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Variation in Plantar Load Distribution and Calf Muscles Activities in Legally Blind Subjects

Kawthar Ali Abdulkhudhur, Maryam Hassan Salaam, Fatima Emaad Hama Raouf, Baidaa Hassan Hammoud
Al Mustaqbal University Engineering college Biomedical engineering department

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Annotation: Balance and locomotion in humans rely on visual, vestibular, and proprioceptive inputs, with visual impairment significantly affecting postural control. Despite existing studies on plantar pressure distribution and muscle activity, research on legally blind individuals remains limited. This study examines variations in plantar load distribution and calf muscle activity among legally blind subjects using plantar pressure sensors and electromyography (EMG). Findings indicate increased muscle activation and altered plantar pressure distribution in visually impaired individuals, suggesting a compensatory mechanism to maintain stability. Results highlight the importance of proprioceptive adaptation in mobility and emphasize the need for tailored rehabilitation programs to enhance balance and gait efficiency in visually impaired individuals.

Keywords: Plantar pressure, electromyography, balance control, legally blind, postural stability, gait analysis.

1. 1 Introduction:

Dynamic maintenance of balance while standing in humans relies on information from visual, vestibular, and proprioceptive inputs required by the brain to appropriately generate the complex array of motor commands needed to achieve equilibrium in a standing position. Sensory impairment can impede adaptive postural control mechanisms and lead to equilibrium loss (i.e., visual; vestibular; proprioceptive; vestibular and proprioceptive) [1]. The contribution of the visual inputs to the balance control is a hot topic and have been previously investigated.

Maintenance of balance control in conditions of visual loss is aided by vestibular and proprioceptive inputs and is manifested via compensatory adjustments of postural weighting. Since postural changes in standing position reflect modifications in our body weight load on the plantar surface, measurement of plantar pressure can be used to quantify the influence of visual input on posture control [1]. A variety of tools have been employed to quantify balance control, such as stabilometry, dynamometry, video system analysis, electromyography during the execution of quiet stance, tandem Romberg test, one leg stance, and reaction-time tasks [1]. The development of miniature, lightweight, and energy efficient circuit solutions for healthcare sensor applications is an increasingly important research focus given the rapid technological advances in healthcare monitoring equipment, microfabrication processes and wireless communication. One area that has attracted considerable attention by researchers in biomedical and sport related applications is the analysis of foot plantar pressure distributions to reveal the interface pressure between the foot plantar surface and the shoe sole. Typical applications are footwear design, sports performance analysis and injury prevention, improvement in balance control, and diagnosing disease. More recently innovative applications have also been made to human identification, biometric, monitoring posture allocation and rehabilitation support systems. Based on this work it is clear that techniques capable of accurately and efficiently measuring foot pressure are crucial to further developments [2,3]. Blindness is a lack of vision or a loss of vision that can't be corrected. The term partial blindness indicates that you have very limited vision, while the term complete blindness indicates that you can't see anything, including light [4].

The formal description of legal blindness is: "Central visual acuity 20/200 or less in the better eye with best correction, or widest diameter of visual field subtending an angle of no greater than 20 degrees". This basically means that even with corrective lenses or surgery, to clearly see an object that a person with normal vision could see from 200 feet away, you would have to be 20 feet or closer [4] (see fig.1).

Legal blindness is not the same as total blindness or low vision (also called visual impairment). A person with total blindness cannot see anything—shapes or light—with either eye. On the other hand, a person with low vision may or may not be legally blind but has enough vision loss to interfere with his or her daily life. The general standard for low vision is visual acuity of 20/70 or worse, with corrective lenses [4].

Figure 1: Comparation between normal and legally blind vision [5].

1.3 Plantar and Calf Muscle Anatomy Overview:

The Plantar aponeurosis is the modification of Deep fascia, which covers the sole. It is a thick connective tissue, that functions to support and protect the underlying vital structures of the foot. The fascia is thick centrally, known as aponeurosis and is thin along the sides. The fascia consists of three parts, medial, lateral and the central part, respectively [6] (see fig.2).

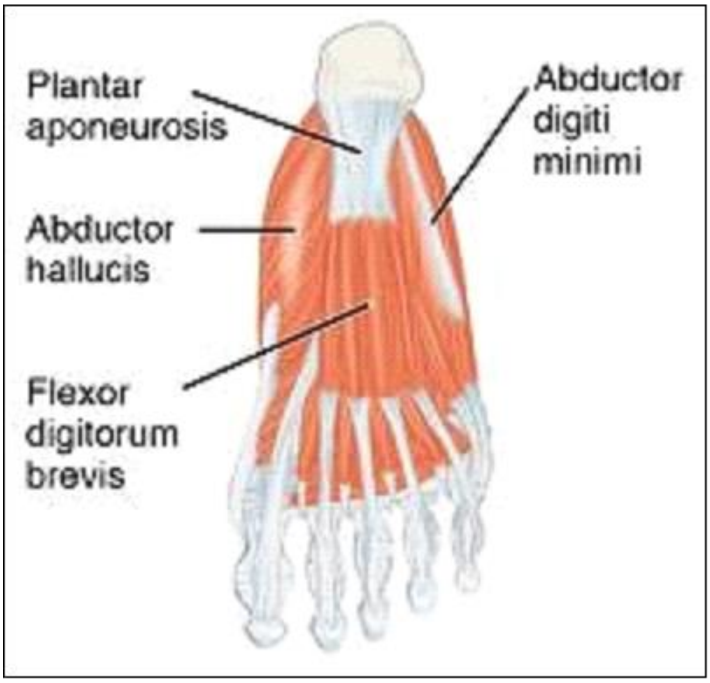

Figure 2: Anatomy of Planter [7].

The calf (Latin: sura) refers to the posterior portion of the lower leg. The two largest muscles in this region include the gastrocnemius and the soleus. The gastrocnemius is the most superficial of the muscles and has two heads, medial and lateral. The two heads of the gastrocnemius converge and form a confluent muscle belly. The lateral head originates from the lateral surface of the lateral femoral condyle and the medial head from the posterior, non-articular aspect of the medial femoral condyle. The muscle belly of the gastrocnemius joins the soleus muscle distally to form the calcaneal tendon (i.e. the achilles tendon), which inserts onto the posterior calcaneus [8] (see fig.3).

The calf muscle plantarflexes the ankle joint and is innervated by the tibial nerve. The soleus is a large, flat muscle located deep to the gastrocnemius. The plantaris is a relatively small muscle with an appreciably long tendonous portion. The tendinous portion can easily be mistaken for a nerve. The plantaris muscle arises from the lateral supracondylar line of the femur and is completely absent in up to 10% of the population.

The muscle descends medially, eventually forming into a tendon that runs down the leg, between the gastrocnemius and soleus. This tendon blends with the calcaneal tendon [8].

