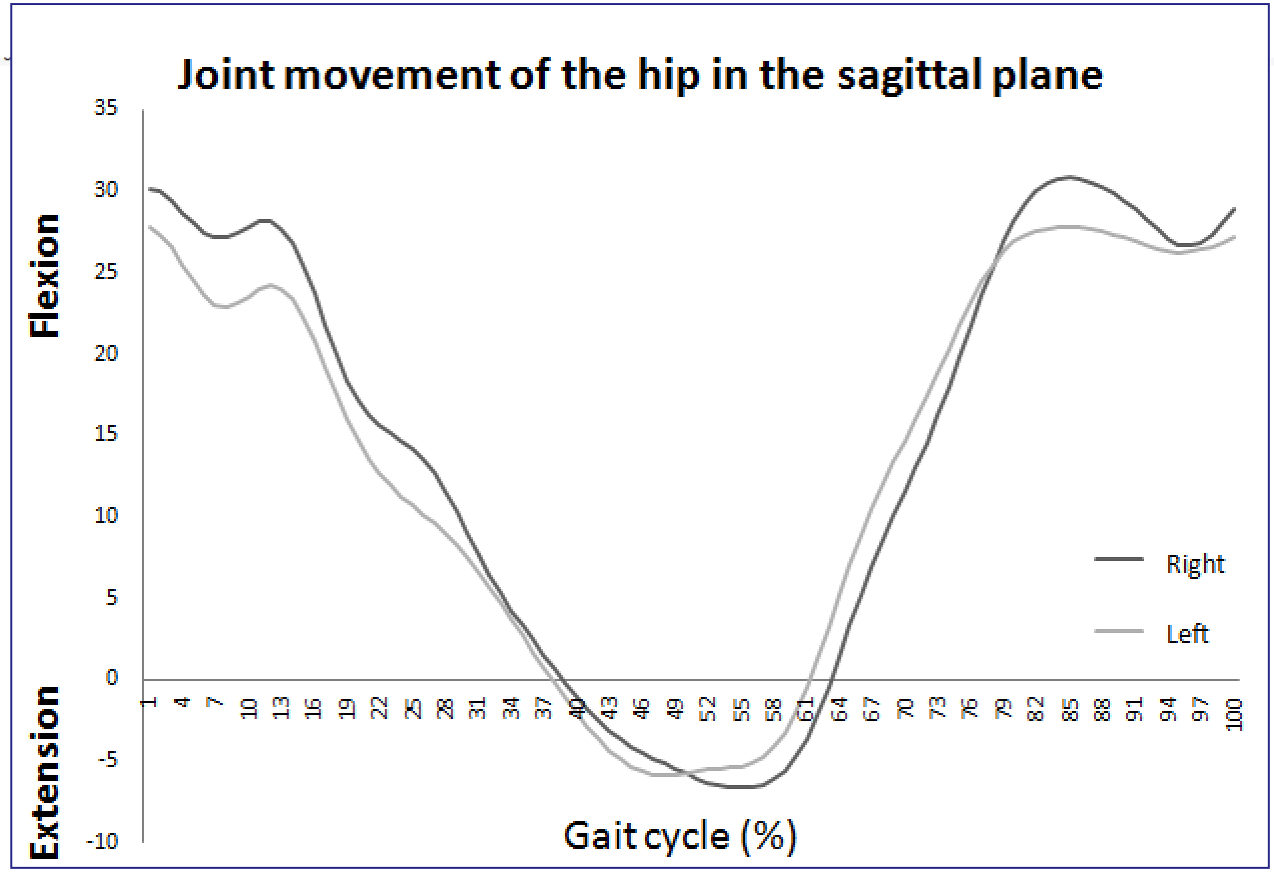


Figure 20. Hip movement analysis related to gait cycle

3.4. OBTAINING THE RESULTS

Outcomes from photogrammetry system	
Kinematics	**Spatiotemporal**
Range of motion • Flexo-extension • Internal-external rotation • Abduction-adduction	Gait velocity (m/s)
	Stride length (m)
	Stride time (s)
	Step length (m)
Peak angle • Maximum plantiflexion and dorsiflexion of the ankle • Maximum flexion and extension of the knee • Maximun extension and flexion of the hip	Step width (m)
	Cadence (steps / min)
	Foot angle in stance/swing phase
	Stance phase duration (s) or (%)
	Swing phase duration (s) or (%)
	Double support time (%)

Table 2. Main outcomes from the kinematic analysis

3.4. OBTAINING THE RESULTS

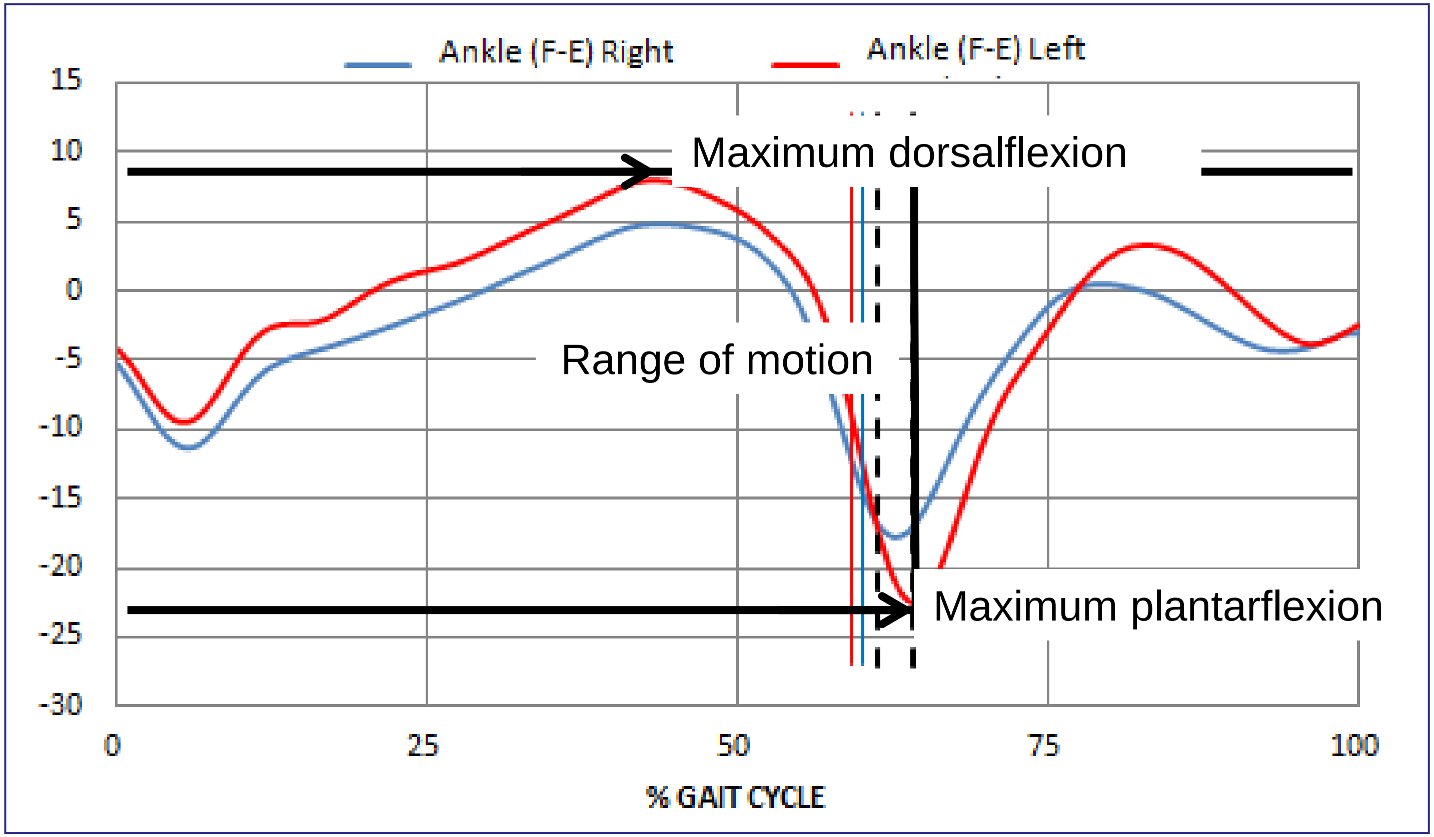


Figure 21. Ankle movement curve in gait cycle. Analysis of the range of motion versus peak angle

4. ADVANTAGES AND DISADVANTAGES

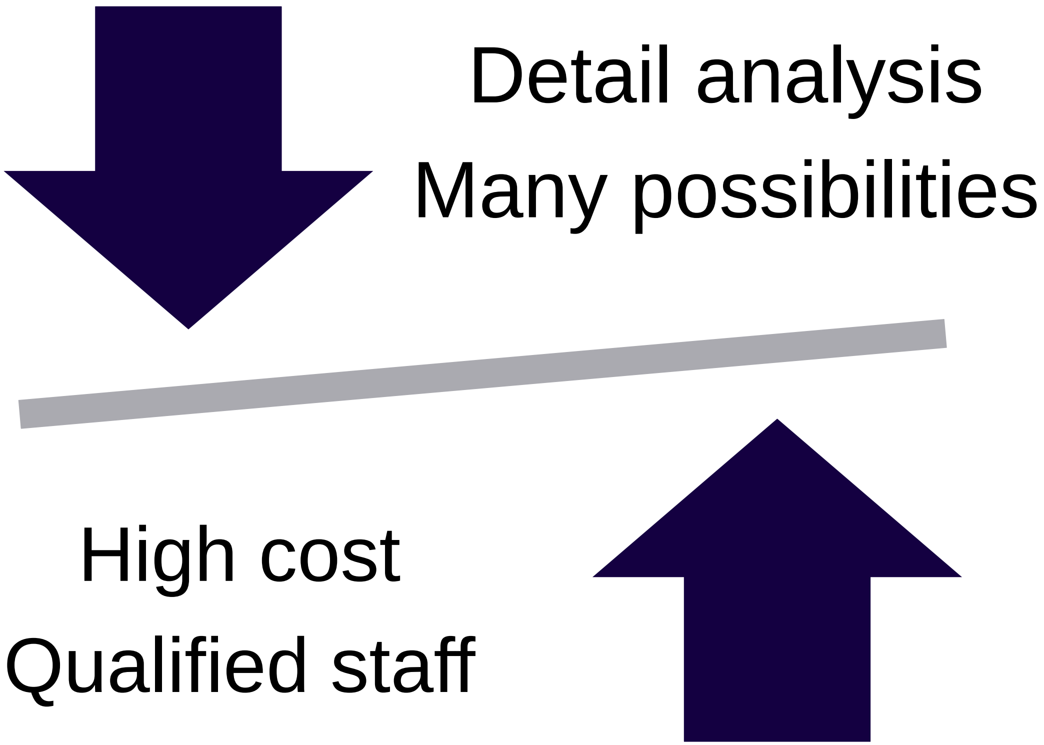


Figure 22. Diagram with the characteristics of the photogrammetry system

4. ADVANTAGES AND DISADVANTAGES

Errors associated with the measurement technique

- Errors involved with marker placement: soft-tissue artefacts

  - Relative errors: movement between two or more markers

  - Absolute errors: movement of a marker with respect to the bony landmark it is representing

4. ADVANTAGES AND DISADVANTAGES

Errors associated with the measurement technique

➢ Errors related to image distortion

- Usual with standard video cameras in two-dimensional analysis
- Marker distortion from higher-speed distal segment movement

4. ADVANTAGES AND DISADVANTAGES

Errors associated with the measurement technique

- Errors in estimating the centre of a maker

Figure 23. Representation of the centroid marker in relation to its size

4. ADVANTAGES AND DISADVANTAGES

Errors associated with the measurement technique

- Other types of errors

  - Related to the gait repetitions → standardization of the procedure

  - Low external validity → unrepresentative

D.1 Which gait biomechanical instruments evaluation protocols exist?

