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# BIPODAL BALANCE PROCEDURES & TESTING

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# INTRODUCTION

**Bipodal balance refers to the ability of an individual to maintain a stable posture while standing on two feet (Pollock et al., 2020).**

This is an essential aspect of daily activities, as it is required for walking, running, and various other movements. Maintaining bipodal balance requires an intricate interaction between the neuromuscular, sensory, and musculoskeletal systems. Any disruption to this interaction can lead to decreased balance and an increased risk of falls. Bipodal balance is crucial in clinical practice, particularly in the fields of physical therapy, rehabilitation, and sports medicine. Impaired bipodal balance is a common problem in patients with various conditions such as stroke, Parkinson's disease, musculoskeletal injuries and concussion. In addition, maintaining good balance is essential for athletes and individuals who engage in physical activities. Therefore, assessing and improving bipodal balance is an essential part of the clinical practice. Traditionally, bipodal balance has been assessed using subjective methods, especially in neurology and gerontology, such as the Berg Balance Scale, the Timed Up and Go test, and the Clinical Test of Sensory Integration of Balance. However, these methods have several limitations, including inter-rater variability, lack of sensitivity, and inability to capture the subtle changes in balance that occur during daily activities. As a result, objective measures such as force plates are becoming increasingly popular in clinical practice.

Force plates are devices that measure the forces acting on the ground during standing, walking, and other weight-bearing activities. The data collected by force plates can provide valuable information on the patient's balance, gait, and functional movements. Force plates typically are 1D or 3D, which means that they can measure either the vertical force alone, or all three forces: vertical force, anterior-posterior force, and medial-lateral force.

The vertical force is the force acting on the ground perpendicular to its surface, while the anterior-posterior and medial-lateral forces are the forces acting on the ground in the sagittal and frontal planes, respectively. One of the most critical variables derived from force plate data is the center of pressure (CoP). The CoP is the point where the vertical ground reaction force intersects the force plate and represents the location of the patient's center of mass. By analyzing the CoP, clinicians can obtain detailed information on the patient's balance and postural control. This information is particularly useful in assessing the stability and sway of a patient's posture. While subjective methods can be used to evaluate the CoP, force plates provide an objective measure of the CoP's displacement, which allows clinicians to measure balance more accurately. In addition, force plates provide valuable information on the forces acting on the ground, which allows for a more detailed understanding of the patient's balance and gait. By analyzing the forces acting on the ground, clinicians can identify areas of weakness and develop appropriate treatment plans. Force plate data is often used to analyze the sway of the CoP, which is a measure of the patient's stability during standing. The sway of the CoP is influenced by several factors including the patient's sensory input, neuromuscular control, and musculoskeletal function. By analyzing the sway of the CoP, clinicians can identify areas of weakness and develop appropriate treatment plans.

DYNAMIC REPORT — 36.0/MIN  
CoP ANALYSIS — STANCE EVALUATION  
CENTER OF PRESSION AND WEIGHT  
ANALYSIS, MEASUREMENT  
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# DATA COLLECTION

## HOW TO PREPARE THE TEST

It's generally recommended to perform a warm-up before any bipodal balance assessment. A warm-up can help increase blood flow to the relative muscles, improve joint mobility and range of motion and enhance neuromuscular function, which can all contribute to better balance performance. The specific warm-up protocol will depend on the nature of the balance assessment being performed. In general, the warm-up should be specific to the demands of the balance assessment and gradually increase in intensity to prepare the body for the task at hand. A warm-up period of 5-10 minutes is typically sufficient, but the exact duration may depend on the individual's fitness level and the intensity of the warm-up activities. But we should also keep in mind that warm up will affect performance and in most cases will improve the results. A warm-up period before a bipedal balance assessment may not always be desirable, depending on the specific context and goals of the assessment. For example, in some clinical settings, such as testing for acute balance impairments or neurological disorders, a warm-up may not be feasible or necessary. However, when assessing the balance of elderly individuals, it's important to consider the natural circumstances of everyday life, where they must frequently get up from a chair and establish balance to avoid falling. In such cases, a warm-up period may not be necessary to assess their true balance abilities. Ultimately, the decision to include or exclude a warm-up period should be based on the specific context and the goals of the assessment, taking into account the age and health status of the individual being assessed.

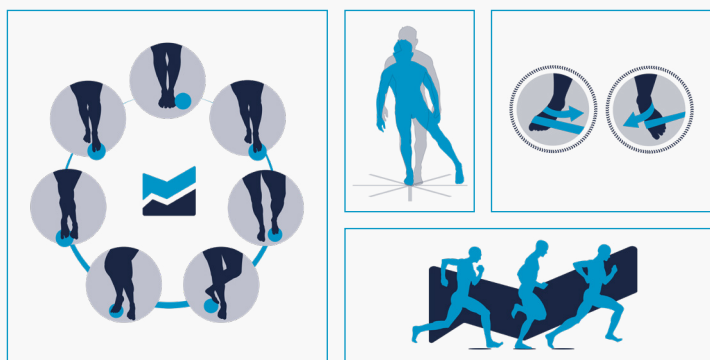


FIGURE 1: Example of a warm-up exercise.

