Analysis of Plantar Pressure and Contact Forces Changes in Locomotion of People with Low Vision

Mihaela I. Baritz

Abstract—**Low vision status installed from different pathological or functional causes can affect posture, movement on different directions or surfaces, walking or running, requiring postural or human aid systems. Most often the plantar surface of both feet suffers an additional tension or even it can cause lesions that will further impede the motor activity of low-vision patients. In general, the movement of these people is accomplished with extra effort over longer periods than normal and can create a high stress on adapting to the surrounding environment. In the first part of the paper are highlighted the general aspects related to the low vision state and related to the plantar pressure developed on the cycle of gait. In the second part of the paper are presented the experimental configuration of the study and also the structure of the assessment procedures for the visual dysfunction simulations. In the third part of the paper are presented the results obtained from *footscan* pressure plate for low vision simulation cases. Also correlative analyses of plantar pressure changes and low vision level are presented and evaluated in the same chapter. In the final part of the paper are presented the results and conclusions obtained in this study, along with highlighting the possibilities of implementing the procedures for different extended biomechanical evaluations.**

Index Terms—**Plantar pressure, low vision, biomechanics.**

I. Introduction

Lifetime low vision may induce structural, functional and behavioural changes in the patient's lifestyle. Such a state can be installed and evolving progressively or rapidly. At the same time, this state of low vision can develop under different pathological forms, in long periods of time or sometimes in very short periods and with a great impact on visual perception or adaptation to the environment. People who develop such a low visual perception begin to isolate themselves from the social environment, present problems of adapting to the requirements of the moment or current activities, diminish participation in different forms of action (movement, communication, social interaction, etc.) and sometimes even unpredictably exposed to domestic or road accidents. In these situations, visual aids can provide patients with additional re-adaptability as long as they are accepted and used appropriately by them.

As mentioned in various research papers [1] "low vision is considered a condition with an impairment of visual function, despite treatment and correction of ordinary refractive errors, and is defined as a visual acuity reduced to 20/60 visual fields or less than ten degrees from the fixation point. Patients with low vision use or have the ability to use vision for planning or executing tasks". In addition, World Health Organization (WHO) documents stipulate the need to develop prevention and visual aid programs that will ensure by 2020 a general level of knowledge of the state of health of the visual function of the entire population. "The mission of the VISION 2020 Global Initiative is to eliminate the main causes of all preventable and treatable blindness as a public health issue by the year 2020" [2].

The WHO's main objectives are:

1) "Raise the profile, among the key audiences, of the causes of avoidable blindness and the solutions that will help to eliminate the problem.
2) Identify and secure the necessary resources around the world in order to provide an increased level of prevention and treatment programmes.
3) Facilitate the planning, development and implementation of the three core Vision 2020 strategies by National Programmes." [2]

The strategies through which these goals can be achieved are also referred to, by the WHO:

4) "**Disease control:** facilitate the implementation of specific programmes to control and treat the major causes of blindness.
5) • **Human resource development:** support training of ophthalmologists and other eye care personnel to provide eye care.
6) **Infrastructure and appropriate technology** development**:** assist to improve infrastructure and technology to make eye care more available and accessible." [2]

In general, the studies and researches performed at the level of the visual function related to the effects on other sensory systems of the human body [3],[4],[5] are extremely low in number and are oriented only to the determination of some concrete aspects, on the cases to be analysed. However, another series of theoretical studies has shown that restraining the functioning of the visual system can lead to an increase in postural instability of the human body and also to the imposition of static and dynamic imbalances. These studies are important in identifying the recovery pathways and postural aid of people who develop visual dysfunctions and who can still continue their activity normally or acceptably.

The main problem with the research in this paper is the identification of the possibility of highlighting changes in plantar pressure and, of course, stability of persons developing visual, pathological dysfunctions (retinopathy, AMD, glaucoma, cataract, etc.) or refractive (myopia, strabismus, aniridia, aphakia etc.).