Part 2. Accelerometers and gait assessment.
Clinical approach

1. DEFINITION

Accelerometers

- Accelerometers are devices which measure the applied acceleration along an axis.
- They are a basic technology that converts mechanical motion into an electrical signal.
- Their internal function is based on the inertia of a mass located on a force sensor, following the Second law of Newton to obtain acceleration.

$$F = m * a$$

Figure 1. Second law of Newton.

1. DEFINITION

Accelerometers in gait

- Acceleration experienced by the lower limb segments.

Linear acceleration

m/s^2 → g (gravity ratio)

Change in the linear velocity over successive time intervals

Acceleration (+)
Deceleration (-)

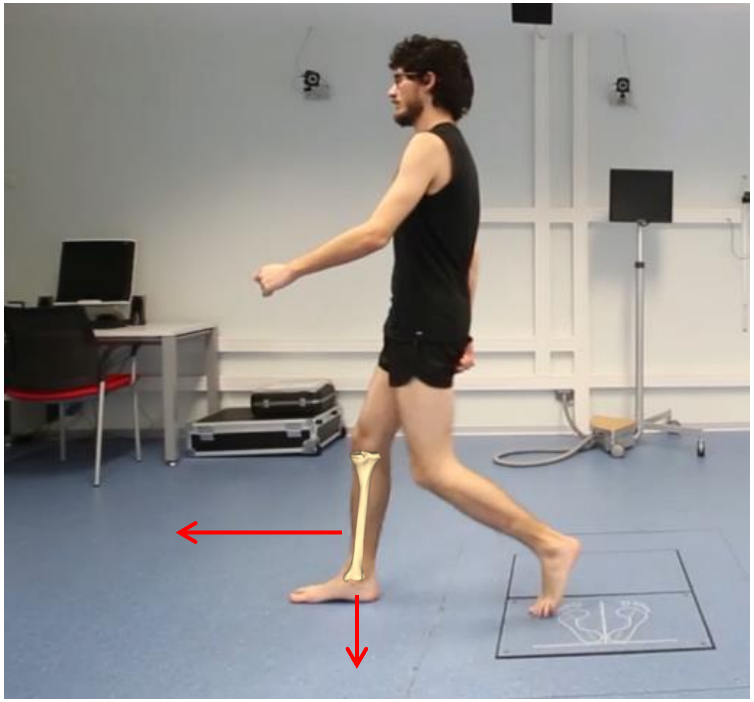


Figure 2. Acceleration representation of the tibial segment during walking.

2. SYSTEM ELEMENTS

SENSOR

- Device that measures the acceleration values from the vibration of the body to which is attached.

Uniaxial **Triaxial**

AMPLIFIER

- Device that amplifies the signal received by the accelerometer and sends it to a computer.

ANALYZER

- It is a computer with the software that receives the acceleration data and allows its subsequent analysis.

2. SYSTEM ELEMENTS

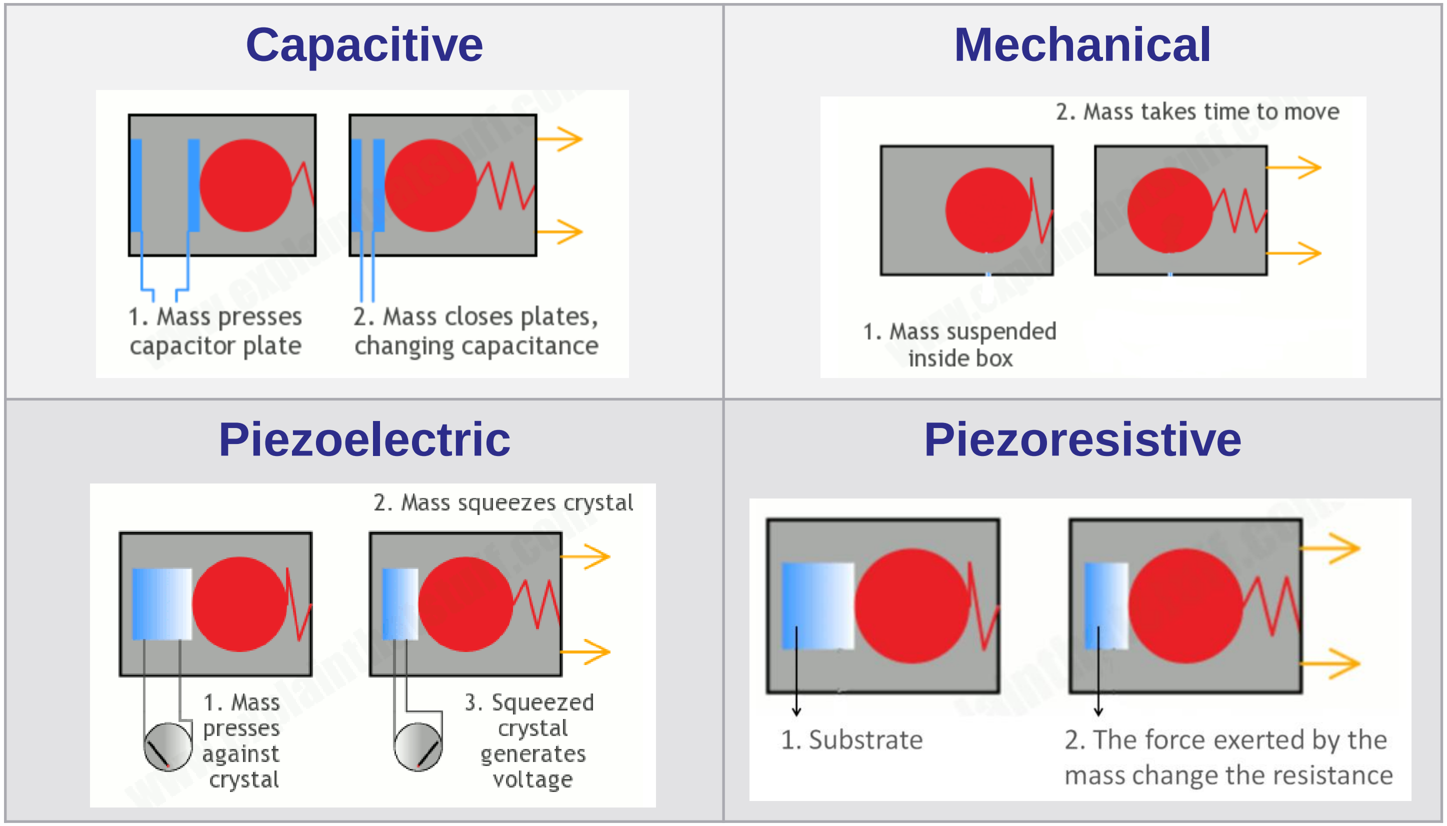


Figure 3.The images show the functioning of the different types of sensors used in an accelerometer device. Images from Woodford, Chris. (2009/2014) Accelerometers.

3. ASSESSMENT PROTOCOL

Previous consideration

- To measure body parts, accelerometers are placed on the body part whose movement is being studied.
- To measure whole body movements, multiple instruments are used.
- In gait analysis for measure the body segment movement, only need a lower frequency (60-100 Hz) and a smaller range (typically 6-9 g)

3. ASSESSMENT PROTOCOL

Placement of equipment in the body

- **Importance of fixed**
  - Good fixation will allow that the device represent the acceleration of the underlying bone
  - To avoid relative movement of the sensor
  - To avoid soft tissue
- **Adhesive material**

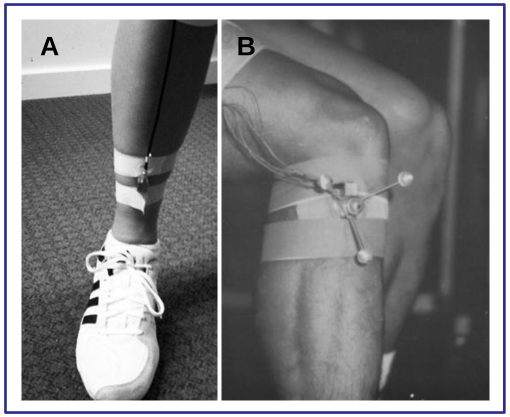


Figure 4. Elements to fix the accelerometer in the tibia. (A) non-invasive system, (B) invasive system, accelerometer subject to Steinmann pins under the skin. Image from Sinclair et a. (2013) and Lafortune M. et al. (1991)

3. ASSESSMENT PROTOCOL

- **Anatomical placement**

TRUNK
- L5 vertebra
- Sacrum

HEAD
- Forehead
- Posterior region

TIBIAL
- Forehead
- Posterior region

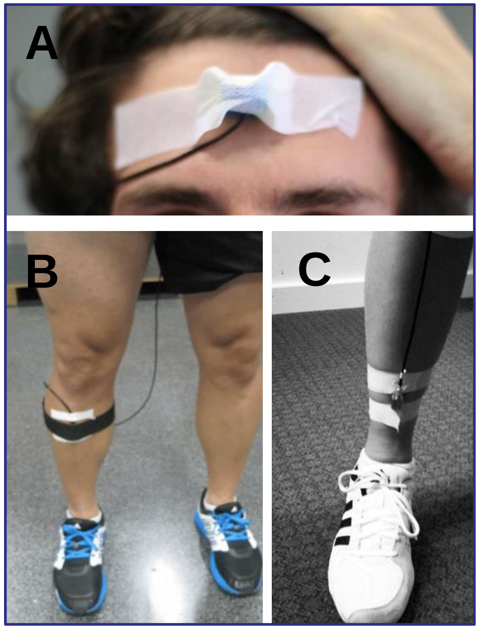


Figure 6. Usual accelerometer placement (A) Forehead location. (B) Tibial location in the proximal end and anteromedial area. (C) Tibial location in the distal end for ground impact measurement.

3. ASSESSMENT PROTOCOL

Obtaining results

- Peak amplitude of acceleration
  - Positive peak
  - Negative peak
  - Different axes
  - Time between peaks
- Spatiotemporal parameters

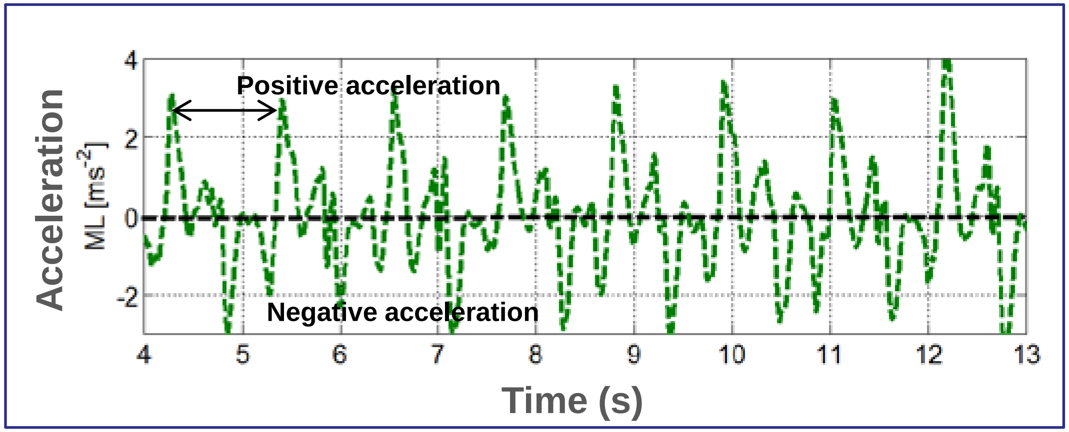


Figure 7. Head accelerations during gait. Image from Brodie, Matthew A D. et al. (2015).