### SUGGESTED CONFIGURATION



5s Preparation Time



3 Repetition



Open/ Closed Eyes



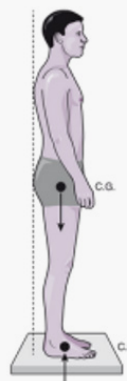
15s Rest



60s Duration

## PROCESS

- **Step 1:** Standing on the platform, the patients take 3-4 steps on the spot to find his/her optimal position
- **Step 2:** Arms are kept relaxed at the side
- **Step 3:** Focus is on a marker between 3 to 5 meters away (for the eyes-open condition)
- **Step 4:** Remain as stable as possible during the duration of the test



Ensure that the position of the subject's feet on the force platform is standardized



# DATA TREATMENT

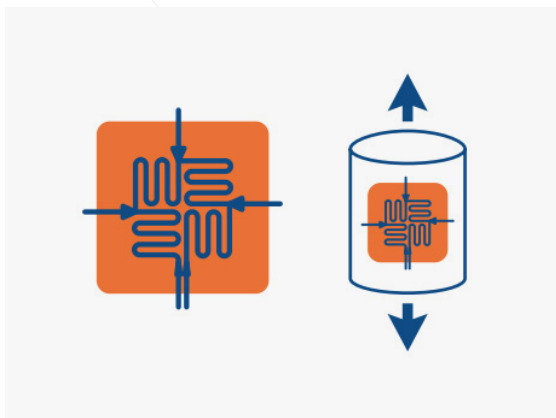
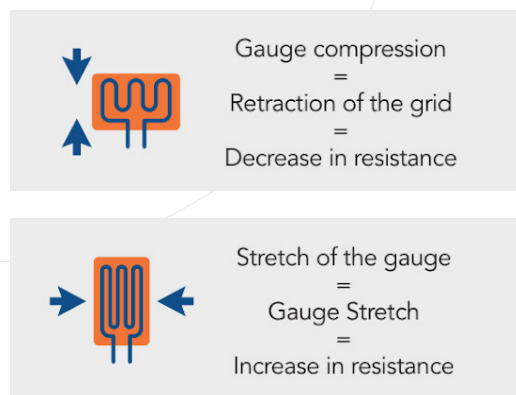
## SIGNAL PROCESSING

### ACQUISITION FREQUENCY

To perform a bipodal stance evaluation, an acquisition frequency of 50 - 100Hz is more than optimal (corresponds to 50 -100 data points per second). A minimum acquisition frequency of 50 Hz is recommended for bipedal balance evaluations because this sampling rate is sufficient to capture the relevant information needed to make accurate and reliable balance measurements. The human postural control system works by constantly making small adjustments to maintain balance, resulting in continuous body sway and center of pressure (CoP) displacement. These movements occur at relatively low frequencies (less than 10 Hz) and are therefore based on Nyquist theorem can be effectively captured at sampling rates of 50 Hz or more. Sampling at a lower frequency than 50 Hz may not accurately capture the high-frequency movements that occur during balance tasks, which can lead to errors in balance measurement and a loss of sensitivity to detect subtle changes in balance performance (Quijoux et al., 2021). However, it's worth noting that in some clinical and research settings, higher sampling rates (e.g. 100 Hz or higher) may be necessary to accurately capture more subtle changes in balance control. In these cases, the optimal acquisition frequency will depend on the specific context and goals of the assessment, and the measurement technology being used.

### HOW THE SENSORS DETECT THE MOVEMENT/SIGNAL

The data are collected by the four (4) force sensors of K-Deltas with a sampling rate of up to 4000 Hz (not optimal for balance evaluations). The mobile application (Kinvent Physio) is connected by Bluetooth to the force plates in which data are filtered and analyzed. KINVENT platforms consist of 4-strain gauge load cells. A load cell usually consists of a steel test body to which the 4-strain gauge grid support is glued. Under the influence of a force, the test body expands or shrinks. The force applied to this body causes a deformation leading to a stress. A gauge is a support that contains a conductive measuring grid that will either compress or stretch and therefore change the electric resistance in the filaments of the grid to determine the strain.



