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Biomechanical Analyzes of Human Body Stability and Equilibrium

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***Abstract*— The authors present some detailed analyzes related to the biomechanical study of the human body stability and equilibrium in normal conditions. Thus, in the first part of the paper the theoretical aspects of the human body behaviour from the point of view of the internal and external forces actions are approached and also the initial research conditions are established. In the second part of the paper we present the experimental considerations concerning the data acquisition methodology and also the experimental setup is described. In the final part we analyze the results and conclusions of the data recorded during the experiments.**

***Index Terms*— stability, biomechanics, human body, force plate.**

I. Introduction

The biomechanical analyzes upon the human body are a significant source of information at this moment, meant for knowing and understanding the human factor behaviour in different configurations of internal or external environments that may affect their stability and space-time orientation.

Locomotion as well as stability or human body equilibrium is due to both its internal forces and the external ones and also due to the displacement and positioning environment. Thus, the human body internal forces should exceed the gravitational force, the weight of the body itself or of the moving or equilibrating segments, the air pressure, environmental resistance, inertia, accelerating forces, reaction forces of the supporting surface, frictional forces and other forms of external resistance.

The gravitational force represents the most important external force acting upon all the bodies and their segments. Being gravitational effects, the human body weight and the weight of some of its segments will act downwards upon the body centre of gravity and are also depending on the volume, length, density and number of moving segments.

The biomechanical principles that marked the set of tests upon equilibrium stability and human body motions can be synthesized as follows:

- Any motion of the human body starts either by means of a stabilization in a suitable and convenient position or a mobilization of the body centre of mass;
- The segments mobilization action is accomplished starting from the centre to the margins;
- If the lower or upper members act like *open cinematic chains*, meaning the peripheral extremity is free, the muscles stepping into action will have a fixed insertion point on their central ends and act upon the segments by means of their peripheral ends;
- When the upper or lower members act like *closed cinematic chains*, meaning that their peripheral extremities are supported or fixed on a certain basis, the acting muscles will take a fixed point on their peripheral ends;
- When the members act like *open cinematic chains*, a series of agonistic muscles will contract in an isotonic way and the motion will be the result of the muscular ends approach;
- When the members act like closed cinematic chains, the agonistic muscles groups will contract in an isotonic or isometric way, successively or both ways;
- The motions execution speed depends on the inversely proportional ratio of the agonistic muscles intensity action and respectively of the antagonistic ones;
- At the end of each performed motion, the antagonistic muscles change to neutralizing muscles and the higher the execution speed, the more intense their action;
- The position is held by equalizing the agonistic and antagonistic action intensity and also by putting all the muscular chains in static action conditions;
- When the external forces action upon the human body is used, the role of the muscular groups is reversed and they keep the body in a resistance stance towards these external forces. But this reversed action is possible in certain conditions of using external forces, only after they triggered the body or its segments motion;
- In case of closed cinematic chains, the bone-joints systems act as supporting elements, while in case of open cinematic chains they act as speed and action systems;
- For the improvement of human body motion or equilibrium mechanisms, we aim at their maximum efficiency operation, using internal forces at minimum values and external forces at maximum values;

When we analyzed the human body equilibrium, it was necessary to establish that the sum of the forces acting on it

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was equal to zero and the sum of the torques acting on it was also equal to zero. In other words, there were no unbalanced forces or torques.

Human body posture is the term used to describe the orientation of any body segment relative to the gravitational vector and the balance refers to body posture dynamics that prevent falling in arbitrary directions.

To maintain balance or equilibrium, the postural neural-muscular control system keeps the body centre of mass (COM) over the base of support (BOS).

The BOS represents the minimum area enclosing the body's contact with the ground.

Therefore, while standing, in bipedal posture, the BOS is the area enclosing the soles of the feet (or shoes). A smaller BOS provides a smaller area for the alignment of the COM, and the body in such a position is considered less stable and may fall over.