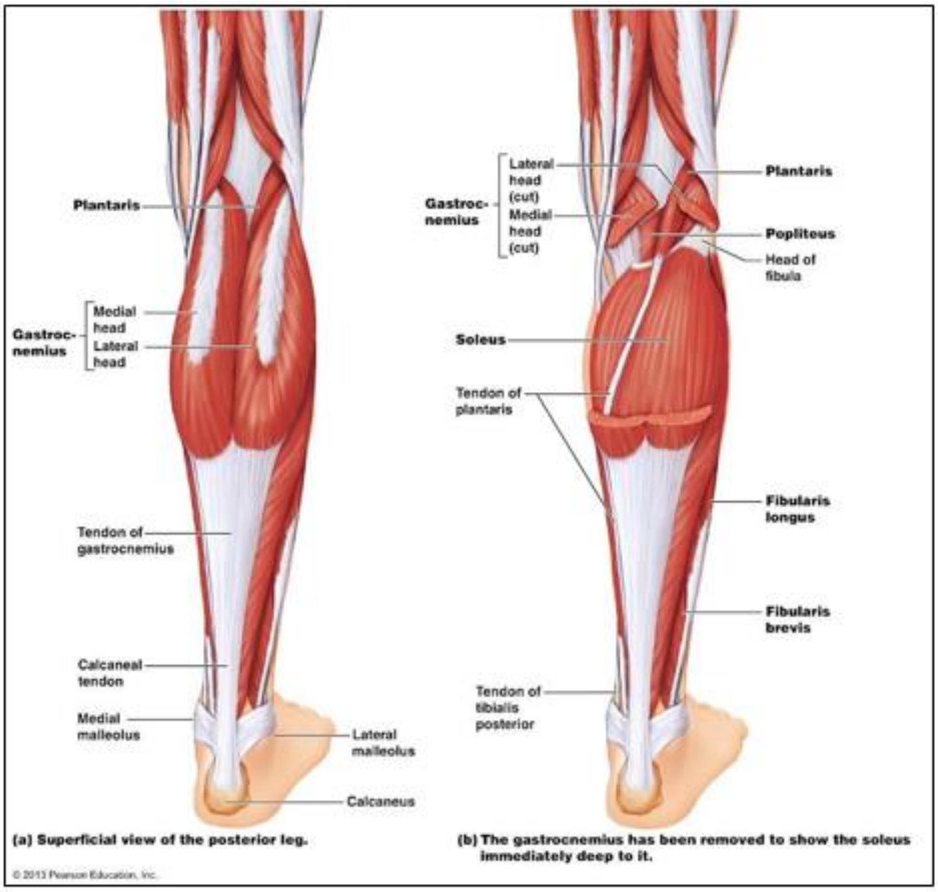

Figure 3: Anatomy of Calf Muscles [9].

1.4 Plantar pressure distribution measurements:

Measurement of ground contact forces can be used to assess the loads to which the human body is subjected in normal activities, like walking, or in more demanding situations such as in sports. With regard to clinical problems, it is useful to compare the loads in the limb either between injured and non-injured or pre- and post-traumatic or operative states. Otherwise, comparisons between patients and control groups are necessary. Measurement of the plantar pressure, i.e., the distribution of force over the sole of the foot, is useful as it provides detailed information specific to each region of contact [10].

The foot is the terminal link of the kinematic chain in human locomotion and it experiences repetitive stresses from bearing the weight of the human body on a daily basis. Furthermore, the interactive forces are transferred between the human body and the ground during walking (see fig.4, 5). The human foot experiences the pressure on the foot skin during daily activities, which means plantar pressure. Therefore, many physical parameters can be obtained from the distribution analysis of plantar pressure, and it has been employed in many areas, including footwear design, balance ability evaluation, rehabilitation training and gait analysis [11].

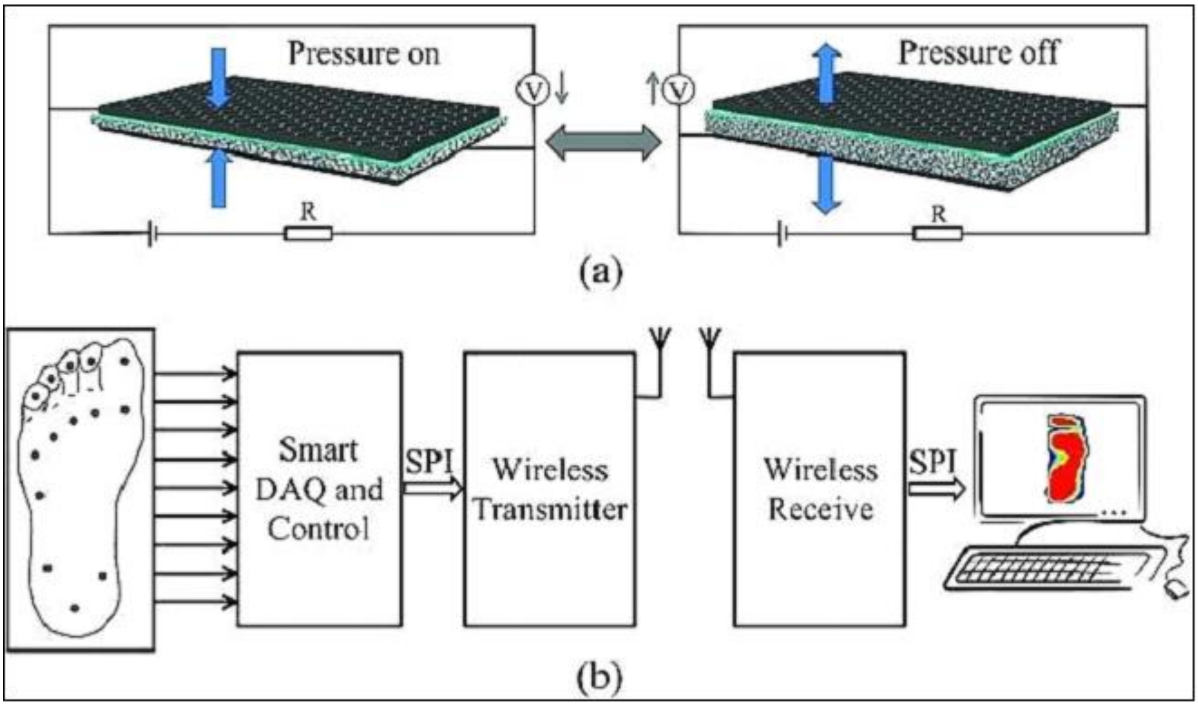

Figure 4: (a) The working principle of pressure-sensitive graphene textile sensor. The flexible textile acts as the support substrate and graphene layers wrapped around each polyester fiber. The thickness of textile decreases with the increasing applied pressure.

(b) Block diagram of the proposed plantar pressure dynamic measurement system [12].