These aspects can be analyzed on the patient's walking

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cycle in order to identify dynamic stability in bipedal locomotion.

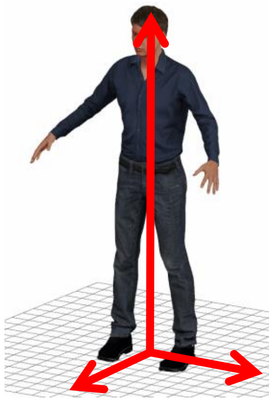


Fig. 1. Coordinate system for human body [6].

As shown in [7] "maintaining balance during walking is one of the fundamental motor skills needed in bipedal locomotion. This dynamic stability can be defined as the capacity to move the body segments in a coordinated fashion so that the body can be displaced with a proper speed, keeping it more constant as possible for the conservation of momentum [8], [9] and minimizing upper body oscillations and hence the risk of fall [10], [11].

In fact, in an unstable gait, walking speed fluctuates, causing higher accelerations and hence inertial forces and perturbations that need to be controlled."

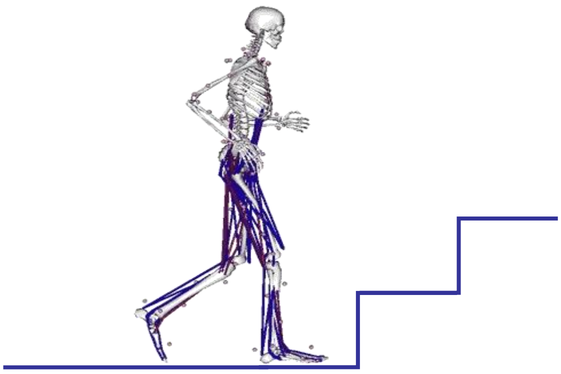


Fig. 2. Human body system in running and stepping locomotion [12].

Therefore, a more in-depth knowledge of the manifestations of the low-vision patient's loco-motor system (joints, muscular system or plantar surface), a systemic approach to the entire mechanism of the walking process (in all forms) can lead to better control on posture, on dynamic and static stability, and can avoid the occurrence of additional dysfunctions that diminish the capacity of patients to reintegrate. Among the most frequent topics addressed in this area, the use of postural analyses of blind patients is related to ways of recognizing patterns of walking and comparing them with those who are without visual problems [7].

The results of these evaluations have highlighted the fact that, although a number of factors (subject gender, experimental environment, ambient sound, speed etc.) were considered, the results were not relevant from the point of view of substantial differences between low-vision and healthy patients. Therefore, the investigations must be carried out on specific components of the locomotion (type of locomotion - Fig. 2), taking into account the contact with the surface, its shape, its size and its structure, and the evaluations are done not only video, but also sensorial to correlate these determinations. An important aspect is also the choice of a pair of footwear suitable for *footscan* recordings.

The plantar surface of the legs has an extremely important contribution to body standing and locomotion, and especially for patients with low vision or blindness, this is also a way for these patients to feel the touch surface of movement. As it is presented in specialized literature "the foot is a hyper-complex structure which supports the body and is characterized by being the only body part in contact with the ground. Among its various functions a key one is to provide afferent information to the central nervous system from plantar receptors, which will then be used to maintain posture and produce movement patterns. In recent years, several lines of research have focused on the study of the influence that afferent information from the plantar receptors of the somatosensory system exerts on balance, postural control and movement, as well as on the occurrence of lesions." [13]

In the same context, the authors of the paper [13] mention that "in addition, sensitivity levels on the plantar surface may vary greatly within the healthy and pathological population, with very different activation thresholds being observed depending on the age, area of the foot, sex or type of stimulus presented (vibratory or pressure-based).

All this suggests that plantar afferent information could directly influence rebalancing ability and the creation of motor patterns." Following these studies, the same authors [13] stated that "sensory feedback from the foot is essential in the maintenance of general (postural and displacement) and specific (sport) patterns.