4. ADVANTAGES AND DISADVANTAGES

Advantages	Disadvantages
Low cost	Sensitive to shock by large deceleration
Transportable	Precision alterations due to instability of skin fixation
Real time information	wired system limited the assessment

D.1 Which gait biomechanical instruments evaluation protocols exist?

Part 3. Dynamometric platforms and gait assessment. Clinical approach

1. DEFINITION

Dynamometric Platform

- Equipment to measure forces
- Widely used in the assessment of human gait and balance, as well as in several human activities
- Fixed in the ground

Ground Reaction Forces (GRF)

Centre of Pressure (COP)

2. SYSTEM ELEMENTS

2.1 The Platform

- Types of sensors

Figure 1. Bertec force platform of strain gauge

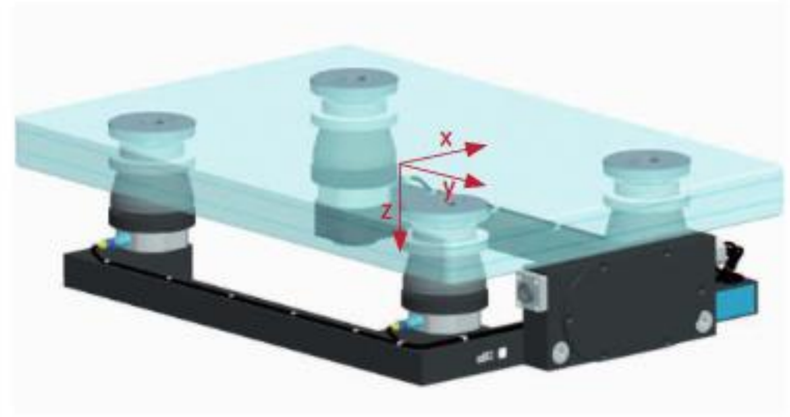


Figure 2. Kistler force platform of piezoelectric sensors

2. SYSTEM ELEMENTS

2.1 The Platform

Principal characteristics of piezoelectric and strain gauge platform	
Strain-gauge	**Piezoelectric**
Material distorted produce a resistance (strain)	Deformation of the crystal that generate an electric current
Less sensitive, less range of force measurement	More sensitive, large range of force measurement
Frequency of 400-500 Hz	Higher frequency, 1000 Hz in three directions
Adequate for general use	More recommend for activities with higher frequency content
Less expensive	More expensive

2. SYSTEM ELEMENTS

2.1 The Platform

- Configuration on the ground

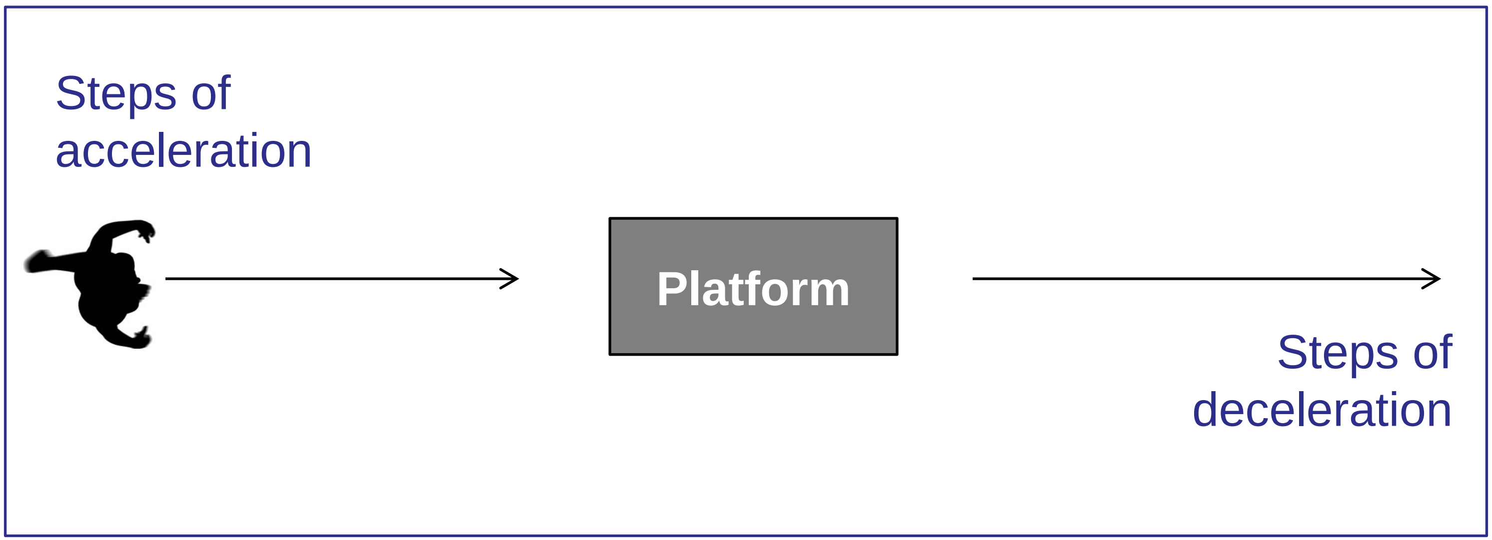


Figure 3. Positioning of the dynamometric platforms in the center of the walkway.

2. SYSTEM ELEMENTS

2.1 The Platform

- Configuration on the ground

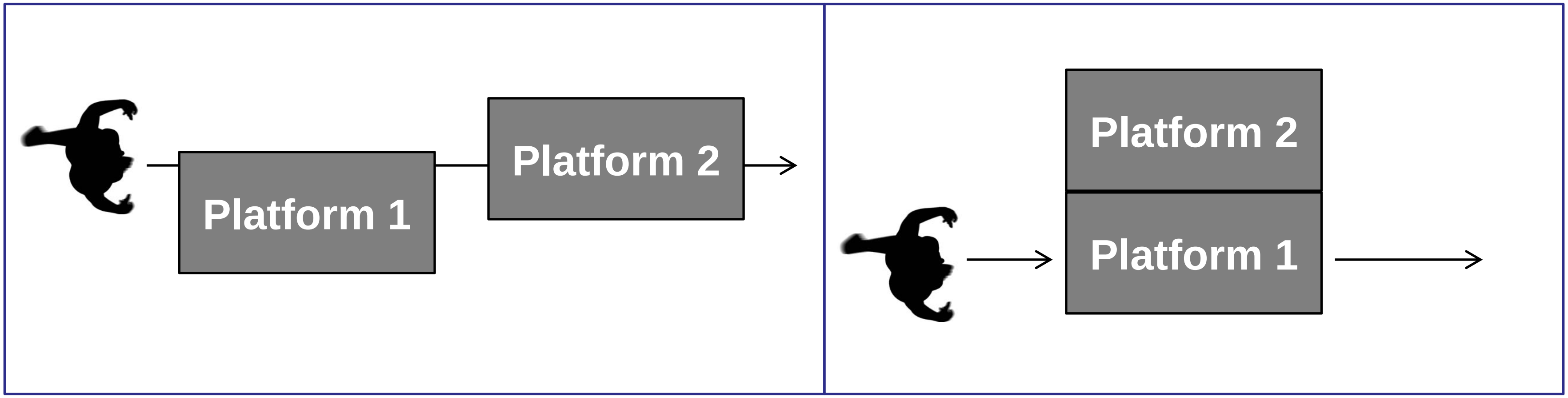


Figure 4. Configuration of two dynamometric platforms. (Left) Basic configuration for gait analysis. (Right) Basic configuration for different functions.

2. SYSTEM ELEMENTS

2.1 The Platform

- Configuration on the ground

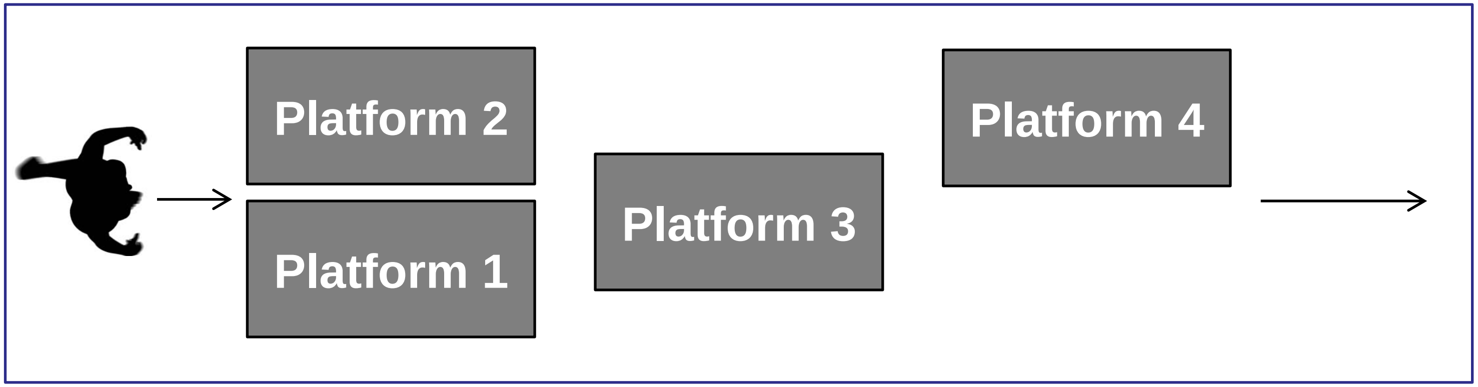


Figure 5. Optimal configuration with four dynamometric platform for gait analysis and another functions.

2. SYSTEM ELEMENTS

2.1 The Platform

- Configuration on the ground

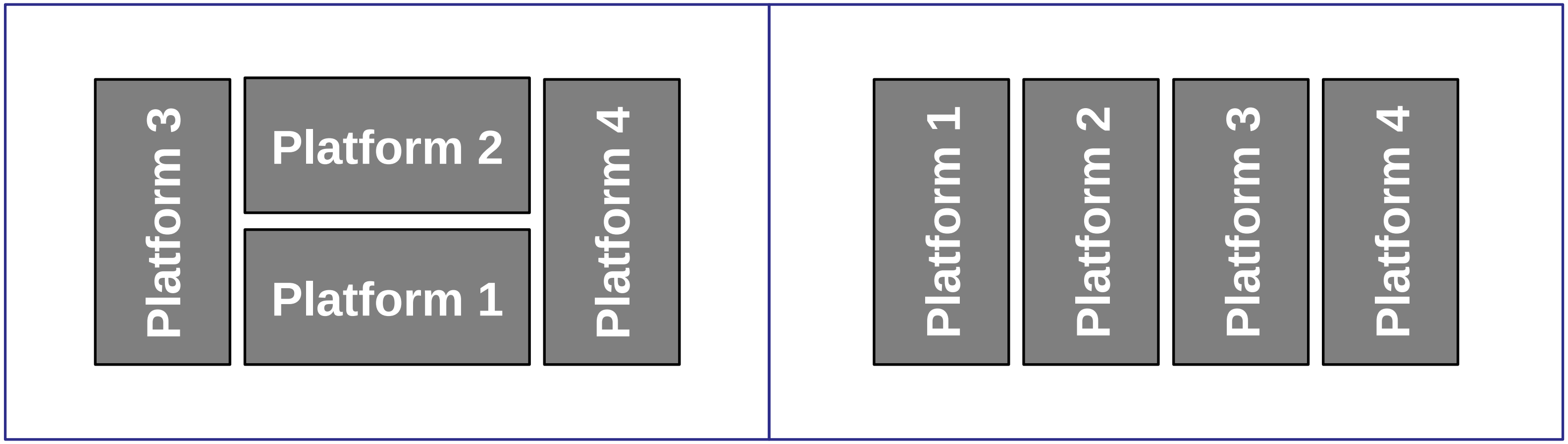


Figure 6. Configuration with four dynamometric platforms for gait analysis in children with neurological disorders.