The force transducers contain 4 strain gauges connected to each other, known as a **Wheatstone Bridge**, which has:

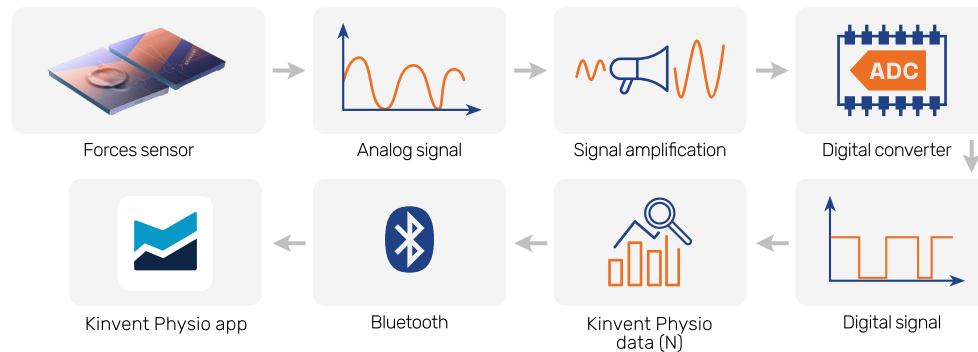
- 2 gauges parallel to the force vector
- 2 gauges mounted laterally to the applied force

These 4 strain gauges are glued to the test body.

When a force is applied to a load cell, the steel deforms and the electric resistance of the strain gauge changes. The output signal gives information about this deformation and thus the force acting on the gauges is calculated.

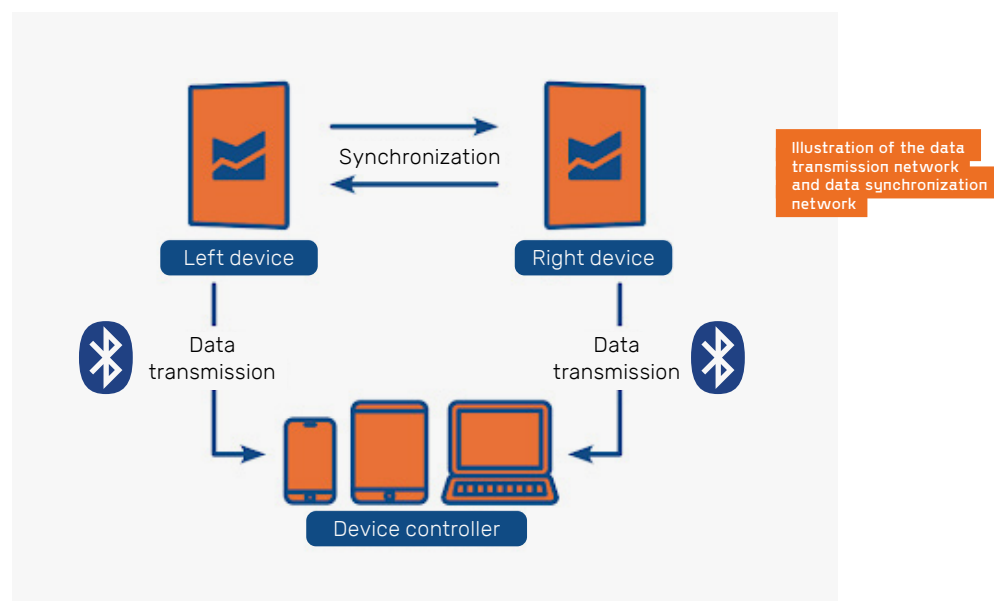
## HOW THE SIGNAL IS DIGITIZED AND SENT TO THE APP

**The devices have 8 force sensors (4 for each pair).** These load cells send out small amplitude analogue signals (a few millivolts). These signals are amplified and then digitized using an analogue-to-digital converter (A/D). The microcontroller in the devices uses our algorithm to determine the force in N from the signal in volts. As the force plate are connected with a mobile application (Kinvent Physio). The data are transmitted with Bluetooth to the application.



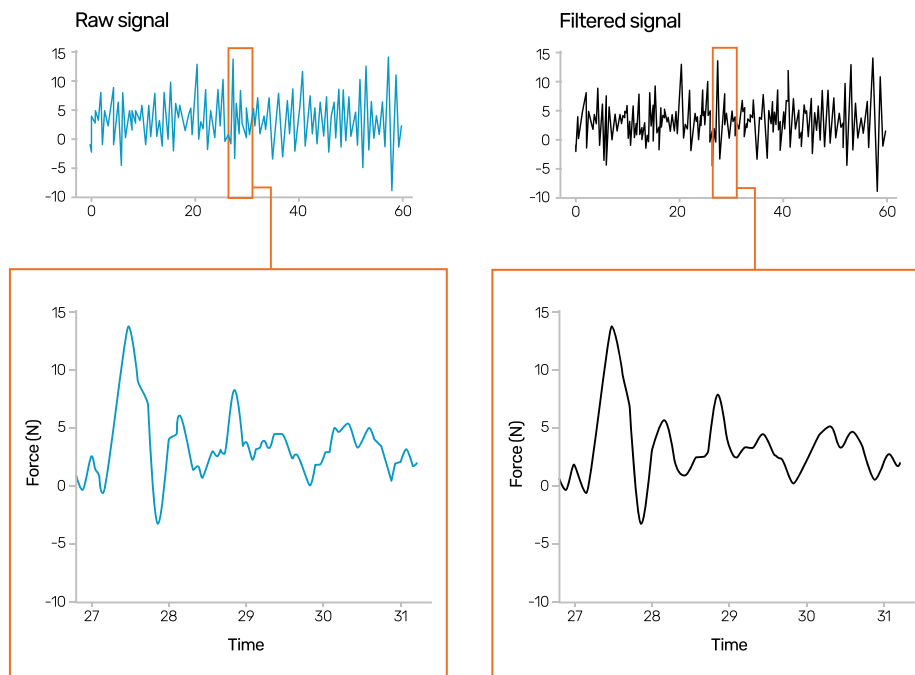
We have built our sensor network using «**SIMULTANEOUS MULTI-PROTOCOL**» technology, which utilizes two communication networks using different transmission protocols at the same time:

- **Data transmission network:** This primary network is used to transfer data between the sensors and the master device. This network uses a standardized transmission protocol like Bluetooth to support more hardware.
- **Synchronization network:** It is the secondary network. It contains only the sensors or actuators to be synchronized. The sensors and actuators use this network to exchange synchronization information. The synchronization network uses this protocol to exchange synchronization information between the sensors without interrupting the data transmission to the mobile device.



## HOW THE SOFTWARE PROCESSES THE INCOMING SIGNAL

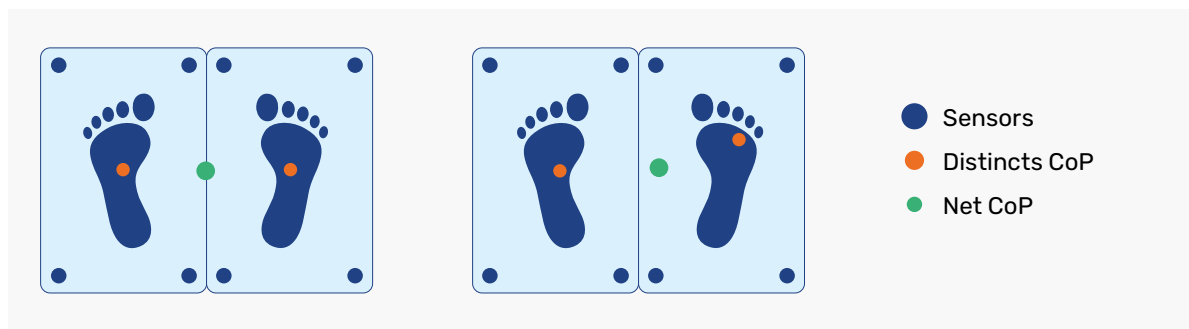
Once the signal has been received, the data will be processed by a proprietary algorithm that has been built into the application. This algorithm will make it possible to filter the data to remove noise from the signal. Additionally, it will make it possible to calculate various parameters for interpreting the signal.