Changes in the quantity or quality of plantar afferent information will not only upset the creation of different patterns but may also increase the risk of injury. In this sense, it will be fundamental to maintain and optimize the ability to collect afferent information from the different systems, as a way to avoid the appearance of injuries and pathologies and improve performance."

II. Theoretical Fundaments of Gait Analysis for Low Vision Patients

In many specialty articles it is stated that sensory information (from somatosensory, vestibular and visual systems) is integrated to ensure the balance of the human body and therefore investigates how sensory values are re-calibrated or how neural strategies are changes in different situations to control the equilibrium reactions and posture to the action of external or internal disturbances.

However, the central postural control system has to deal simultaneously with the two important tasks it coordinates, namely, the one that establishes a distribution of tonic muscle activity ("posture") and the other that is specialized for compensation internal or external disturbances ("balance"). [14]. If these disturbances, especially the internal ones due to the dysfunctions of the sensory systems, are of high (pathological) level, then the two components, the posture and the balance of the human body are affected and in turn, they determine the sensory system dysfunctions or even structural changes of other systems from human body. Operational control designed to compensate deviations from the reference position along with real-time postural control is designed to provide an energetic level of human body position to ensure steady and secure bipedal position throughout the standing.

Mostly, human body posture analysis uses the calculation principles of the inverse pendulum model, considering that the plantar surface represents the fixed contact area with the soil of the human body that can oscillate around the equilibrium position. This position is defined by the center of mass (COM) and the center of pressure (COP) that is determined in relation to the projection of the center of gravity in the base of support (BOS) and the height of the human body, respectively (Fig. 3).

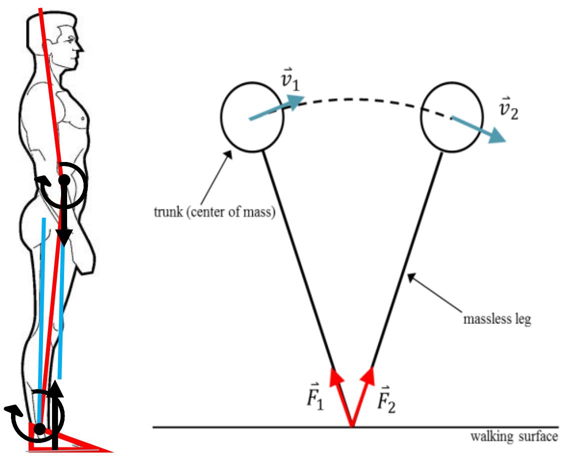


Fig. 3. Human body system like inverted pendulum model

According to the definitions given by specialists "posture is describes by the orientation of any body segment relative to the gravitational vector. It is an angular measure from the vertical. Balance is a generic term describing the dynamics of body posture to prevent falling. It is related to the inertial forces acting on the body and the inertial characteristics of body segments.

Centre of mass (COM) is a point equivalent of the total body mass in the global reference system (GRS) and is the weighted average of the COM of each body segment in 3D space. It is a passive variable controlled by the balance control system. The vertical projection of the COM onto the ground is often called the center of gravity (COG).

Centre of Pressure (COP) is the point location of the vertical ground reaction force vector. It represents a weighted average of all the pressures over the surface of the area in contact with the ground. It is totally independent of the COM. If one foot is on the ground the net COP lies within that foot. If both feet are in contact with the ground, the net COP lies somewhere between the two feet, depending on the relative weight taken by each foot." [15]

Due to the complexity of the human body, many approximations have been developed and in some cases the posture model has been approximated as an inverted pendulum. From the researchers' observations it was found that the human body in the vertical position is more stable in the frontal orientation than in the sagittal orientation. In the frontal orientation, the human body has two support zones (the planting surfaces of both feet), and the distance between the legs allows more control, but in sagittal orientation the body has only one "point" of support, and the control entirely depends on the ankle muscles. Therefore, the kinetic and potential energy of the system thus considered is expressed by the following relations, where K = kinetic energy and P = potential energy:

$$\begin{aligned} K &= \frac{1}{2}m_1\left(\left(l_1\dot{\theta}_1\cos\theta_1\right)^2+\left(l_1\dot{\theta}_1\sin\theta_1\right)^2\right)+ \\ &+\frac{1}{2}m_2\left(\left(l_1\dot{\theta}_1\cos\theta_1\right)+l_2\dot{\theta}_2\cos\theta_2\right)^2+ \\ &+\frac{1}{2}\left(l_1\dot{\theta}_1\sin\theta_1+\left(l_2\dot{\theta}_2\sin\theta_2\right)\right) \\ P &= g\left(m_1l_1\cos\theta_1+m_2l_1\cos\theta_1+m_2l_2\cos\theta_2\right) \end{aligned} \quad (1)$$

"where, θ_1 is the ankle angle respect to the vertical axis, θ_2 is the hip angle respect to the vertical axis, l_1 is the distance between the ankle and the hip, l_2 is the distance between the head and the hip, m_1 is the mass of the segment between the hip and the ankle, m_2 is the mass of the segment between the head and the hip, and g is the gravity constant." (Fig. 3) [16] As shown in equilibrium determinations, using the Lagrange equation (equation 2), the angular accelerations of the segments that form the double inverse pendulum assimilated to the structure of the human body will be obtained.

$$L = K - P \quad (2)$$

$$\frac{d}{dt}\frac{\partial L}{\partial\dot{\theta}_i}-\frac{\partial L}{\partial\theta_i}=0 \quad (3)$$

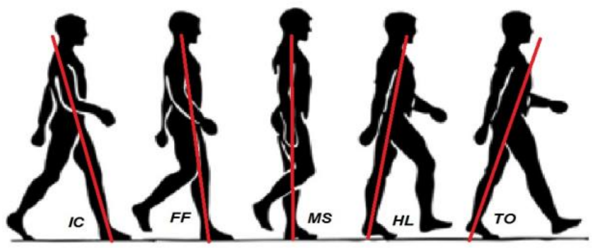


Fig. 4. Human body in gait cycle [17].

This positioning of the human body, wherein the COM is the center that generates the posture oscillations, is analyzed in relation to the support base and especially to the traveling speed in the walking cycle formed by the following steps shown in Fig. 4, wherein "image highlights left leg initial contact (IC), foot flat (FF), midstance (MS), heel lift (HL) and toe off (TO) as significant phases and of importance biomechanically. Foot flat refers to forefoot loading so the entire foot is in ground contact."[17]

This behaviour is even more evident in patients with low vision status, which reduces travel speed in the gait cycle along with a different weight distribution on both plantar surfaces of feet. In this regard, the COF trajectory recorded on the plantar surface of the right and left foot changes randomly according to the surface quality, the type of shoes and the level of impairment of the visual function, presenting substantial deviations from the normal trajectory.

III. Experimental Setup

The experimental system proposed for carrying out the research takes into account the succession of the registration procedures and is represented by a modular, flexible structure that gathers data on the pressure exerted on the planting surfaces of the subjects who have experienced visual impairments of the low vision type (cataract).

These visual dysfunctions have been induced by the subjects selected for recording, with the help of glasses that have allowed binocular simulation of cataract-type low vision, retinopathy (some of the most common visual dysfunctions that can lead to decreased vision dramatically) respectively of the state of blindness (Fig. 5).

The sample of subjects selected for the experiment had a number of initial criteria that determined the choice of subjects with normal visual status to simulate visual dysfunctions due to the use of specially prepared glasses. In addition, 6 subjects were selected according to the following parameters: mean age (23 years), mean height of 170.83 cm (minimum 163 cm and maximum 180 cm), mean body weight of 56.5 kg (minimum 43 kg and maximum 82 kg), average shoe size 38.5 (minimum 37 and maximum 42), as shown in Fig. 6.

Fig. 5. Spectacles to simulate visual dysfunctions: cataract, diabetic retinopathy and blindness.