This postural control process is referred to as *dynamic stability*.

The biomechanical goal of the human body stability analysis is to adjust the relation between the COM and the BOS.

Situations requiring balance can be classified into three general conditions:

- Keeping a stable position,
- Postural adjustment to voluntary movements, and
- Reactions to external predicted and unpredicted mechanical perturbations (slipping or stepping).

In dynamic stability, both the BOS and the COM are in relative motion. Prevention of falls requires effective balance function under dynamic conditions because most falls are caused by sudden motion of the BOS or by sudden acceleration of the COM. [1]

The main key to dynamic stability is the momentum control of the COM. The distribution of body mass is achieved by two-thirds of mass distributed in the head, arms, and trunk and the rest into different human body parts. Because of the large mass and inertia moment of the upper body, its position and movement (forward momentum) can be critical in the overall stability of the upright stance.

For that, stability can be defined as the ability of human body to return to its original state that means desired actions or movement trajectory after a disturbance or stable position.

II. METHODOLOGY AND EXPERIMENTAL SETUP

The experimental methodology structure needs for the start of the investigations the initial human parameters so, different physiological parameter are recorded and analyzed.

It is important to have the physiological parameters recorded in each of the investigations moments and also that the human model obtains the response from the interaction between human body and environment, during the working activities.

During the first step of investigation we recorded the physiological information about *weight, height, blood pressure and pulse, oxygen quantity in the blood, lactic acid and quantity of glucose and temperature*.

The persons participating to this investigation were monitored three times daily (morning, afternoon and evening) in order to have all kind of information about the variations of these parameters in day time or about the variations of values for human body weight in the same period.

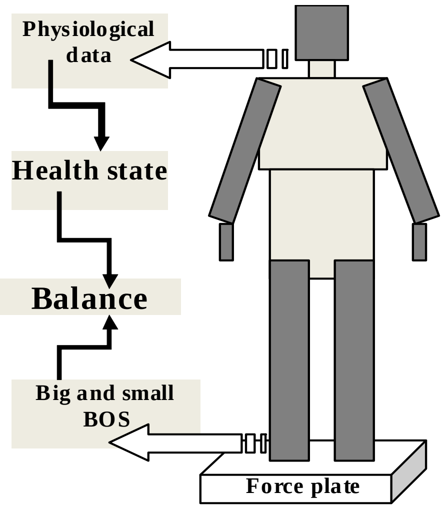

Fig.1. Schematic representation of the experiment

The subjects sample participating in the experiment consisted of 11 persons aged between 23 and 56 years, with normal anatomical configurations but also with specific features.

These subjects were investigated in the same environmental conditions, at the same time during one hour in order to avoid the metabolic and physiologic changes.

The experimental setup consists of a Kistler force plate that allows the forces and torques measurement developed by the human body in balanced bipedal position and an assembly of devices for the assessment of the subjects' physiological stance.

The setup is completed by a video recording system and also an image processing soft on a performing computer.

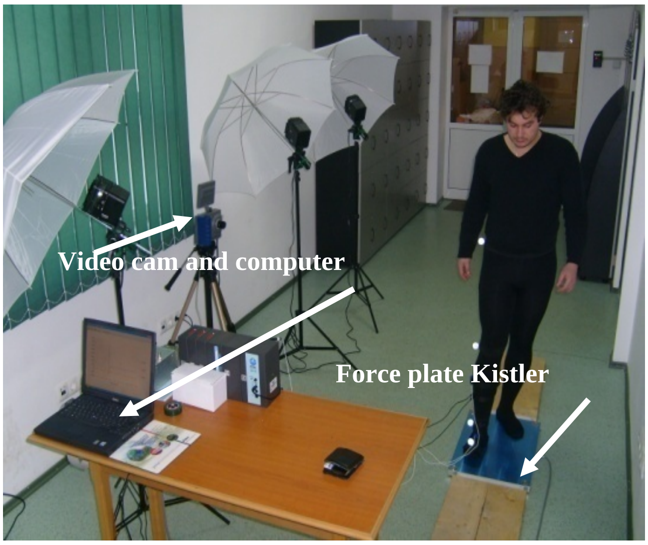

Fig.2 Experimental setup

The recordings of the stability stance were developed on the same experimental configuration, during a gradually longer time interval, with open eyes or closed eyes, with big support base (corresponding to each subject).