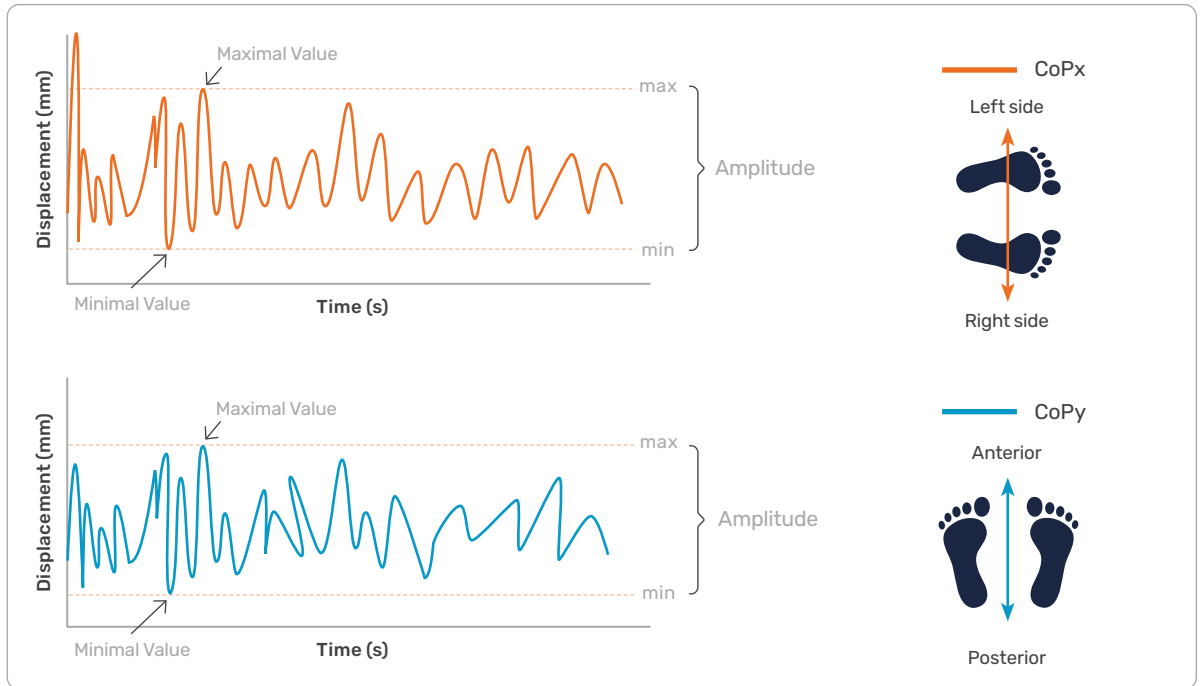
## BIOMECHANICS

### How we move from force values to CoP values:

A bipodal balance test conducted on a force platform yields information about the Center of Pressure (CoP), which is defined as the “point location of the vertical ground reaction force vector” and represents a weighted average of pressures over the surface in contact with the ground (Winter, 1995). The net CoP is located between the two feet, determined by the relative weight on each foot. Since both feet are in contact with the ground, there are separate CoPs under each foot reflecting the neural control. Each sensor detects forces that vary according to the subject’s position, and an algorithm uses this information to determine the distinct CoP position under each foot. The net CoP values along the medial-lateral (CoPx) and antero-posterior (CoPy) axes are then calculated using the appropriate formulas.



The CoP is characterized by antero-posterior (CoPy) and medio-lateral (CoPx) movements



## KEY PERFORMANCE INDICATORS

### Ellipse area

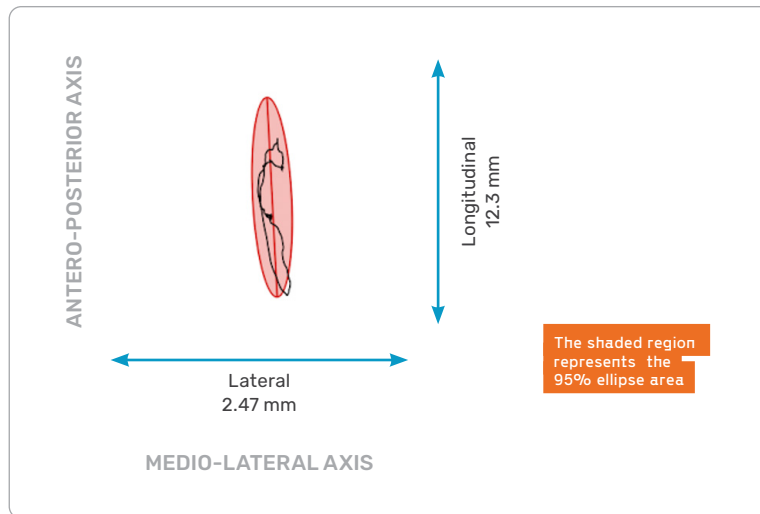
A very significant KPI during balance assessment is the the ellipse area and can be calculated using the covariance method. This method involves analyzing the movement of the center of pressure (CoP) during a balance task.

To calculate the area of the ellipse using the covariance method, the following formula is used:

$$\text{Area} = \pi \times SD_{(AP)} \times SD_{(ML)} \times \sqrt{(1 - [\text{Cov}_{(AP, ML)} / (SD_{(AP)} \times SD_{(ML)})]^2)}$$

#### Where

- **A** is the area of the ellipse
- $\pi$  is the mathematical constant pi
- $SD_{(AP)}$  is the standard deviation of the center of pressure (CoP) position in the anterior-posterior (AP) direction
- $SD_{(ML)}$  is the standard deviation of the CoP position in the medial-lateral (ML) direction
- $\text{Cov}_{(AP, ML)}$  is the covariance between the CoP position in the AP and ML directions



### CoP Path Length

The CoP (center of pressure) path length in balance refers to the distance that the CoP travels during a balance task. It is a measure of the overall movement of the CoP and is used as an indicator of postural control.