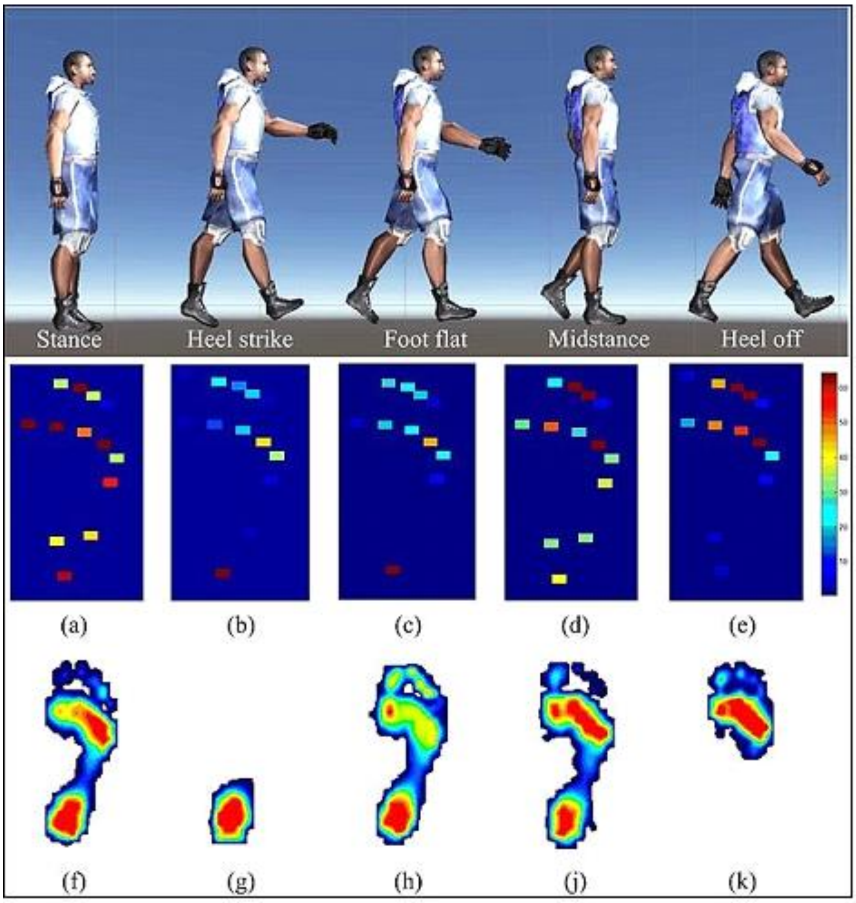

Figure 5: Plantar pressure distribution of right foot in the major phase of one full gait cycle. (a–e) images measured by our developed system. (f–k) images obtained by commercial pressure measurement device [12].

1.5 Calf Muscles Activities Measurements:

During human locomotion and everyday movements, muscular activity has been found to dampen soft tissue kinetic vibrations during each heel strike. Lower limb muscles such as the gastrocnemius medialis (GM), gastrocnemius lateralis (GL), soleus (SO), tibialis anterior (TA), peroneus longus (PL), and peroneus brevis (PB) play an important role in absorbing kinetic energy when the foot makes contact with the ground.

These muscles also assist with foot stability and rigidity during weight bearing tasks including heel raises and push-offs [13].

Electromyography is often used in research and clinical environments to examine muscle excitations in normal and pathological conditions. There are two predominant forms of EMG measurement; surface and intramuscular EMG. Non-invasive surface EMG is widely used for superficial, large, and easily accessible muscles. With surface EMG, excitation level is acquired from a large area including several motor unit populations [14] (see fig.6).

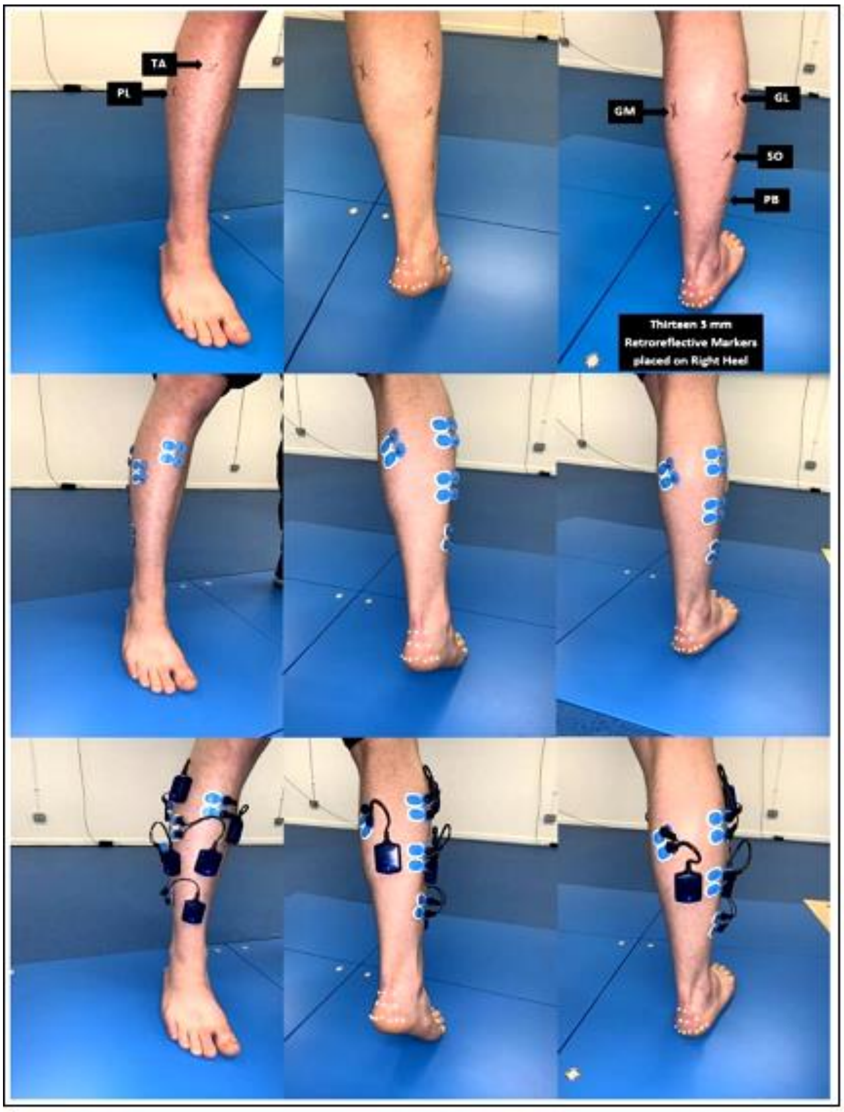

Figure 6: Row 1: Presented on the right leg are marked positions of the lower limb muscles. Row 2: The marked positions are covered with self-adhesive AMBU surface electrodes positioned on the GM, GL, SO, TA, PL and PB. Row 3: The self-adhesive AMBU surface electrodes were connected to the Myon 320 transmitters (transmitters were secured to the calf muscles with double-sided tape) [14]. The objective of this project is to characterize the load distribution variations in plantar and to evaluate longitudinal changes in muscle activities of the calf muscles in legally blind subjects' individuals.