The recording time was about 20 sec for each subject and the results were displayed according to the Oz force (Fig.3 up) and respectively to the stability area of the subject upon the force plate. (Fig.3 bottom)

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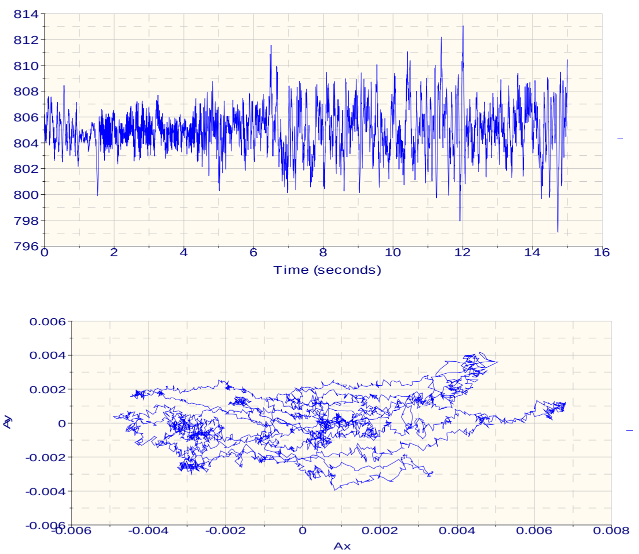

Fig.3. Force diagram and stability area

The experiments were developed following the standard procedure, namely the previous briefing of the subjects, performing of a set of trial recordings to avoid the acquisition jams, preparing the subjects for recording (position, posture, reactions, etc.), initial physiological data acquisitions and then real recordings.

Thus we performed a set of 3 experiments, each with two required situations (open eyes, closed eyes during the recordings on the force plate) for the entire subjects' sample.

The 3 experiments consisted of data acquisition concerning the bipedal stability of the subjects in two required situations and took place in the morning (between 9 am and 10 am), in the afternoon (between 1 pm and 2 pm) and in the evening (between 6 pm and 7 pm).

III. RESULTS AND CONCLUSIONS

For the results exemplification we chose one of the subjects, having the weight of 80,4kg, female, aged 52, that was recorded in the above mentioned conditions, was instructed to maintain a bipedal position with big base of support, arms along the body, open eyes, look ahead and no visual or acoustic stimulus (the subject wears glasses being near-sighted). The force plate and the data acquisition system have been calibrated for each measurement as the subjects have different weights and the filtering basis changes. From the diagram presented in fig.4 we may only notice the change of the minimum force during recording time in comparison to the maximum values of the force measured along Oz, also during the same time. By comparing the values presented in fig.3 and 4 we may notice that the subject was more stable (values close to the nominal weight) at the beginning of the recording time, unlike the final time interval when the subject showed disequilibrium and lateral balance due to a complex equilibrating – re-equilibrating system, which acts every time upon the entire human body and attempts to keep the equilibrium towards the external forces.