All the subjects provided informed consent prior to the test. The experimental protocol was conducted according to the Declaration of Helsinki [20].

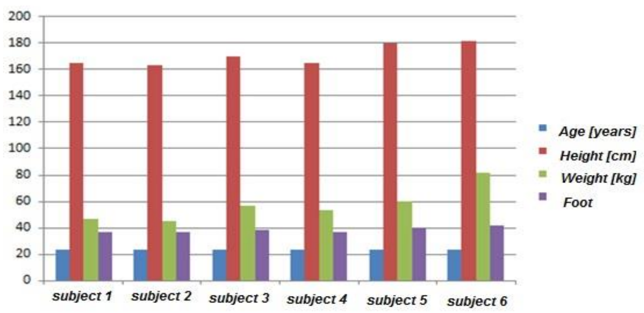


Fig. 6. Initial parameters of human subjects sample [19].

They have been informed about the protocol of the experiment and the devices that were used.

All of the subjects have been chosen with no locomotors pathology and any other pathology that could influence the results in any way.

At the beginning of the experiment, the subjects were trained to follow the basic instructions, explained the manoeuvres they had to follow during the recordings, and also made a general anamnesis of the general health and visual state.

Following these initial tests, it was found that the subjects met the main conditions and could participate in the experiment, especially because they wear similar footwear (sports shoes type) with flexible soles or bottom heel.

Additionally, the subjects had a light, lightweight, non-constrained dressing to not influence walking or stability.

The equipment used in the walking cycle evaluation procedures consists of: *footscan* pressure plate, *RSScan*, high speed video camera for two-way recording of the pressure plate cycle.

In order to be able to analyse in real time the effects of visual dysfunction simulation on the walking cycle, a set of sensor arms, on both legs (with pressure sensors) was added and used, with the acquisition of Arduino plate data (Fig. 8).

Fig.7. Shape of shoes used in experiments [19]

This experimental system is used in the structure of procedures for assessing the walking cycle and the pressures exerted on the plantar surface in six successive stages.

These stages are:

1) Record the normal cycle of subjects in the initial state (without simulation spectacles) on the RSScan plate, looking forward at the target at 5 + 2 = 7 m (the distance measured from the entrance of the subject on *footscan* plate);
2) Record the normal cycle with the subjects wearing the simulation spectacles (cataract, retinopathies, blindness) on the RSScan plate;

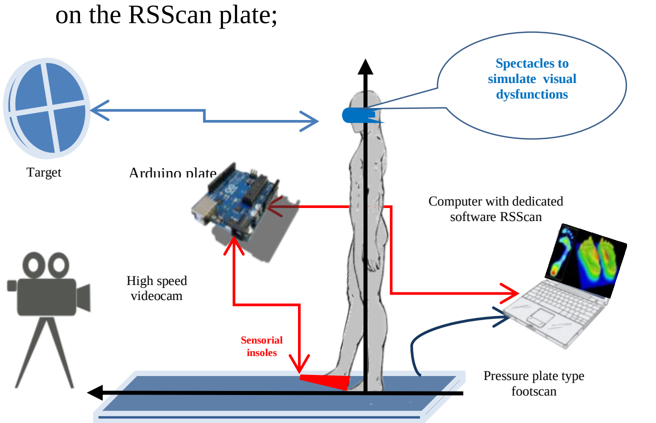


Fig. 8. Experimental setup.

3) Recording, with the aid of the sensor-based system, the normal walking cycle with subjects without simulation goggles and targeting 7 m in front of them;
4) Recording, with the aid of the sensorial system, of the normal walking cycle with the subjects wearing the simulation spectacles;
5) Recording, using the *RSScan* pressure plate and the sensory insoles, of the normal gait cycle of the subjects without the simulation spectacles;
6) Recording with the help of the *RSScan* pressure plate and the sensory insoles, the normal gait cycle of the subjects wearing visual simulation spectacles (cataract, retinopathies, and blindness).