1.7 Motivation:

Individuals with visual impairment, low vision, vision loss, or blindness are negatively impacted on more than one fundamental aspect, be it social, financial, psychological, or physiological. Such disabilities deprive these individuals from enjoying several Activities of Daily Living; thus, impacting their quality of life - the most crucial of which are mobility and navigation [15].

Plantar pressure measurement is a quantitative tool that allows the objective assessment of dynamic weight bearing forces distributed over the plantar surface of the foot as a result of postural stability, locomotion, and other biomechanical activities. Such measurements have been employed in clinical and research studies, involving normal and pathological foot, in sports medicine, orthopedic biomechanics, and rehabilitation engineering [16].

1.8 Literature survey:

The ambulatory forces exerted underneath the plantar surface of the foot of visually-impaired individuals have not been fully studied. The number of plantar pressure studies has increased substantially in recent years. These studies have provided relevant information regarding various aspects of foot biomechanics; however, studies that touch on the effect of vision impairment on locomotion remain scarce.

According to Menkveld et al., four functional tasks are accomplished by the foot during the stance phase of gait: i) acceptance of impact load at heel strike, ii) terrain acclimation during weight acceptance, iii) stability and load distribution during foot flat, and iv) propulsion for forward progression during push-off [17].

According to Hallemans *et al.*, low vision does affect the dynamic stability of gait since visual perception of the environment during locomotion allows: i) orientation towards a goal, ii) adjusting heading direction, iii) avoiding collisions with objects, iv) avoiding obstacles, and v) accommodating different surfaces. In their study, the authors reported that adults with visual impairment walked with a shorter stride length, less trunk flexion, and an earlier plantar foot contact at heel strike than did sighted individuals. Hallemans *et al.* concluded that visually impaired individuals utilize a more cautious walking strategy through adaptive changes that employ the foot to probe the ground for haptic exploration [18]. In their study, Hallemans et al., using two 6-camera motion analysis systems, observed that there are differences between the kinematics of gait of normal-sighted adults compared with that of visually-impaired individuals. The authors stated that “vision is important in the control of locomotion, even in a safe and uncluttered environment”. They concluded that typical adaptations performed by these individuals include a smaller stride length and an added plantar foot contact; hence, overcoming the challenges due to sensory deprivation so as to maintain stability during locomotion [18].

Definitions and uses of blindness, low vision, visual impairment, functional vision, and vision loss as set by visual standards have been delineated by Abu-Faraj *et al.* [16].

It had been estimated by the World Health Organization (WHO, Geneva, Switzerland), in epidemiologic studies performed in 2012, that there are in the world 285 million people who are visually impaired: 246 million of these have low vision, while the remaining 39 million are blind [19].

In another study, Ray et al. showed that restricted vision has a negative impact on postural stability and balance, and that individuals with profound vision loss use modified hip strategy to maintain postural stability since these individuals have to heavily rely on somatosensory and vestibular information as a sensory substitution in order to maintain their postural stability [20] .

Human research implementing biopsy of mixed fiber-type quadriceps muscles has produced conflicting results on the topic, with some studies showing differential fiber-type specific hypertrophic effects between loading conditions [21] and others showing negligible differences [22].

Although discrepancies in findings are not entirely clear, a possible explanation might be related to differences in the intensity of effort employed in these studies. Specifically, studies showing differential adaptations between fiber types seemingly did not train to muscular failure [21] while those showing no differences reportedly did [22].

2. 1 Methodology:

Since birth, our first involuntarily movement is walking, which is any human's daily activity and gait plays an important role in the human movement. The synchronization of both neural and musculoskeletal systems is essential to achieve stability and balance of the body during movement. Analysis of gait parameters plays an important role in the evaluation of different factors. The feet are the major source of support during gait and are corresponding to the rapid changes of the surrounding and thus, are exposed to large force. The deduction of the human foot pressure distribution can provide the essential information and thus, greatly assist the medical diagnosis. Thus, this foot plantar pressure device will provide better efficiency and improve functionality than the already existing devices in the measurement system.

Also, during normal walking muscles produce forces which act directly on the musculoskeletal system. In recent years, musculoskeletal models have been used to generate simulations of normal and pathological gait patterns. Musculoskeletal models consist of a set of body segments connected by joints with specified degrees-of-freedom (dof) spanned by muscles and ligament Joint or segmental motions and external forces are specified and an optimization routine is employed to determine muscle and ligament forces.

Electromyography (EMG) is a common technique that measures the biopotential produced by the contraction of muscles. This technique detects the current generated by the ionic flow across the muscle fiber and transmitted through neighbor tissues. By using electrodes to connect to the body and proper instrumentation, an EMG quantifies the electrical activity of the muscle fibers in the vicinity of the electrodes during contraction.

2.2 The measurement of plantar pressure distribution:

Plantar pressure measurements can be used to assess the loads to which the human body is subjected in normal walking or in sports. Measuring the distribution of force over the sole of the foot is useful as it provides detailed information specific to each region of contact. Especially in patients with legally blind, these data are crucial for detecting areas with high loads and for the monitoring of intervention measures.

The human body master's forward movement by transferring forces into the ground. This happens via the sole of the foot during the rolling-off process. This results in a pressure load on different parts of the foot that may change significantly in the presence of pathologies. The measurement of plantar pressure distribution helps give us quantitative and reproducible metrics on pressure load.

Hence, it has a distinct advantage over the blueprint which provides detailed information about the foot load but cannot be adequately reproduced or quantified. Compared to a force measuring plate, no shear forces can be determined in the plantar measurement of pressure distribution; the information is therefore limited to the vertical component of the ground reaction force. However, the force measuring plate does not provide information about the load distribution on the sole of the foot [23].

Commonly used technologies are capacitive sensors by which two capacitor plates move closer together as a result of the applied force (see fig. 2.1,2.2). The change in charge causes a change in voltage. Resistive sensors where the contact area of two conductive layers is altered by the force. The change in resistance causes a voltage change. Piezoelectric sensors where the force alters the charge distribution in a crystal lattice. The charge shift causes a change in voltage [23].