2. SYSTEM ELEMENTS

2.2 The Software

- Registration of ground reaction forces and the subsequent editing of the data
- Control of gait velocity
- Management of more than one instrumental technique at the same time

3. ASSESSMENT PROTOCOL

- CALIBRATION
- ANTHROPOMETRIC DATA
- DATA CAPTURE
- REVIEW OF THE TRIALS
- OBTAINING RESULTS

3.1. CALIBRATION OF THE EQUIPMENT

- Procedure that indicate the system when there is no load. Signal to zero.
- Reset procedure
- Avoid possible signal drift

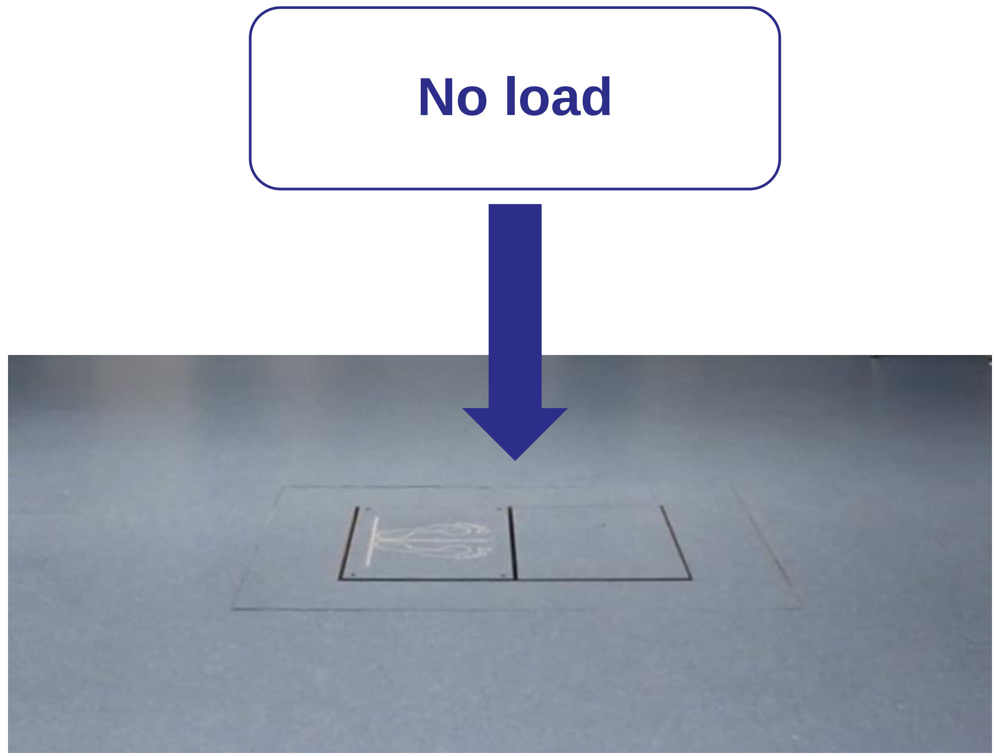


Figure 7. Force platform without load for calibration procedure.

3.2. ANTHROPOMETRIC DATA RECORDING

- Anthropometric data are crucial to describe the participants in a study or make comparisons between groups.

- Weight of the person evaluated is important to use the ground reaction forces registered in posterior comparisons between-group analysis.

Normalization of the forces

Figure 8. Weight registration on a dynamometric platform prior to gait analysis.

3.3. DATA CAPTURE PROCEDURE

1. With or without shoes
2. Delimited walkway
3. Standardization of the instruction
4. Valid registration
5. Number of the repetitions
6. Gait velocity control

3.3. DATA CAPTURE PROCEDURE

- With or without shoes

Figure 9. Gait assessment modalities with dynamometric platform.

3.3. DATA CAPTURE PROCEDURE

- Delimited walkway

Figure 10. Delimited walkway from gait assessment with dynamometric platform. (Right) Space that allows acceleration before to the step within the platform. (Left) Space for deceleration after stepping on the platform.

• Walk looking forward

3.3. DATA CAPTURE PROCEDURE

- Standardization of the instruction

Walk in a straight line from one mark to another when the "start" indication is given

Walk looking forward

Walk at a comfortable, usual or self-selected speed

Walk without any kind of supports to avoid transmitting the force to another point

3.3. DATA CAPTURE PROCEDURE

- Valid registration

Figure 11. Gait assessment with dynamometric platform. (Left) Valid repetition. (Middle) Invalid registration due to the interference of the previous step. (Right) Invalid registration due to the interference of the next step.

3.3. DATA CAPTURE PROCEDURE

➢ Number of the repetitions

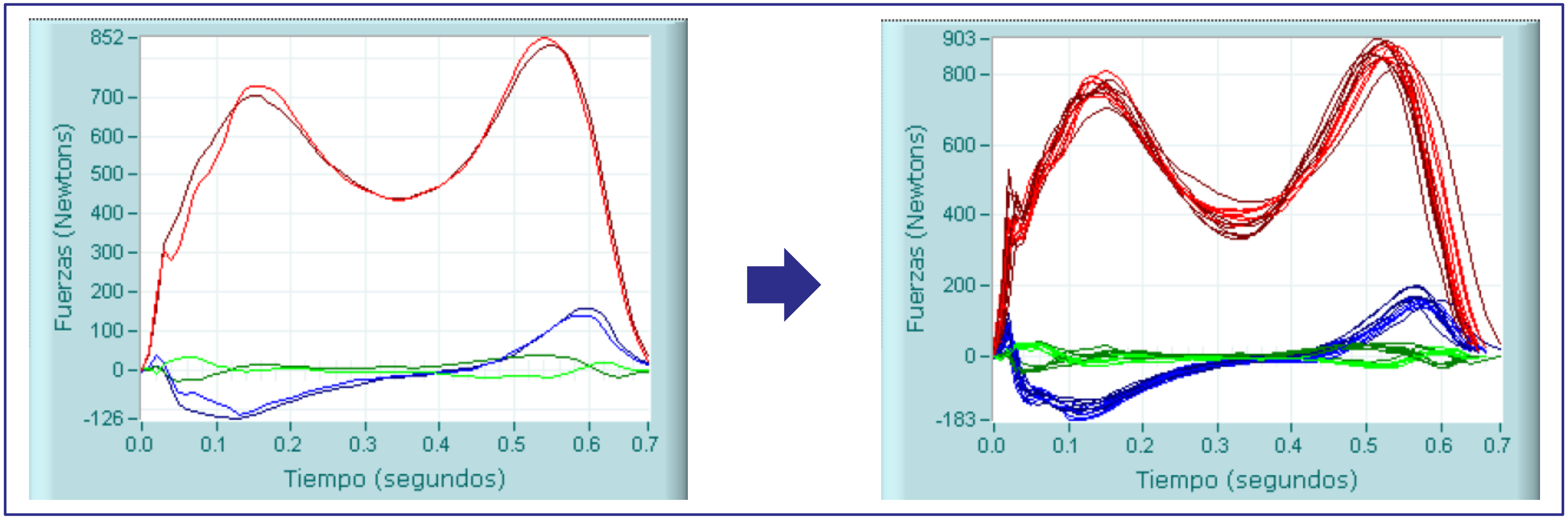


Figure 12. Curves of ground reaction forces. Red: vertical force. Blue: anterior-posterior force. Green: mediolateral force. (Left) Evaluation that includes a single record of reaction forces for right and left foot. (Right) Evaluation that includes several records for right and left foot.

3.3. DATA CAPTURE PROCEDURE

- Gait velocity control

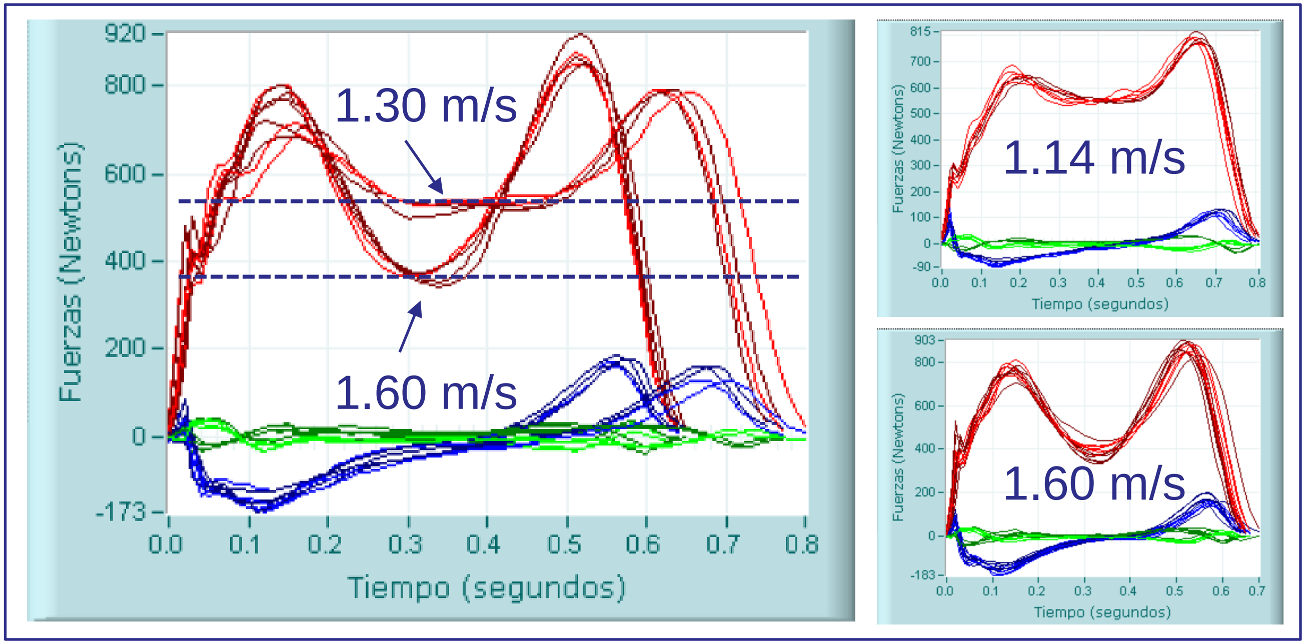


Figure 13. Curves of ground reaction forces at different gait speed (m/s, meter per second). In each graph, the magnitude of the force (N, Newton) is shown on the Y axis and the time (s) on the X axis.