The explanations of human postural control system are very complex approaches and they involve multiple sensory systems and motor components. There are possibilities of investigating human balance control under quasi-static (unperturbed) conditions or dynamic (perturbed) conditions, but despite these approaches, a very important variable remains, the fact that sensorial motor components are integrated into the postural control system and the system uses similar mechanisms and strategies under quiet-standing and perturbed conditions. Having the complexity of the postural control system, we may consider that its output is highly irregular. For example, during quiet standing, the centre of mass (COM) under an individual's feet continually fluctuates in a stochastic manner. (fig.5)

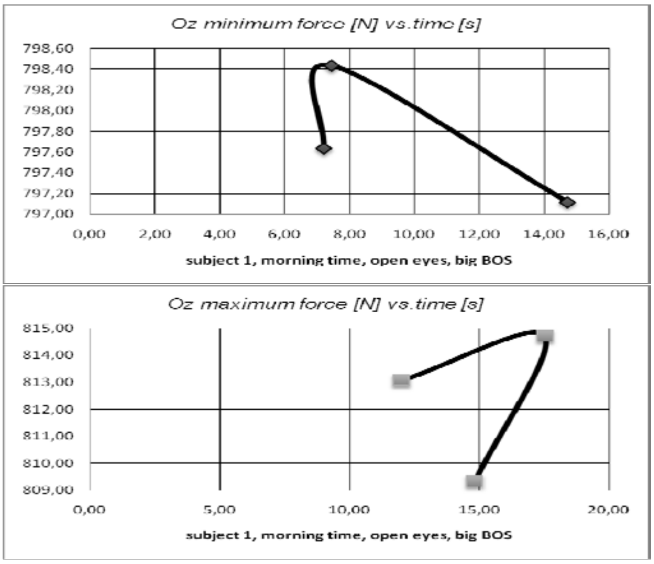

Fig.4. Minimum and maximum force diagram (open eyes)

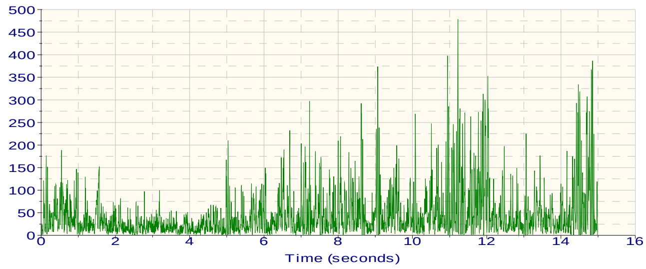

Fig.5. COM fluctuations in time

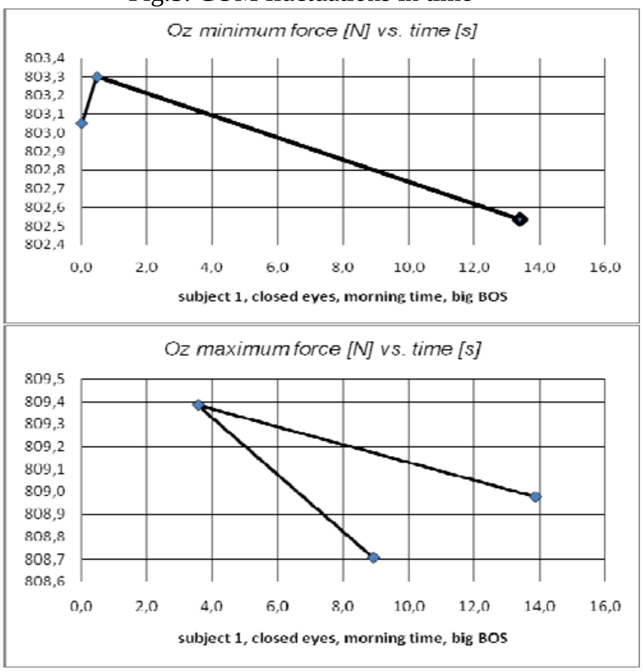

Fig.6. Minimum and maximum force diagram (closed eyes)