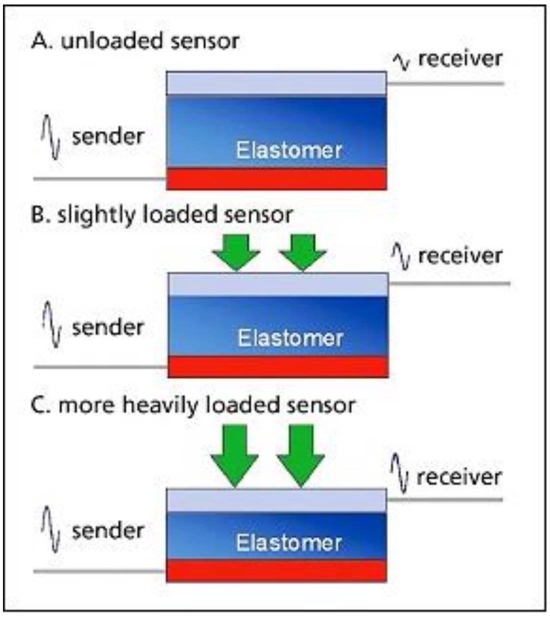

Figure 2.1: Functionality of a capacitive sensor: If the sensor is unloaded (A), the highfrequency signal measured at the receiver is low. This signal corresponds to zero. If the sensor is loaded with increasing pressure (B and C), the distance between the surfaces becomes smaller and the signal at the receiver becomes correspondingly stronger. Thus, this change in the receiver signal is a measure of the pressure produced.

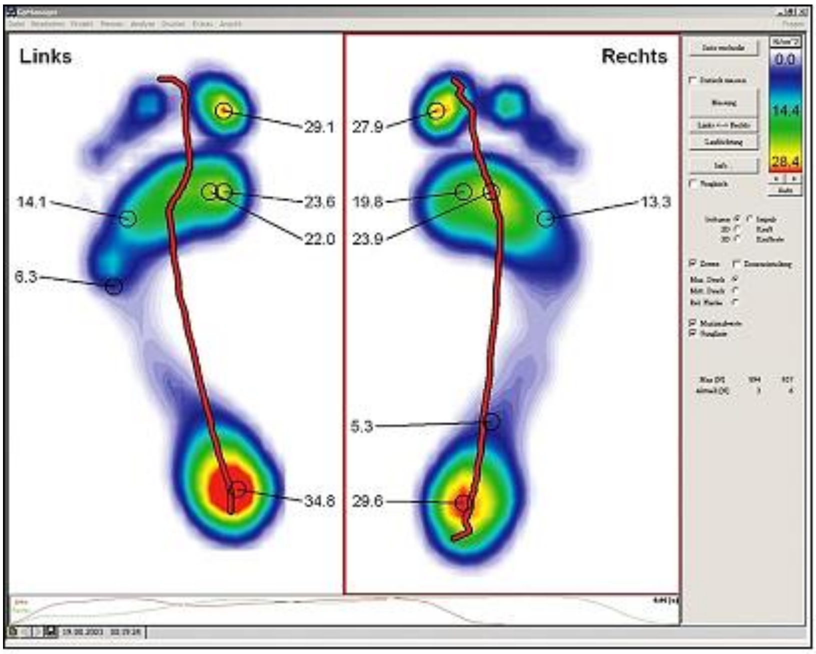

Figure 2.2: Screenshot of foot pressure measurement showing the maximum pressure values in the different areas of the foot and the line of force application points of the individual frames (gait line) (platform measurement by GeBioM).

2.2.1 Parameters of the pressure distribution measurement [23]:

1. Maximum force: Describes the maximum vertical force measured by the sensor over the entire roll-off process.
2. Contact surface: Describes the area of all sensors that have provided data during the rolling process
3. Contact time: Describes the duration of ground contact.

4. Peak pressure: Describes the maximum pressure measured by the sensor over the entire rolling process.
5. Force-time integral (pulse): Describes the length of time the force is applied to a particular area of the foot.
6. Gait line: Consists of the force application point of the individual measurements and provides information about the stability of the foot and the temporal distribution of the roll-off process.

2.2.2 Benefits of plantar pressure distribution measurement [23]:

1. Allows assessment of orthotic footwear.
2. In diagnostics, complements clinical examination.
3. Helps establish the degree of functional impairment.
4. Allows outcome evaluation after completion of therapy (conservative/surgical).
5. Monitors healing process and/or -disease progression.

2.3 Calf Muscles Activities Measurements Using EMG device:

Lower leg muscle activity contributes to body control; thus, monitoring lower leg muscle activity is beneficial to understand the body condition and prevent accidents such as falls. Amplitude features such as the mean absolute values of electromyography (EMG) are used widely for monitoring muscle activity [24].

Electromyography (EMG) is the standard technology for monitoring muscle activity in laboratory environments, either using surface electrodes or fine wire electrodes inserted into the muscle. Electromyograms (EMGs) may be recorded from within the muscle or from the skin surface. In the former case, EMGs are often used to study physiological properties of motor units (e.g., fatigability, recruitment threshold). Classic bipolar surface EMGs, on the other hand, are expected to provide a global indication on the degree and timing of muscle activity (see fig. 2.3). Distinct applications for intramuscular and surface EMGs result from obvious differences in detection selectivity; in relation to surface EMGs, intramuscular recordings sample from a smaller fraction of the muscle volume [25].

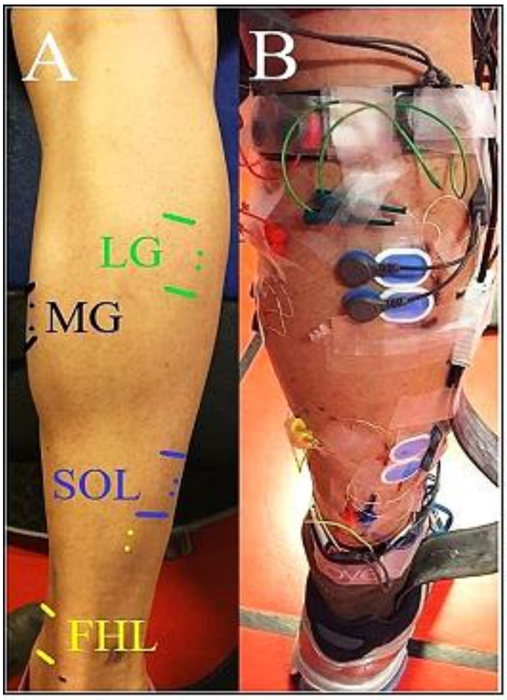

Figure 2.3: Measuring lower leg muscles activities using EMG.

2.4 Proposed Technique

The deduction of the human foot pressure distribution can provide the essential information and thus, greatly assist the medical diagnosis. This foot plantar uses the FSR, force sensitive resistor sensors to collect the necessary data which is then processed to give digital output.

These values are fed in custom-made software to give a pedobarography image that depicts visually the different pressure distribution of the foot. The study of pressure fields acting between the plantar surface of the foot and a supporting surface is called pedobarography. This image will be saved in a document format with the help of the custom-made software and can be studied by doctors for proper diagnoses.

On the other side, electromyography (EMG) is used widely for monitoring muscle activity. Biopotential signals that activating muscle fibers propagate from the neuromuscular junction to the tendon along the muscle fibers. An electrical field is created by the stimulation from the neuron activating the muscle fiber's chemical receptors. By placing electrodes on the surface of the skin, biopotential signals are measured as EMG signals. An EMG signal-based system has several applications. The simplification of EMG signal measurement is considered important for further popularization; however, it is necessary to select the muscle site to be measured, and to determine the position where the electrode is to be placed, based on kinematic and anatomical knowledge.