3.4. REVIEW OF THE REPETITIONS COLLECTED

- Check the speed differences of each gait repetition
- Remove curves with morphology clearly different from most recorded curves

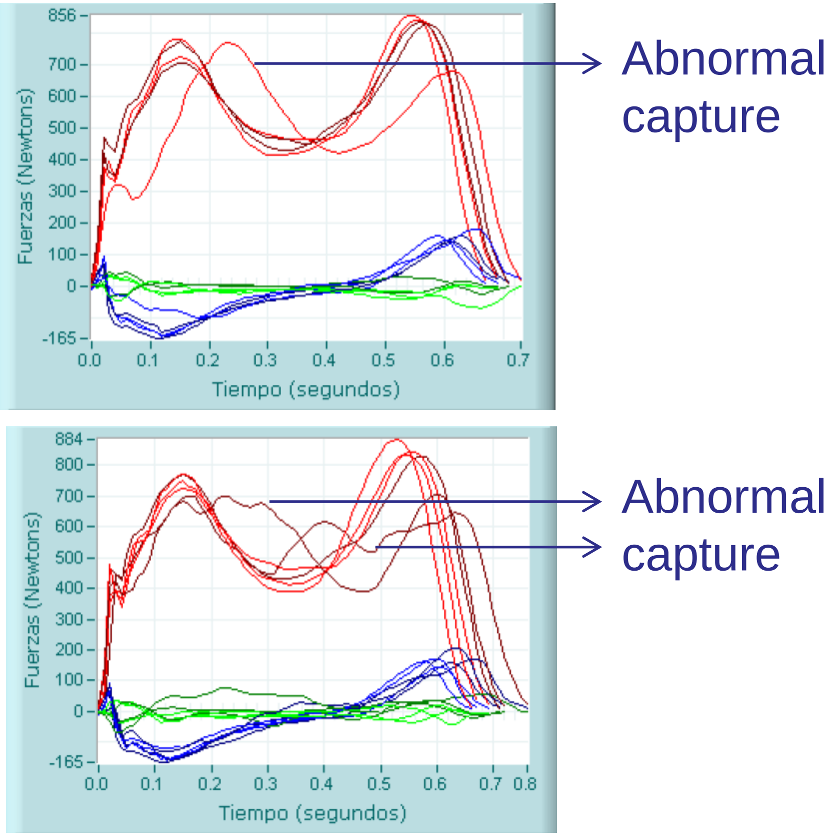


Figure 14. Examples of gait assessment with dynamometric platforms. In both graphs the participant suffers an involuntary ankle inversion.

3.5. READING THE RESULTS OBTAINED

Ground Reaction Forces (GRF)

Centre of Pressure (COP)

- Force th as a re resting hitting t can be position moveme human

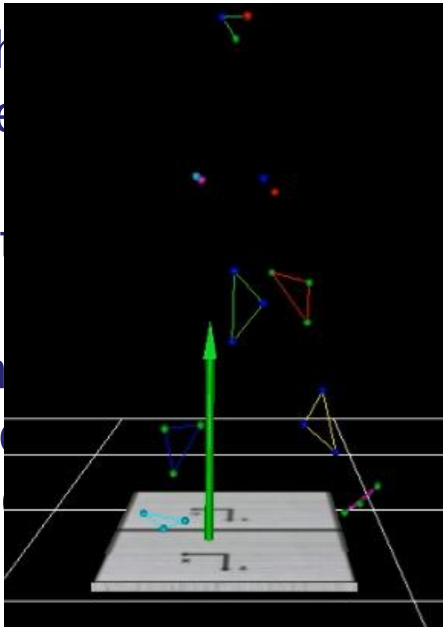


Figure 15. Ground reaction force vector.

- The position on the floor of the ground reaction force vectors is known as the Centre of pressure.

- The COP refers to the average pressure point beneath the foot or feet.

3.5. READING THE RESULTS OBTAINED

The ground reaction force components

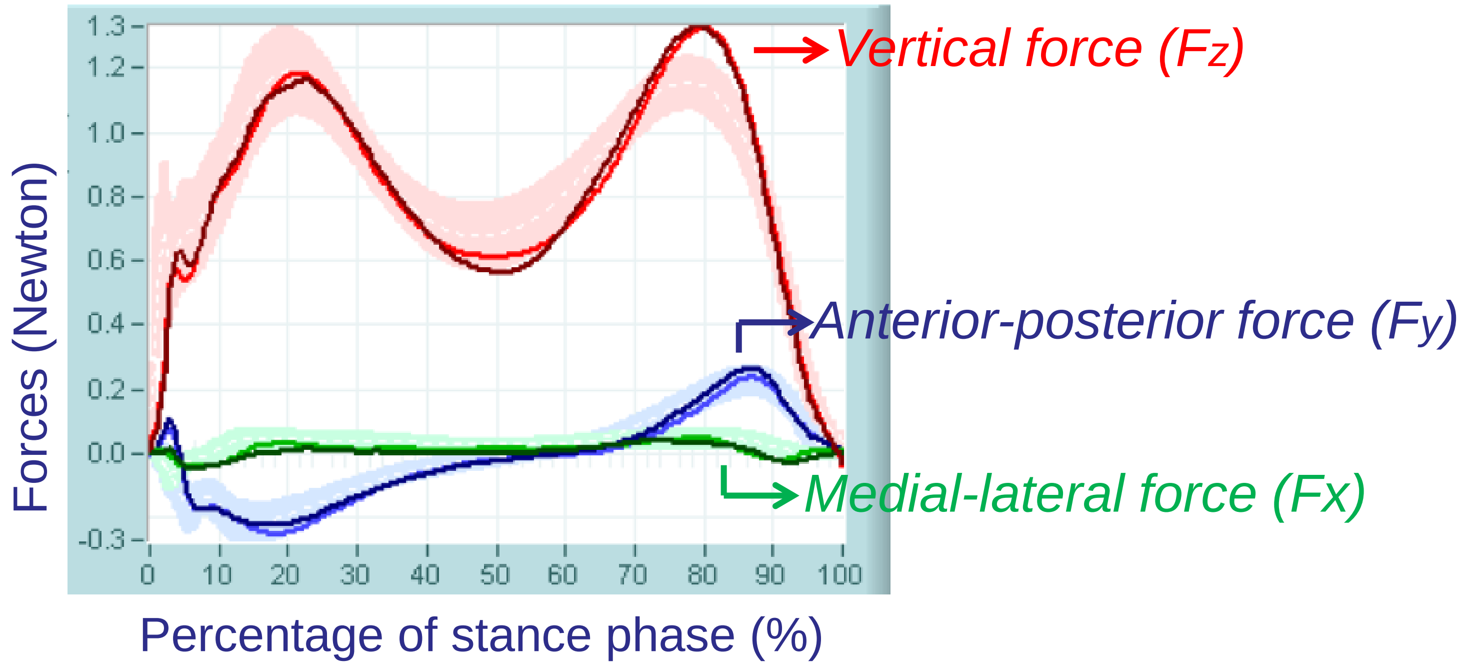
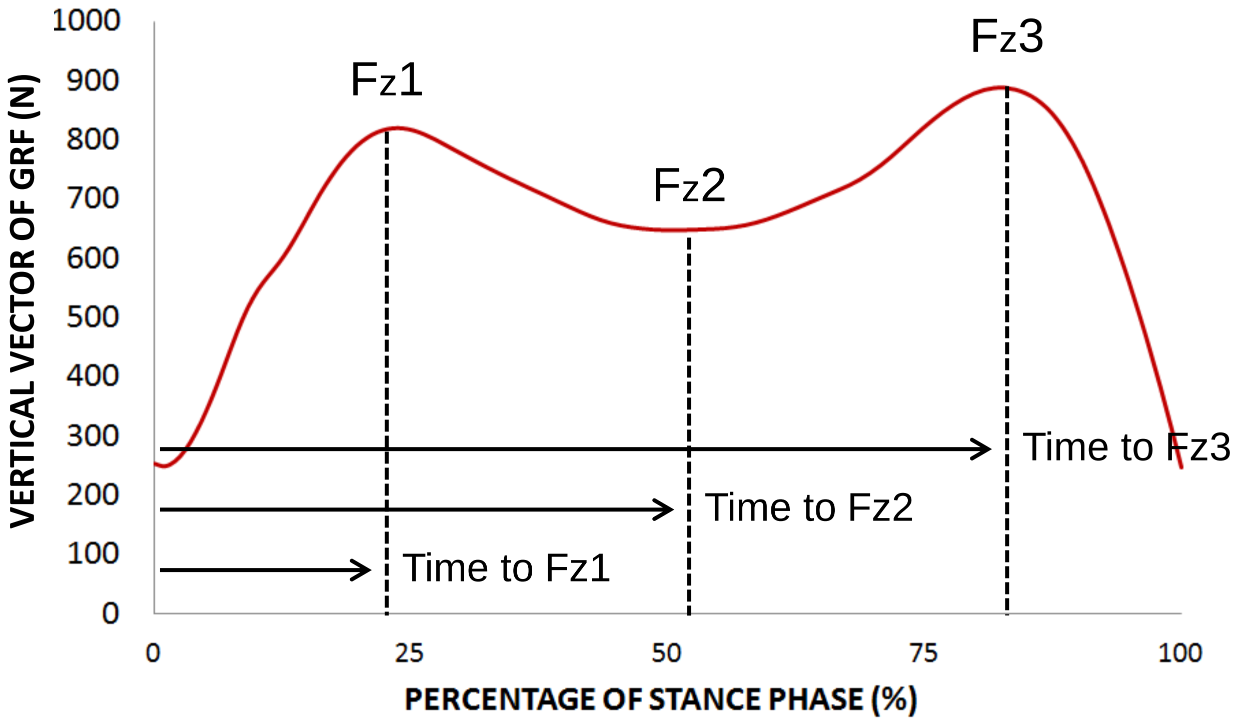


Figure 16. Ground reaction force and its three components.

3.5. READING THE RESULTS OBTAINED

The ground reaction force: Vertical component



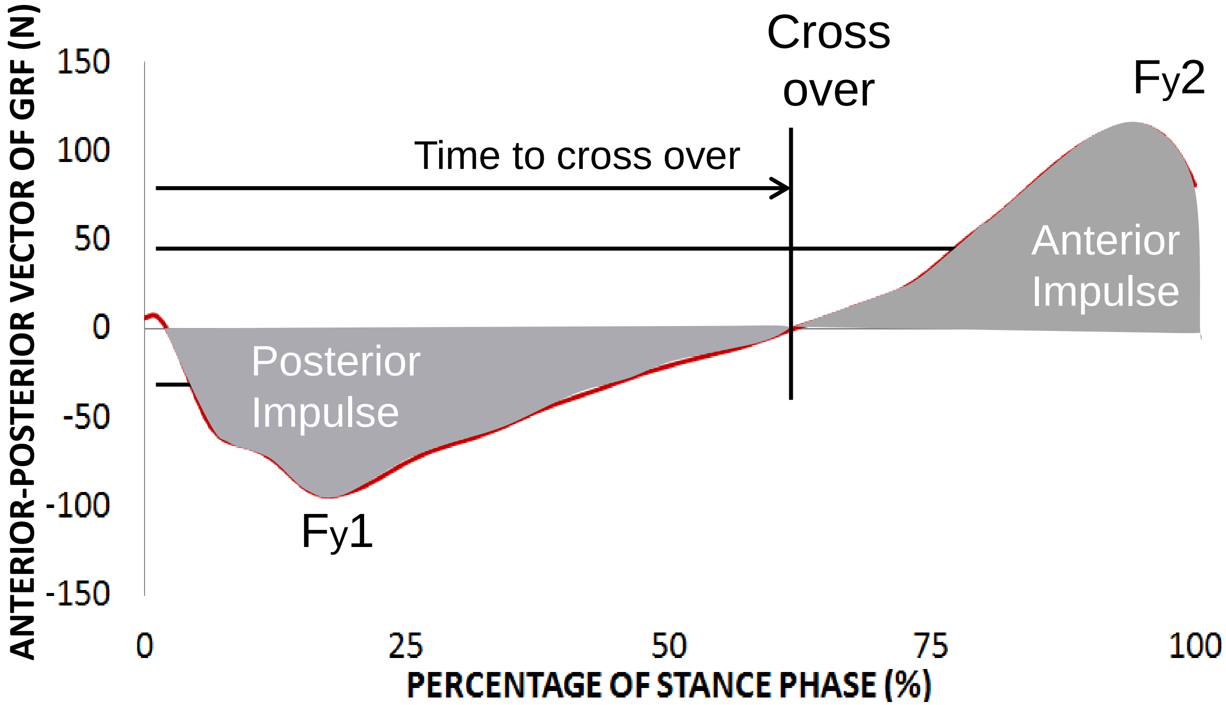
Fz 1: Peak force in maximal weight acceptance