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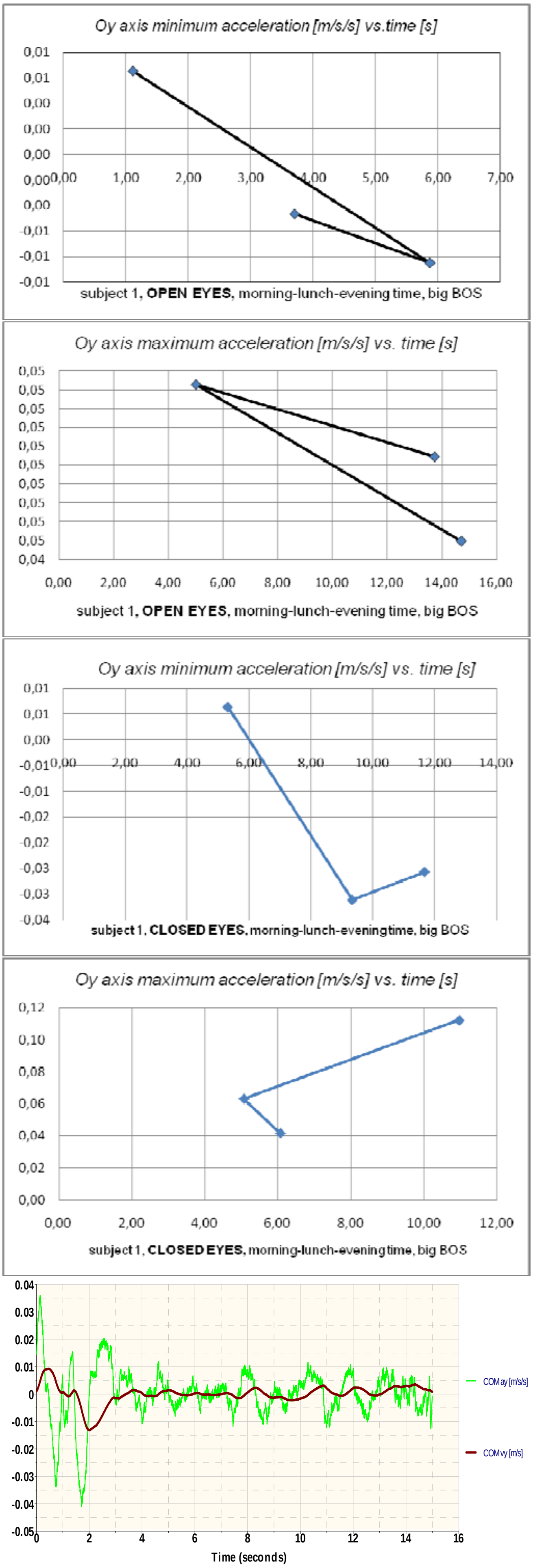

Fig.7 Accelerations diagrams in various conditions

From the analysis of the diagrams in fig.6, referring to the same subject, in bipedal position, for 16 sec, without external stimuli we may notice a behaviour according to the stance (closed eyes) that induces a certain initial instability (first 4 sec) which is fast compensated by the subject due to the neural-sensorial mechanisms controlling the muscular system.

The same behaviour is analysed in the diagrams in fig.7 where the change in the accelerations on the Oy axis of COM highlights these postural instability phenomena along the three phases of the experiment.

For instance the analysis of the COM acceleration along Oy emphasizes for subject 1 the same instability, lateral balance when the subject keeps arms along the body, closed eyes, even if it is measured in the morning in normal metabolic conditions.

By extending the analysis to the entire subjects' sample we may notice similar manifestations but also specific aspects according to the analyzed stability type.

The determinations made by correlation (accelerations on three directions correlated to the speeds, COM displacements on Oz and Oy, variation of the stability axis correlated to the base position and subject vertical inclination) showed a complex connections mechanism between the human body structures so that once determined a measurement, this may be considered an initial element and then transformed in an evolution parameter.

Using this set of procedures we may assess the behavioural performances of the subjects and we may determine their physical or psychical fatigue degree along an active day.

These recordings may indicate in time a certain manifestation of the neural-sensorial equilibrium instability and not last we may establish some correlations between the metabolic level and the body's wear.

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