We used plantar pressure distribution device to measure the balance for 60 seconds when the patient's eye was open, and then we re-examined the patient with his eye closed. At the same time, the electrodes of the EMG device were attached to the patient's right leg in the Calf Muscles area to measure muscle activity, and the results appeared on the screen. Then all the results were recorded, and the data saved for the purpose of the study (see fig. 2.4,2.5,2.6).

Figure 2.4: Collecting data from the patient by connected the EMG electrodes to calf muscles and using planer pressure measurement device to measure planter pressure distribution.

2.4.1 Procedure:

- First, we took 4 cases and examined them using the EMG device and the foot plantar pressure.
- Second, we made the patient stand on the foot plantar pressure device.
- Third, we attached the 3 EMG electrodes to the patient's calf muscle.
- Fourth, we measured the patient's muscle activity for 60 seconds when he was in the open eyes condition and then we asked them to close the eyes and we also took the muscle activity for 60 seconds.
- Fifth, we recorded the results of each case and stored them in the computer.

Figure 2.5: The result of measure planter pressure distribution of the patient.

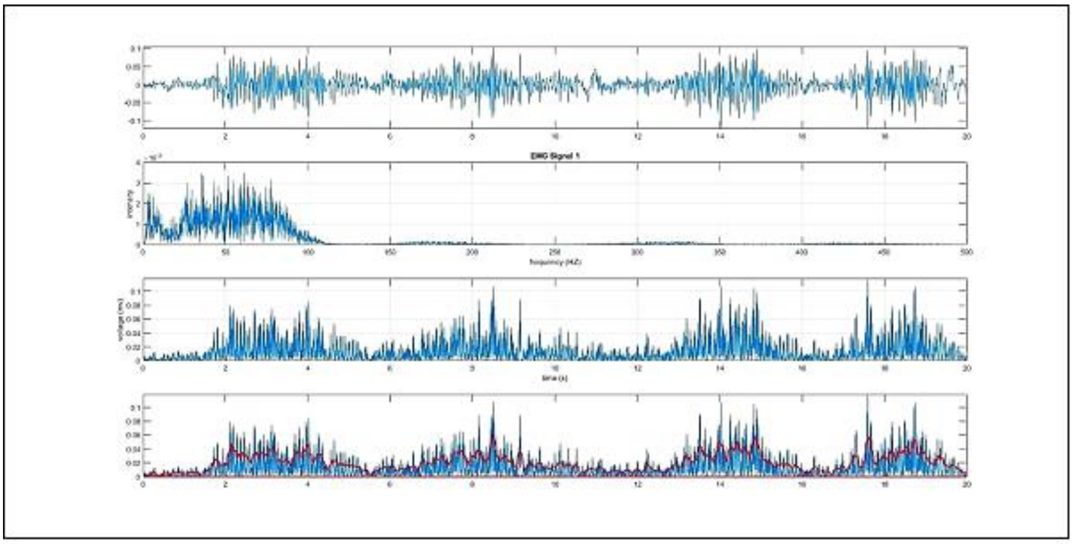

Figure 2.6: The result of measure calf muscle activities of the patient.

2.4.2 EMG signal processing steps:

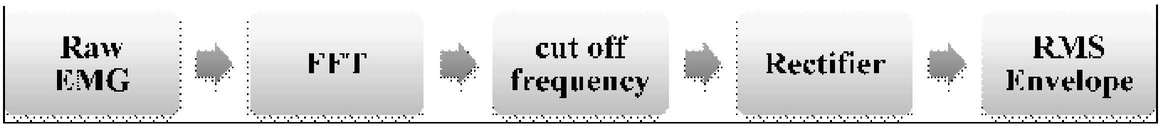

Figure 2.7: Methodology of EMG signal processing.

3. Results and Dissection

3.1 The measured results of case (1):

For the EMG signal (as shown in fig. 3.1), the red line represents the person with open eyes and the black line represents the person with closed eyes.

Analyzing the EMG signal, we note that the muscle activity in the case of closed eyes is higher than in the case of open eyes, and this indicates that the muscle is trying to control more of the ankle joint and prevents the movements that occur in the body.

And to explain the reason for the increase in the signal is that the person loses the sense of the place around him, that is, when he closes his eyes, he loses one of the most important inputs, and here he started trying to prove himself, but he does not know where, so the muscle becomes more active until it controls the body's activity, prevents it from falling and maintains balance.

At the end of the time period, we notice the appearance of a high peak. This represents the activation process of the muscle. This peak means that movement occurs and the muscle activates until it prevents this movement and becomes high activation and this does not appear in all cases. When the eyes are open, this peak does not appear.

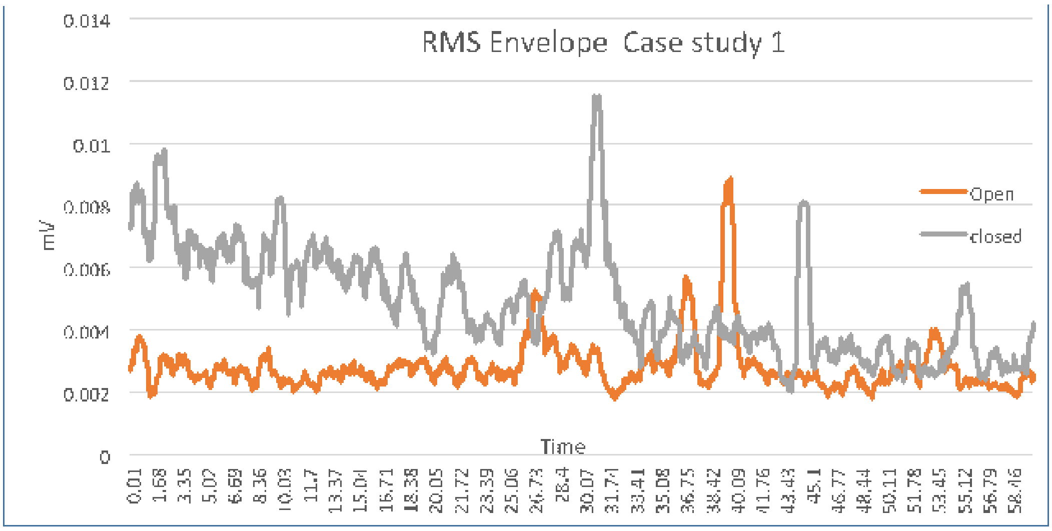

Figure 3.1: Case (1) EMG test.

For feet analysis (plantar pressure), the area of the ellipse in the case of open eyes is larger because of the change in the center position is more. We recorded 10.9 mm^2 in the open eyes and 1.51 mm^2 in the closed eyes (as shown in fig. 3.2 and 3.3).