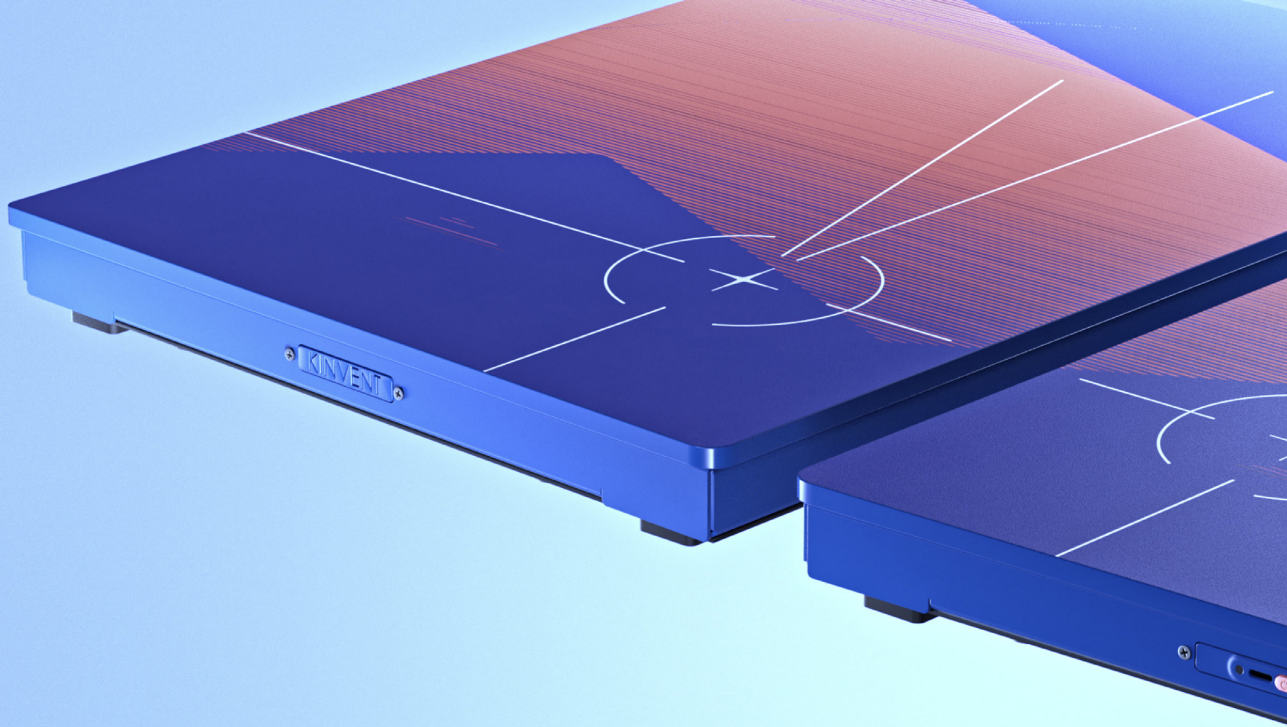
The CoP path length is typically calculated by summing the distances between each consecutive CoP point measured during the balance task. This can be done using the following equation:

$$\text{CoP}_{\text{path length}} = \sum \left[ \sqrt{((\text{CoP}_{x(i)} - \text{CoP}_{x(i-1)})^2 + (\text{CoP}_{y(i)} - \text{CoP}_{y(i-1)})^2)} \right]$$

#### Where

- $\text{CoP}_{x(i)}$  and  $\text{CoP}_{y(i)}$  represent the x and y coordinates of the CoP at point i
- $\text{CoP}_{x(i-1)}$  and  $\text{CoP}_{y(i-1)}$  represent the x and y coordinates of the CoP at the previous point (i-1)
- $\sum$  refers to summing the values for all i from the beginning to the end of the task

By calculating the CoP path length, we can obtain an overall measure of the movement of the CoP during a balance task. This measure can be used to assess postural control, as well as to track changes in postural control over time.