Fz 2: Peak force in mid stance

Fz 3: Peak force in push-off

3.5. READING THE RESULTS OBTAINED

The ground reaction force: Anterior-posterior component

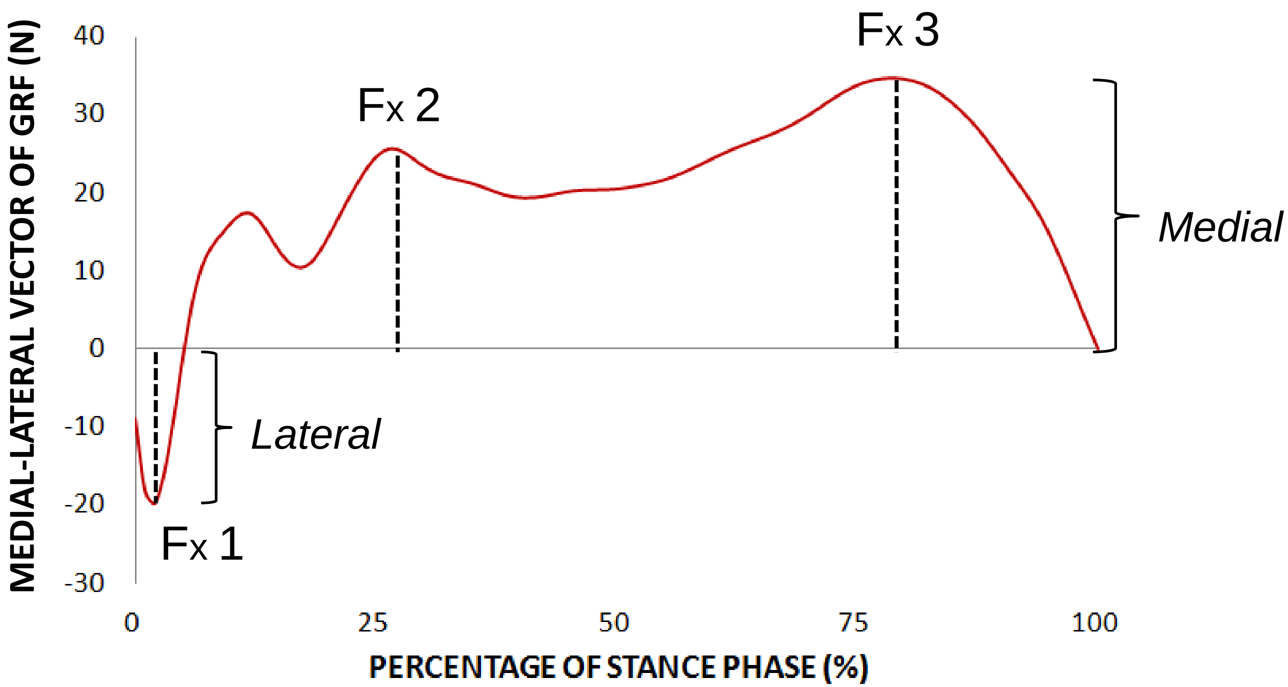


Fy 1: Maximum posterior force. Correspond to the breaking

Fy 2: Maximum anterior force

3.5. READING THE RESULTS OBTAINED

The ground reaction force: Medial-lateral component



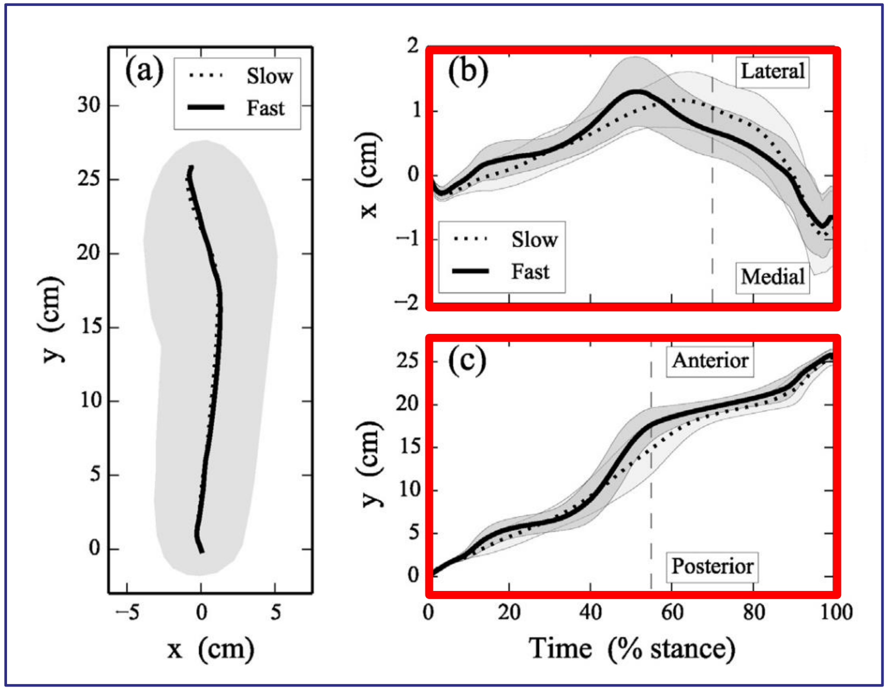
Fx 1: Maximum lateral force

Fx 2: Maximum loading medial force

Fx 3: Maximum propulsion medial force

3.5. READING THE RESULTS OBTAINED

The Centre of pressure (COP)



Medial-lateral against Anterior-posterior

COP speed against Time (stance phase)

Figure 17. Centre of pressure movement during gait at slow (dashed line) and fast velocity (solid line) . From Todd C. Pataky et al. 2014.

(a) Trajectory in the X and Y axes
(b) Medial-lateral movement
(c) Anterior-posterior movement

3.5. READING THE RESULTS OBTAINED

Pedotti diagram

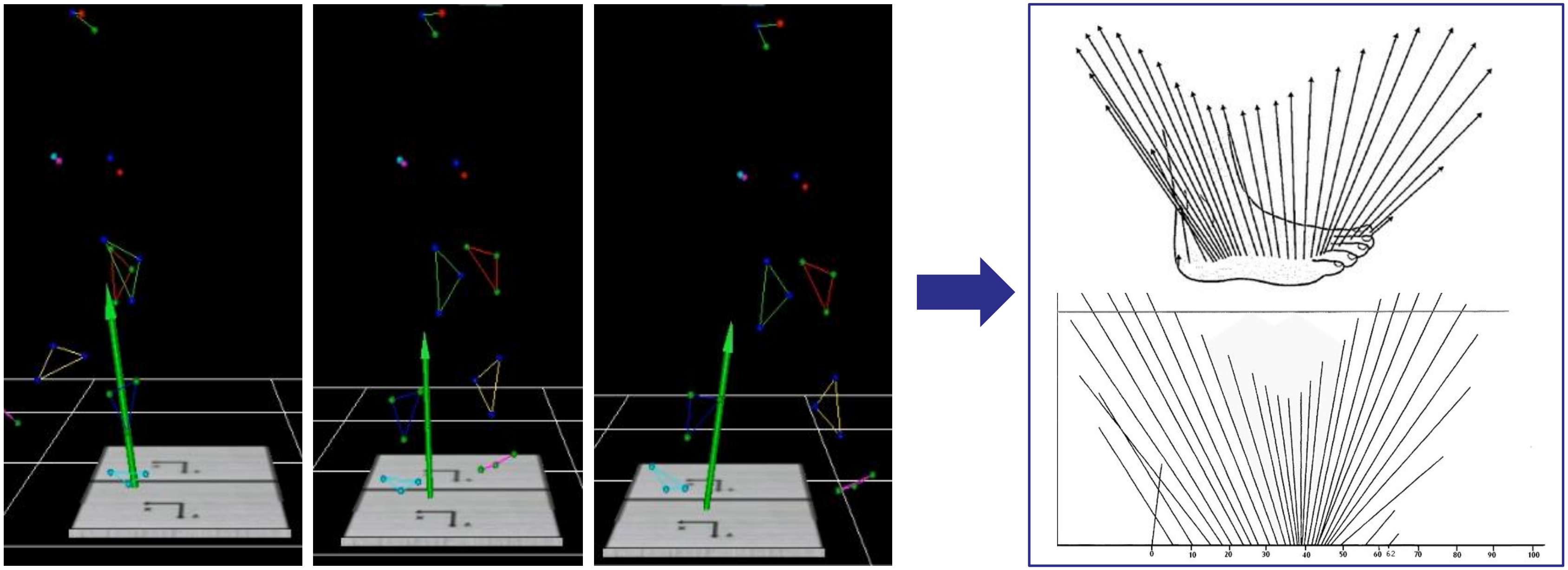


Figure 18. Pedotti diagram. Each arrow represent de ground reaction vector at each point of the stance phase, the base of each vector being the centre of pressure at that point in time. Image from Clinical Movement Analysis, Vrije Universiteit. Available: www.studeersnel.nl.

3.5. READING THE RESULTS OBTAINED

The momentum on a force plate

- Not directly measurable

- Can be calculated with the location of the centre of the platform in the medial-lateral and anterior-posterior directions

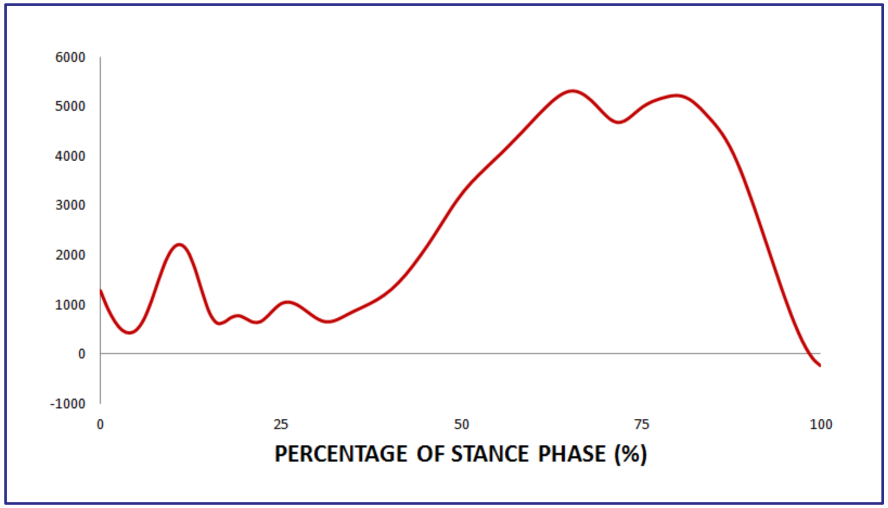


Figure 19. Momentum on the platform during the stance phase of a healthy subject gait assessment.