We note that the center of pressure in the first case when the eyes are open is in the heel of the right foot, and for the left foot did not change in the case of closing the eyes, meaning that the center of pressure is in the same place .

For the left foot, when eyes open the highest pressure in the foot is 204.4 kpa, the average pressure is 56.2 kpa, and the foot area is 103 cm^2. And, when closed eyes, the highest pressure is 204.6 kpa, and we did not notice a strong change in the pressure value. The average pressure is 58.5 kpa, and the foot area is 106 cm^2 meaning that most of the feet are on the ground to achieve balance.

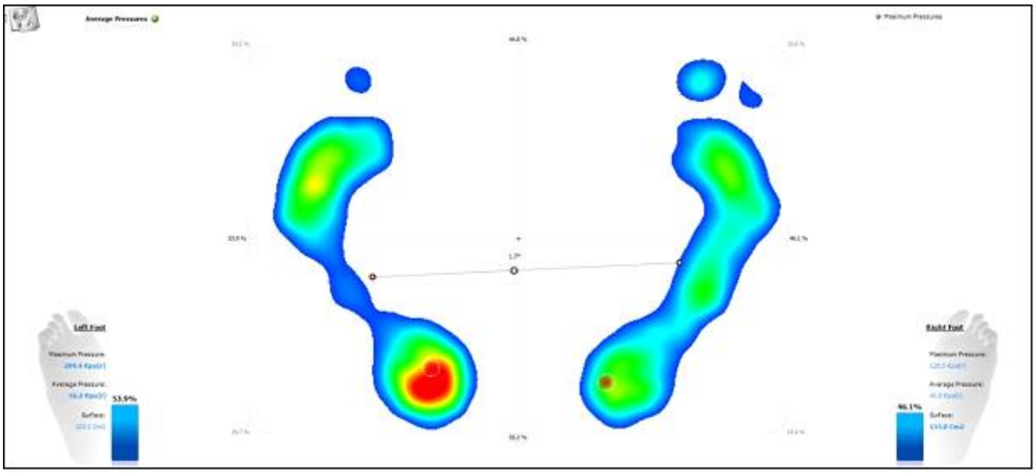

Figure 3.2: Case (1) Planter pressure when the eyes were opened.

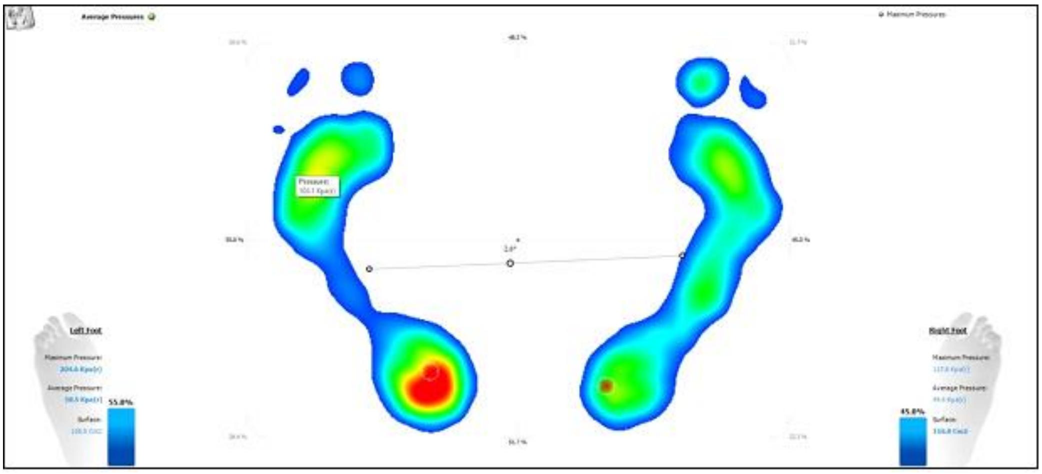

Figure 3.3: Case (1) Planter pressure when the eyes were closed.

For the right foot, when the eyes open, the highest pressure is 120.3 kpa, the average pressure is 43.1 kpa, foot area is 115.0 cm^2 and in closed eyes, the highest pressure is 117 kpa, and we notice a decrease in pressure, and the average pressure is 44.6 kpa, which means it has increased, and the foot area is 116.0 cm^2.

Each curve has three movements: lateral, anterior-posterior motion, and body center motion. We notice the difference in movements in the case of closed eyes, that is, movements are more and less stable. In the case of open eyes, it has more stability (as shown in figures 3.4, 3.5,3.6,3.7,3.8 and 3.9).

In the case of closed eyes, he has more oscillation, and this connects with muscle activity, meaning that he tries to stabilize, but he cannot and tries to prevent movement when it occurs, i.e., there is a higher oscillation in movement.

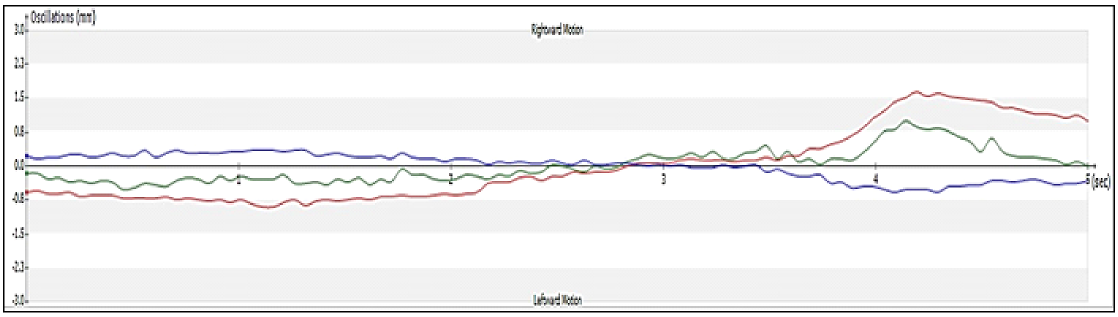

Figure 3.4: Case (1) Planter pressure when the eyes were opened (rightward and leftward motion).

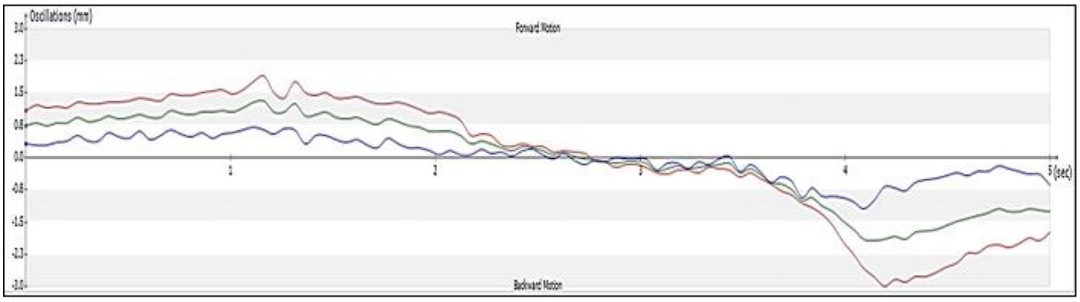

Figure 3.5: Case (1) Planter pressure when the eyes were opened (forward and backward motion).