JUMP HEIGHT PE

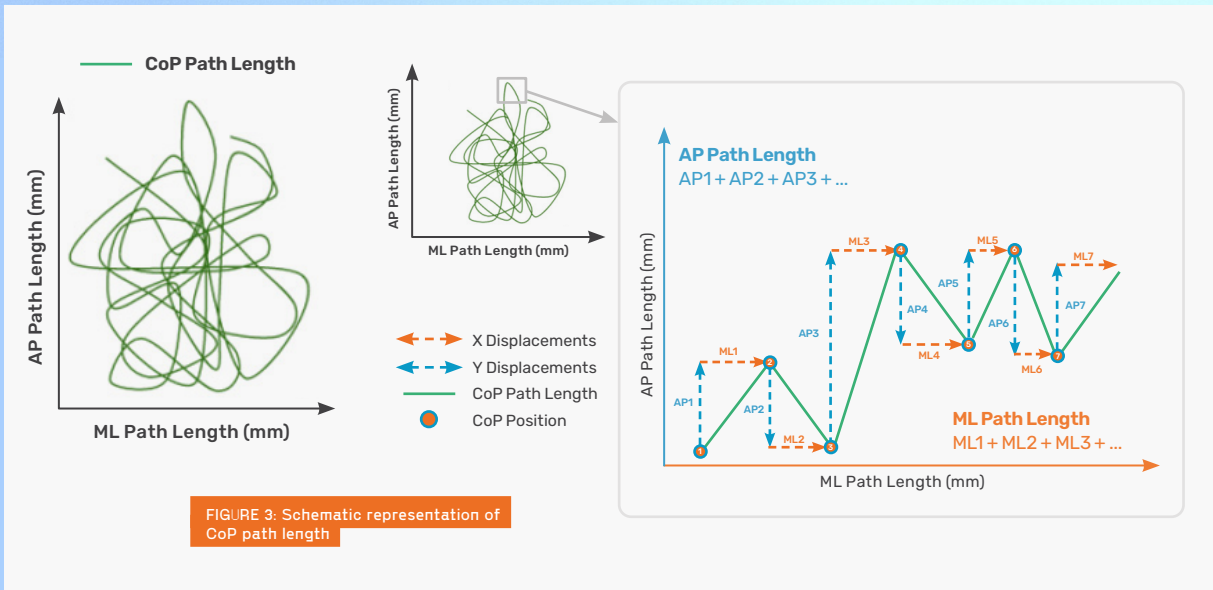


FIGURE 3: Schematic representation of CoP path length

### CoP mean velocity

Once the CoP path length has been determined, we can calculate the average speed of the CoP. The CoP mean velocity is defined as the sum of the distances between consecutive points.

$$\text{CoP}_{\text{Mean Velocity}} = \frac{\text{CoP Path Length}}{\text{Total Time}}$$



## CLINICAL INTERPRETATIONS

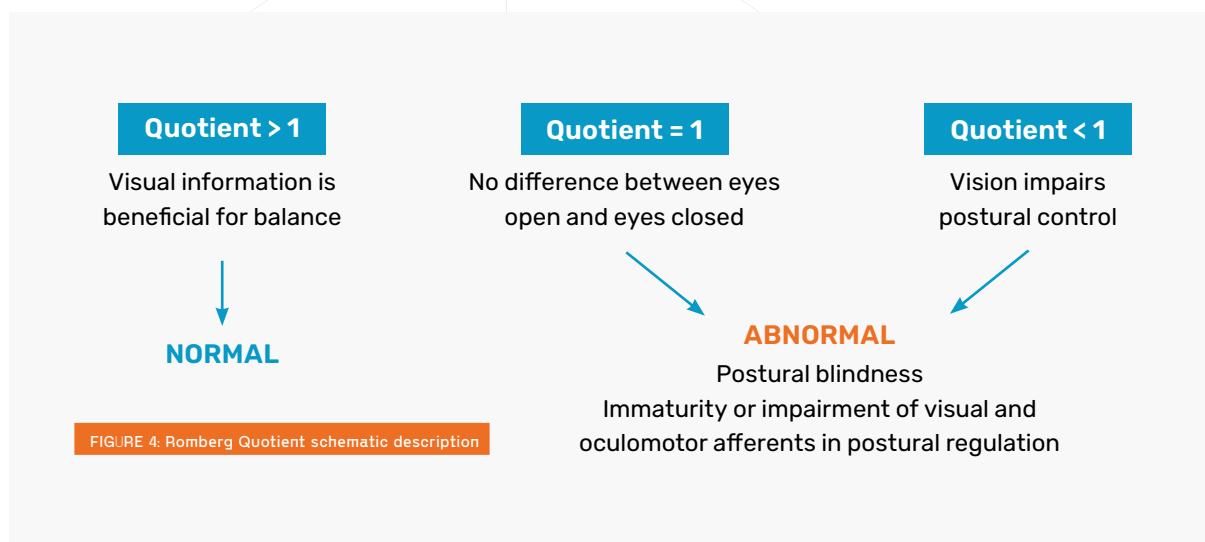
KPI	CLINICAL RELEVANCE
<b>COP ELLIPSE AREA (mm<sup>2</sup>)</b>	<p>Research has linked the ellipse area, which is a common measure of postural sway obtained during balance assessment, with various pathologies and conditions that affect balance and postural control.</p> <p>For example, studies have found that the CoP ellipse area is larger in individuals with Parkinson's disease compared to healthy controls during standing and walking tasks (Paolucci et al., 2020). Other studies have investigated the ellipse area in individuals with multiple sclerosis, stroke, and other conditions affecting balance and postural control. These studies have generally found that increased ellipse area is associated with decreased postural control and increased risk of falls (Gama et al., 2019).</p> <p>In addition, the CoP ellipse area has been used as a measure of treatment effectiveness and can be used to track changes in postural control over time. For example, studies have found that interventions such as balance training, visual feedback, and proprioceptive training can lead to reductions in the ellipse area in individuals with various pathologies (Miko et al., 2018).</p> <p>Overall, the CoP ellipse area is a useful measure for assessing postural control and balance in various populations, and can provide important information for diagnosis, treatment, and rehabilitation of conditions affecting balance and postural control.</p>
<b>COP PATH LENGTH (mm)</b>	<p>Research has linked the CoP (Center of Pressure) path length with various pathologies and conditions that affect balance and postural control.</p> <p>For example, studies have found that individuals with Parkinson's disease, a neurological disorder that affects movement and balance, have a larger CoP path length compared to healthy controls during standing and walking tasks (Morenilla et al., 2020).</p> <p>Other studies have investigated the CoP path length in individuals with ankle sprains, stroke, and other conditions affecting balance and postural control (Verhagen et al., 2004). These studies have generally found that increased CoP path length is associated with decreased postural control and increased risk of falls (Gama et al, 2019).</p> <p>Overall, the CoP path length is a useful measure for assessing postural control and balance in various populations, and can provide important information for diagnosis, treatment, and rehabilitation of conditions affecting balance and postural control.</p>
<b>COP MEAN VELOCITY (mm/s)</b>	<p>Research has provided some links between the CoP (Center of Pressure) mean velocity and certain pathologies, particularly those affecting the balance and postural control system.</p> <p>For example, studies have found that individuals with Parkinson's disease have a higher mean CoP velocity compared to healthy controls during standing tasks (Morenilla et al., 2020). Other studies have investigated the CoP mean velocity in individuals with multiple sclerosis, stroke, and other conditions affecting balance and postural control. These studies have generally found that increased mean CoP velocity is associated with decreased postural control and increased risk of falls (Gama et al, 2019).</p>