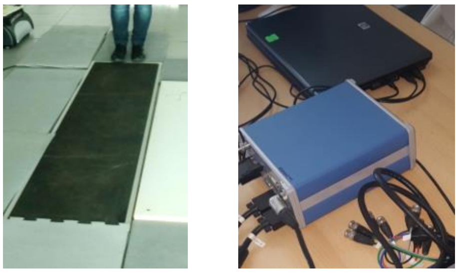
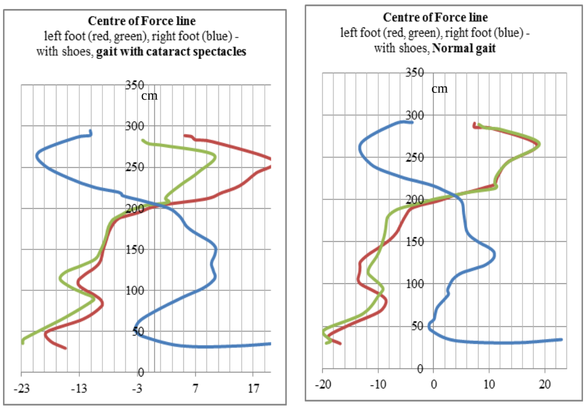


Fig. 9. Experimental pressure plate type RSScan with acquisition box.

The plantar pressure recordings of the participants were made on the pressure plate having an active length of 2 m and which made the data transfer through an acquisition box to the computer to be then interpreted by the software application *RSScan footscan 7.97 Gait 2nd generations*.

IV. Results and Conclusions

The results of plantar pressure recordings, trajectories and the variation of the pressing force on the ground by the plantar surface are shown in Fig. 10-12, corresponding to the first two stages of the experiments.



a) b)

Fig. 10. Centre of force line for left and right foot in normal gait, with shoes, with (a) and without (b) cataract simulation spectacles.

In all cases, according to each plantar area, the normal force on the plate, with and without the simulation spectacles, the graphs representing the force center line (Fig. 10), the force distribution of all contacts on the force plate (Fig. 11), the distribution of pressure on the plantar surface in normal gait with and without simulation spectacles were recorded, (ex. left foot Fig. 12).

For example, in the case of one of the subjects, the analysis of the two graphs presented shows a substantial change of the centre line trajectories in relation to the direction of displacement, in the case of simulation of the visual dysfunction compared to the initial normal gait situation. This was observed in the entire sample of subjects, with the percentage of deviations from the direction of travel averaging to 15.6%, predominantly outward, which indicated an extra effort to maintain balance during the gait cycle

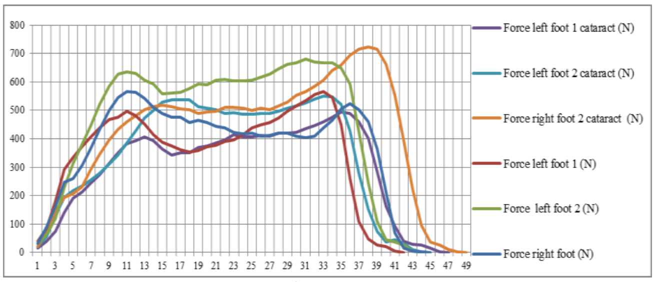
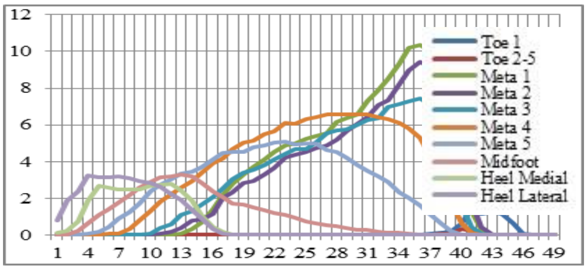


Fig.11.Comparison between forces in gait with cataract simulation spectacles and in normal gait

The same modifications, this time of the forces exerted by the planting surfaces on the ground, can also be observed in the case of the left and right leg distribution (fig. 12), the differences reaching up to +/- 22% of the average weight of the subject. At the same time, there is a retained approach to walking the distance of 2 m when the subject wears the simulation spectacles to the situation in which it goes normal, pressing more on the pressure plate especially during the second step of the cycle.