4 ADVANTAGES AND DISADVANTAGES

Advantages	Disadvantages
➢ No instrumentation is required	➢ It should be built on the walkway
➢ Ease of use and interpretation of results	➢ The number of different contact surfaces to be measured is limited
➢ Precise measuring equipment	➢ Need for more than one platform
➢ Development of portable platforms	➢ High economic cost

D.1 Which gait biomechanical instruments evaluation protocols exist?

Part 4. Instrumented pressure insoles and gait assessment. Clinical approach

1. DEFINITION

Instrumented insoles for plantar pressure

- Kinetic analysis technique
- Insoles with pressure sensors
- In-shoes pressure system
- Portable equipment
- Gait assessment in functional conditions
- *Importance of measuring pressure*

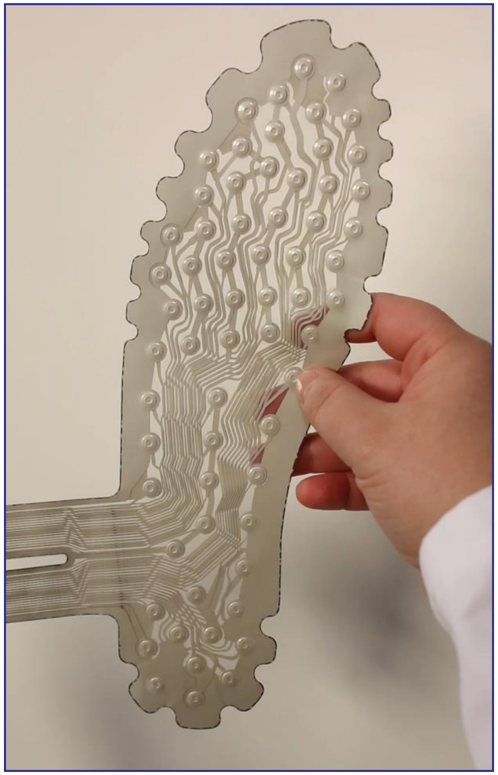


Figure 1. Instrumented insoles with pressure sensors.

2. SYSTEM ELEMENTS

- The insoles with pressure sensors
- A signal amplifier
- A wireless transmitter module
- Software (and computer)

Figure 2. Elements of a plantar pressure measurement system based on instrumented insoles. Biofoot/Biomechanics Institutes of Valencia system.

2. SYSTEM ELEMENTS

Instrumented insoles

- Types of sensors
- Different sizes
  - Avoid folds
  - Sensor distribution
- Pressure unit: kPa
- Careful maintenance

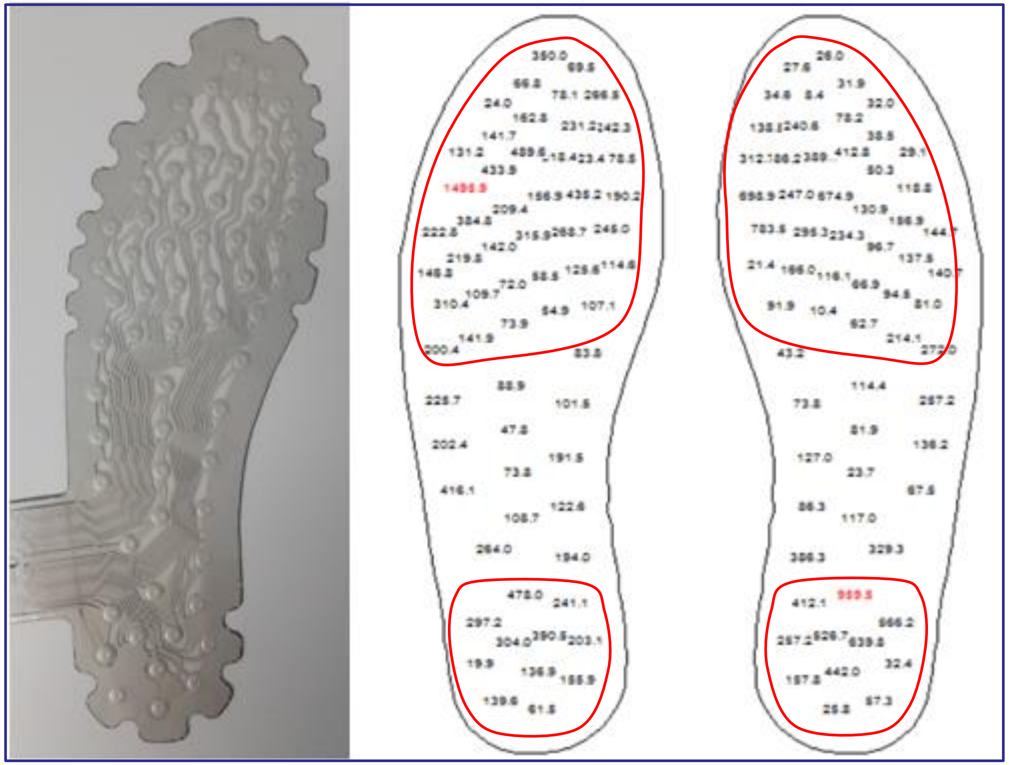


Figure 3. Pressure sensor distribution in instrumented insole.

2. SYSTEM ELEMENTS

Instrumented insoles: types of sensors

Capacitive	Resistive	Piezoelectric
Measurement changes in electrical capacitance	Measurement the change in electrical resistance	Measurement the voltage from the applied pressure to a material

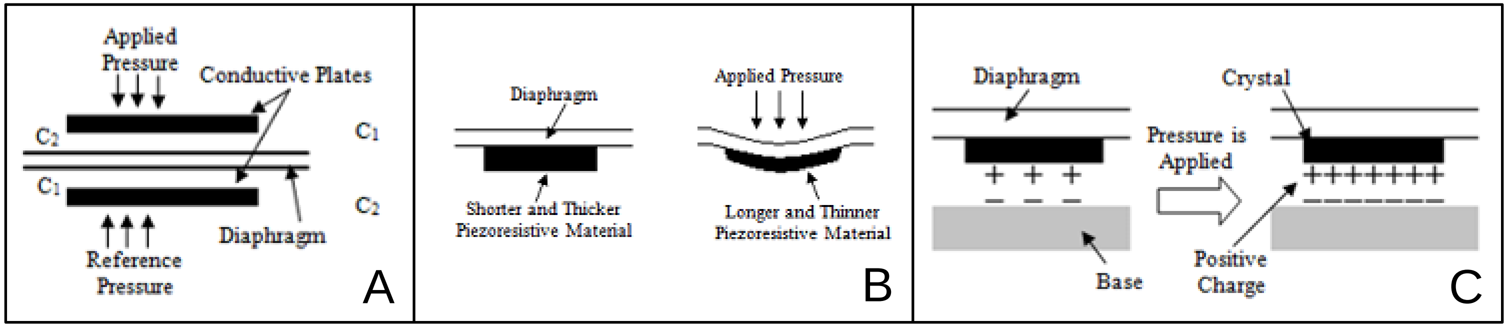


Figure 4. Functioning of pressure sensors. (A) Capacitive. (B) Resistive. (C) Piezoelectric. Images from Nader Ahmadzadeh et al. 2016.

2. SYSTEM ELEMENTS

Instrumented insoles and elements

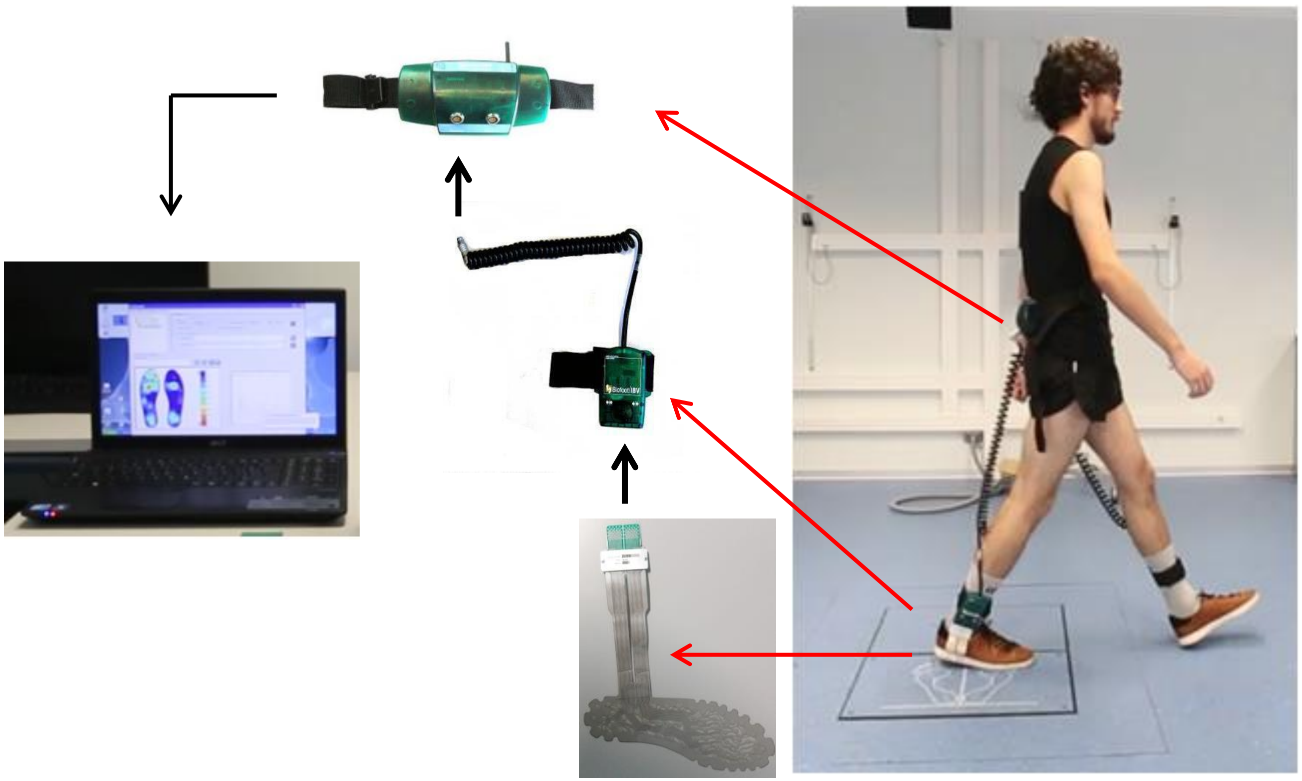


Figure 5. Pressure plantar measurement system.