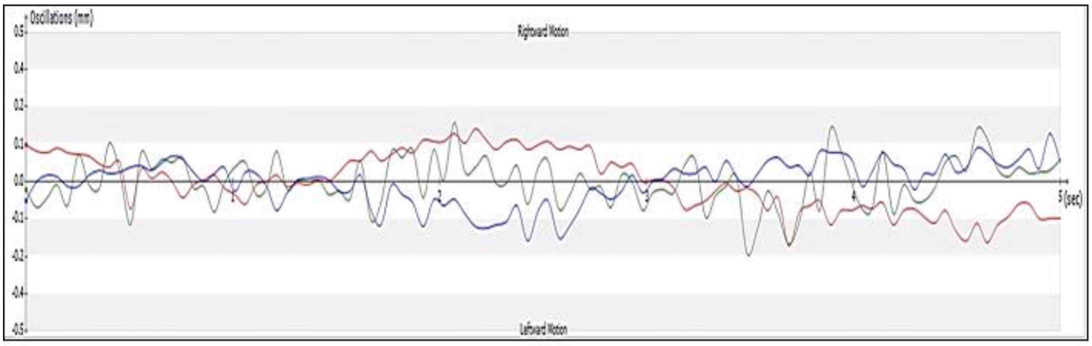

Figure 3.6: Case (1) Planter pressure when the eyes were closed (rightward and leftward motion).

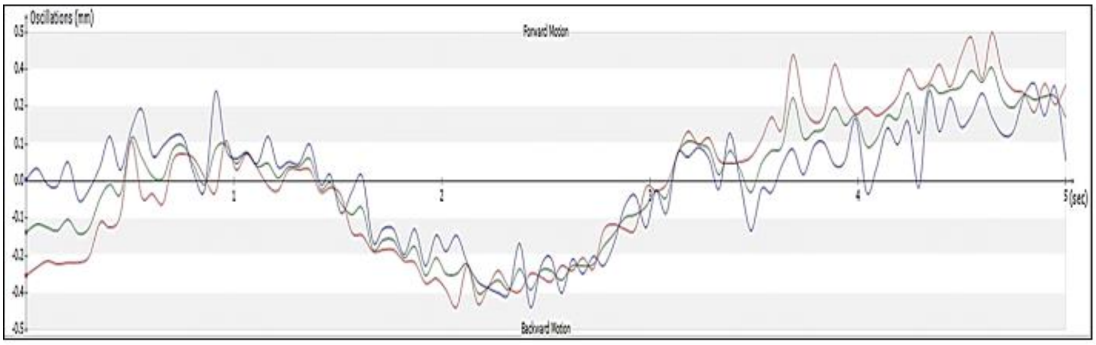

Figure 3.7: Case (1) Planter pressure when the eyes were closed (forward and backward motion).

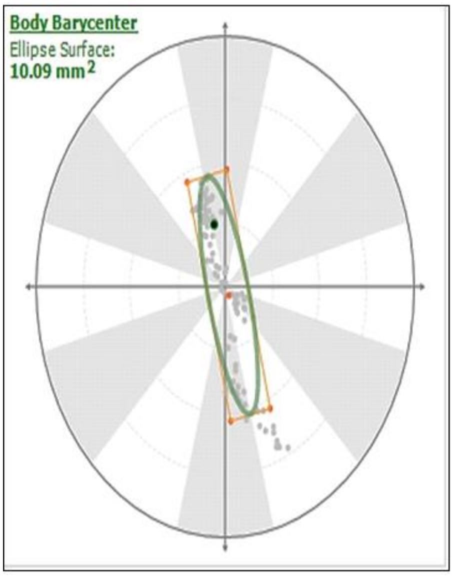

Figure 3.8: Case (1) Planter pressure Body Barycenter when the eyes were opened.

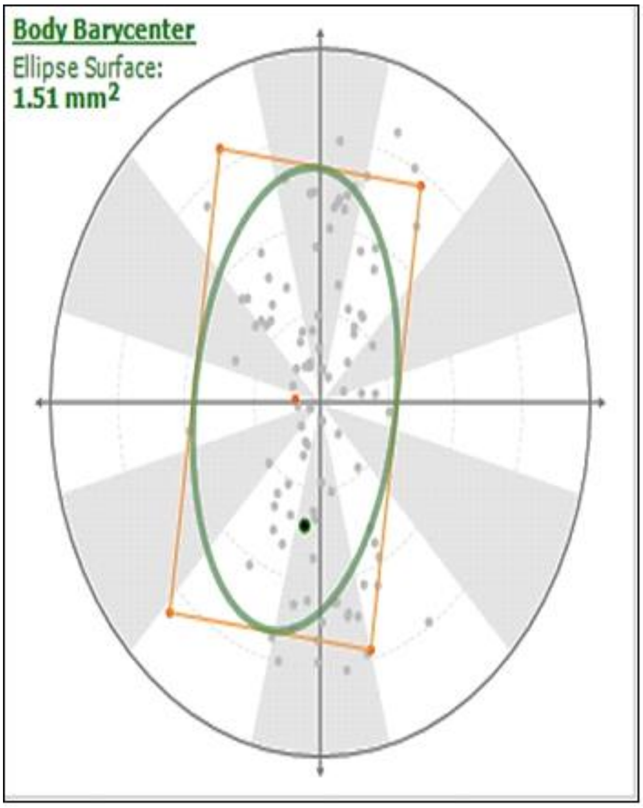

Figure 3.9: Case (1) Planter pressure Body Barycenter when the eyes were closed.

3.6 Conclusions:

- The EMG signal in all cases increased in the case of closed eyes, because the person is trying to control his balance and muscle activity increases.
- When a person closes his eyes, he loses the feeling of those around him, because the eye is the most important part that helps maintain balance, so the person tries to maintain his balance by increasing muscle activity.
- The Ellipse surface in all cases, when the eyes are closed, there is a decrease in the area of the Ellipse because there is a change in the center of the foot.
- As for the center of pressure, it does not change in most cases, but in some cases, we notice that the center of pressure was at the front of the foot in the case of open eyes and when the eyes were closed, it became at the end of the foot (heel of the foot).
- The max pressure, we notice that in closed eyes, there has been a decrease in the pressure value for the right foot, while for the left foot, we notice an increase in the pressure value.
- Average pressure increased in case of closed eyes for the right foot, but for the left foot there was a decrease in some cases and in some cases, there was an increase.
- The foot Area increased when the eyes were closed on both feet, because the body is trying to balance, so it brushes its feet on the device, so the foot Area increases.
- These results were taken from only four cases and cannot be generalized to all patients.

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