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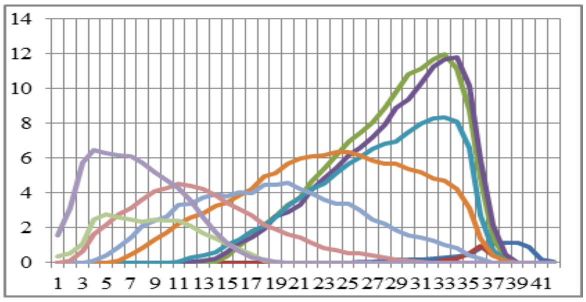


b)

Fig.12. Comparison between pressure distribution for left foot, with (a) and without (b) cataract simulation spectacles, for the same subject from sample.

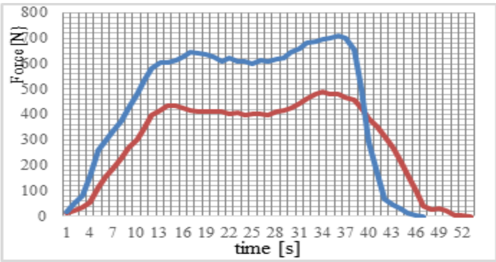
The first observation in this case is that the subject goes much safer on the pressure plate in the initial situation (normal walking without visual dysfunction simulation) compared to the situation where a cataract type deficiency is simulated (Fig. 12), having a more uniform pressure distribution, both on the metatarsal and on the medial and lateral heel. If the walking cycle with visual dysfunction simulation is recorded, the subject moves the body weight, by default, the pressure distribution, on the metatarsal area and less on the medial and lateral heel. In a similar form, the rest of the subjects in the sample, on average, have a predilection to go, in the case of visual dysfunction, with the displacement of the pressure to the tarsal-metatarsal area.

Fig. 13. Experimental setup for sensorial insoles with Arduino plate [18].

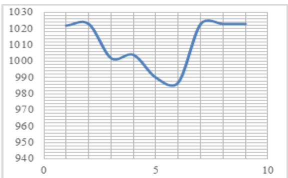
Along with this equipment was used a second system, like sensory insole, mounted in shoes, with data acquisition on the Arduino plate, with the same purpose, namely recording plantar pressure (forces) on the gait cycle (fig.13).

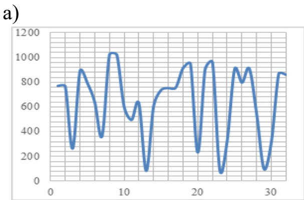
The sample subjects were tested with this device and then the pressing force on the plantar surface was compared to the sensory insole use (Fig.14.a).

In Fig.14.a it can be noticed that the recording of force variation on one of the plantar surfaces (example) highlights the same behaviour of contact between soil and foot.



a)





b) c)

Fig.14. Gait with (red) and without (blue) sensorial insole (a) in cataract simulation

By using the sensorial insole (Fig. 14.b) and by using them with visual dysfunction simulation, strength variations are obtained in the zones and contact moments between the soil and the plantar surface (Fig.14.c).

It can be seen that the length of the contact area when using the sensorial insole (without visual dysfunction simulation) is reduced, the subject walking normally and easily.

If visual dysfunction is simulated, sensory insole recording is more sensitive and highlights the variations in the push force when contacting the ground.

The vertical scale of the two graphs that record behaviour in the situation without and with dysfunction simulation represent the values recorded on the Arduino plate which are then converted to values corresponding to the pressing forces.

Therefore, the effect of visual dysfunction simulated by the glasses on the sample of subjects highlights the important and substantial effect of diminishing the perception of the environment on the keeping of the posture and stability, and especially the safety in locomotion, during the gait cycle.

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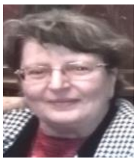

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