KPI	CLINICAL RELEVANCE
<b>COP MEAN VELOCITY (mm/s)</b>	<p>Also, a study published in the journal Gait and Posture in 2010 found that CoP mean velocity was significantly higher in individuals with chronic ankle instability compared to healthy controls, suggesting that this measure may be useful in assessing the balance deficits associated with this condition (Wikstrom et al., 2010).</p> <p>COP mean velocity has also been shown to be a significant predictor of falls in older adults and in individuals with vestibular disorders (Pizzigalli et al., 2014).</p>

## ROMBERG QUOTIENT

The Romberg Quotient is a clinical tool that is often used to assess balance, particularly in individuals with neurological or vestibular impairments. To perform the test using a force plate, the individual stands on the force plate with feet together, first with eyes open and then with eyes closed. The force plate records the CoP displacement in the anterior-posterior and medial-lateral directions, and the duration of each trial is typically 30-60 seconds. The Romberg Quotient is calculated by dividing the CoP sway area with eyes closed by the CoP sway area with eyes open (Maatar, 2013).



The idea behind the Romberg Quotient is that balance is maintained through the integration of visual, proprioceptive, and vestibular inputs. When the visual input is removed, as in the eyes-closed condition, reliance on proprioceptive and vestibular inputs increases, and balance can be more challenging to maintain. By examining the quotient, clinicians can get an idea of the degree to which an individual relies on visual input for balance. The Romberg Quotient has been shown to be a useful tool in the assessment of balance in a variety of populations, including older adults, individuals with Parkinson's disease, and individuals with vestibular impairments. However, it is important to note that the test even performed on a force plate is not a stand-alone diagnostic tool and should be used in conjunction with other measures of balance and functional ability.

## SUMMARY

**In conclusion, bipodal balance evaluation with force plates is a valuable technique in clinical practice that can provide valuable insights into a patient's physical health.**

By measuring the forces and pressures exerted on the force plates, clinicians can gain a detailed understanding of a patient's balance and stability. This information can be used to identify areas of weakness, monitor progress during rehabilitation, and evaluate the effectiveness of interventions. Additionally, bipodal balance evaluation with force plates can be useful in identifying fall risk in older adults and developing strategies to improve balance and reduce the risk of falls.

While bipodal balance evaluation with force plates requires specialized equipment and expertise, it can provide a level of detail and precision that is not possible with other evaluation techniques. As such, it is an important tool for clinicians working in a range of settings, from neurology and orthopedics to geriatrics and rehabilitation. By incorporating bipodal balance evaluation with force plates into clinical practice, healthcare professionals can provide more accurate assessments, track progress over time and develop more effective treatment plans for their patients.

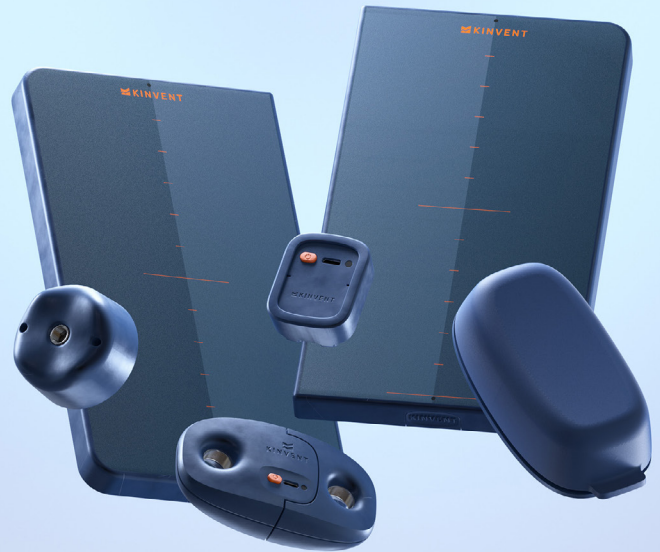


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