2. SYSTEM ELEMENTS

Technical specifications and recommendations for gait

Number of sensors per insole

- 24 – 1000 sensors per insole
- Critical zones

fr ... z)

- Nu ... es the syst ... of mea ... ond
- Fo ... Hz

Pressure range (kPa)

- Range of pressure capable of measuring
- Normal gait: 200-500 Hz
- Diabetic neuropathology 1000-3000 Hz

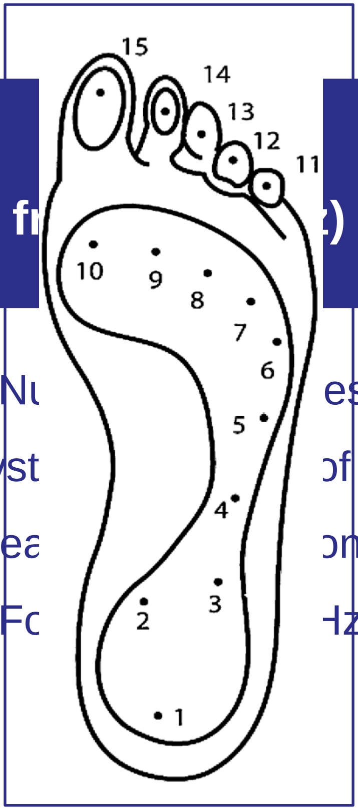


Figure 6. Foot anatomical areas that support the major body-weight. Image from Lin Shu et al. 2010.

3. ASSESSMENT PROTOCOL

Insoles selection and instrumentation

- Suitable insole “*not too tight or loose*”
- Subject seated
- Closed shoe

Figure 7. Insoles positioning.
Biofoot/Biomechanics Institutes of Valencia system.

3. ASSESSMENT PROTOCOL

Intrumented insoles calibration

- Necessary to avoid drift signal
- Calibration of pressure sensors across system varies considerably
  - Standing with the weight of the subject
  - Sitting
- System with piezoelectric sensors: Period for temperature and humidity adaptation inside footwear

Figure 8. Position for calibration procedure.

3. ASSESSMENT PROTOCOL

Control of gait speed

Confortable speed gait

Slow | **Fast**

Speed variations between trials of the same condition: no more than 10%

- The magnitudes of the forces generated when walking depend on several factors, including speed
- In an evaluation of plantar pressures, the speed performed must be controlled
- An increase in walking speed causes an increase in pressures under the foot

3. ASSESSMENT PROTOCOL

Obtaining the results

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

- Definition of pressure
- Colour scale

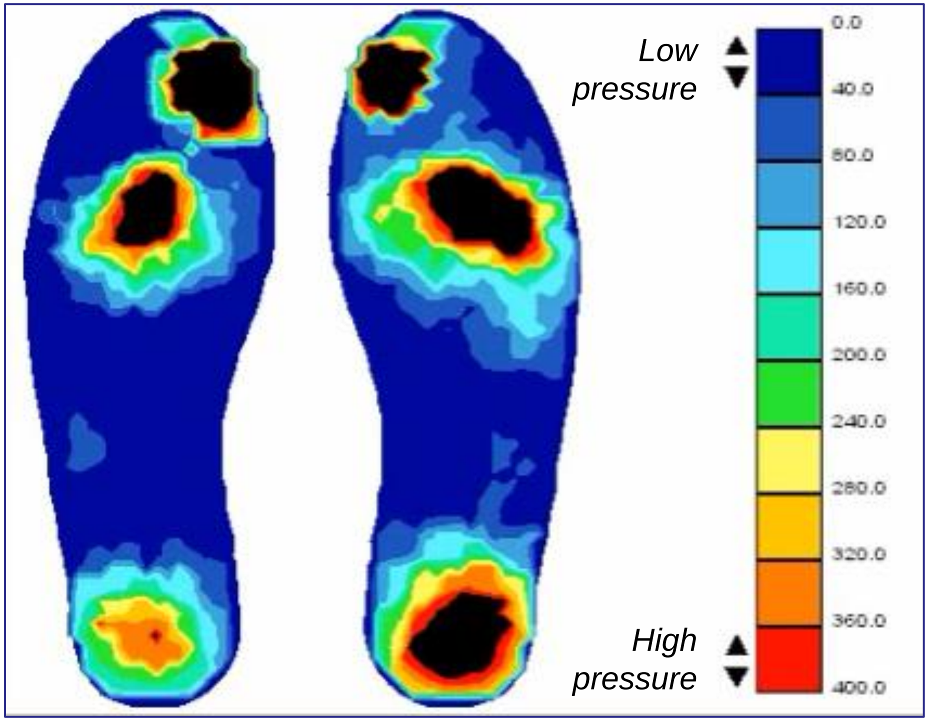


Figure 9. Colour scale map from a plantar pressure assessment.

3. ASSESSMENT PROTOCOL

Obtaining the results

- Regions of interest
- Average pressure
- Peak pressure

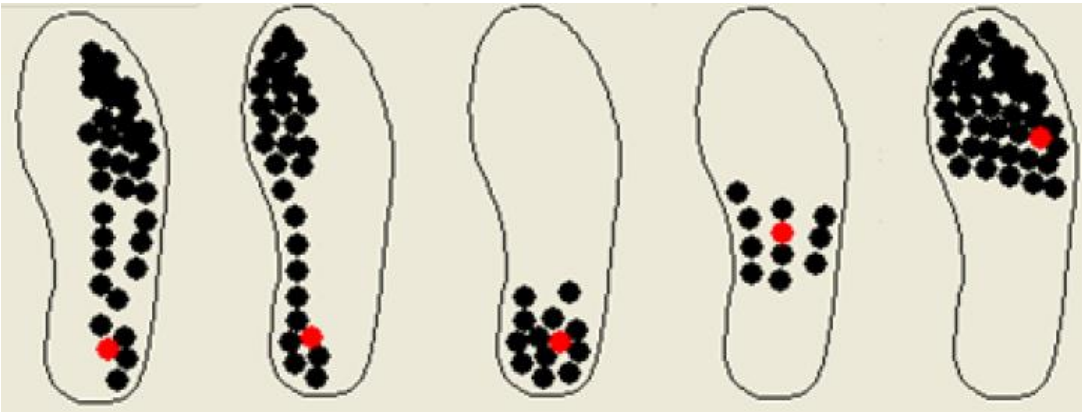


Figure 10. Study of plantar pressures per area of the foot. In order from left to right: medial area, external area, heel, midfoot and forefoot. Image from User manual, Biofoot/Biomechanics Institutes of Valencia system

3. ASSESSMENT PROTOCOL

Obtaining the results

- Pressure-Time Integral
- Centre of pressure
- Other spatiotemporal parameters.

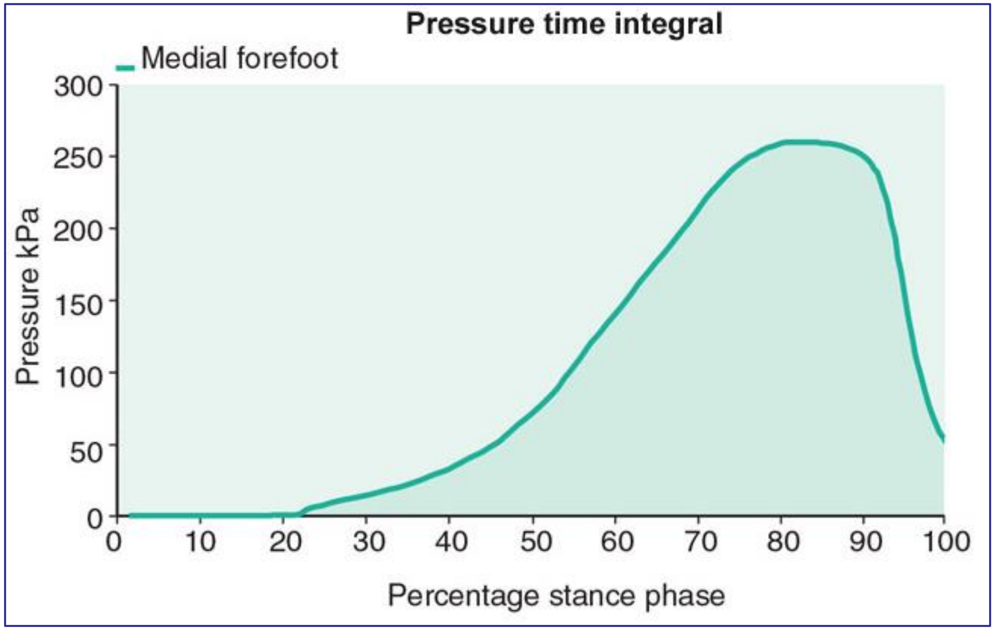


Figure 11. Pressure-time integral curve. Image from Richards J. (2018) The Comprehensive Textbook of Clinical Biomechanics. 2nd ed.

4 ADVANTAGES AND DISADVANTAGES

Advantages	Disadvantages
Allow the direct measurement of pressure acting on the foot	The curvature of the foot
Assessment in functional conditions: in movement and with shoes	The lack of space for the transducers
	The use of wires from the inside of the shoe
It does not require excessive preparation of the subject	Is not recommended to compare pressure measurement values between different system

D.1 Which gait biomechanical instruments evaluation protocols exist?

Key Ideas

KEY IDEAS

- Human gait can be evaluated with different biomechanical assessment instruments, which allow us to objectify its performance and deficits.
- Photogrammetry is a technique for measuring kinematic variables from images, either from photo cameras or video cameras.
- To perform a gait analysis with photogrammetry, it is necessary to instrument the person evaluated with a biomechanical model composed of markers that will indicate the points that make up the body segments that perform the movement
- The most used biomechanical model to measure gait is the Calibrated Anatomical System Technique (CAST), which allows to analyze the march in the three planes of movement.

KEY IDEAS

- Among the clinical gait variables that can be measured with photogrammetry are Range of flexion-extension movement, internal-external rotation, abduction-adduction in each joint of the biomechanical model and Peak angles, which refers to the maximum degree of movement reached in the analyzed curve.
- Linear acceleration during gait is possible to measure with an accelerometer system and is refers to the change in the linear velocity over successive time intervals. The unit of acceleration, in the International System of Unit, is meters per second square (m/s2) although it can often be found expressed in gravity ratio (g). Positive acceleration have a positive value, but a negative value represents a deceleration.
- The protocol using accelerometers in gait analysis typically consists of attaching an accelerometer to the trunk, head and tibial segment. One of the most important points of the protocol is the fixation of the accelerometer on the skin, which must prevent the relative movement of the accelerometer to faithfully represent the acceleration of the segment to be measured.

KEY IDEAS

- A force platform or a force plate is an equipment to measure ground reaction forces (GRF) and their point of application known as centre of pressure (COP). It is an element widely used in the assessment of human gait and balance, as well as in a several human activities and functions.
- The registered forces will depend, as we have already said, on the speed, but also on the weight of the valued person. That is why, in order to make comparisons between individuals we need to divide the forces obtained by the weight of the person and thus obtain a comparable dimensionless parameter between subjects. On the other hand, the control of gait speed is also necessary between gait trials of the same condition.
- The ground reaction force vector has three component, in the three axes of space: a) Vertical force component in the Z axis, b) Anterior-posterior force in the Y axis, and, c) Medial-lateral component in the X axis.

KEY IDEAS

- The instrumented insoles for plantar pressure are a kinetic analysis technique that, inside the insoles have a several of pressure sensors strategically distributed, to measure the static and dynamic plantar pressure. These insoles are located inside the footwear of the person evaluated, so it is a portable equipment and allow the assessment of gait in functional conditions, it is mean, with footwear and in movement. The importance of measuring plantar pressure is that excessive pressures can cause tissue damage.

- In the analysis of plantar pressures, it is more useful to study the parameters for each area of the foot. Usually the devices allow to analyze the results of the plantar pressure divided in the heel, midfoot, forefoot and internal and external area of the foot.

D.1 Which gait biomechanical instruments evaluation protocols exist?

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