Analyses of noise effects on standing human body stability

MIHAELA BARITZ[1], DIANA COTOROS[2], LUCIANA CRISTEA[1], ION BALCU[3],
[1]Precision Mechanics and Mechatronics Department
[2]Mechanics Department
[3]Strenght materials and vibration Department
University TRANSILVANIA of Brasov
Address: 29 Eroilor St., Brasov 500036
ROMANIA
mbaritz@unitbv.ro , http://www.unitbv.ro

Abstract: - This paper presents some considerations and results concerning measurements of the human body stability as a main part of the bio-behavioral analyses in order to research the noise effects on occupational comfort or detecting some mobility deficiencies or even attention failures. We performed studies upon a healthy organism, the recordings being made by help of some complex interconnected systems and the results are used to improve the working conditions in sound pollution situations. The methodology and the investigations procedures are presented in the second part of the paper while in the final part the results and the conclusions of this work are presented.

Key-Words: - acoustic, stability behavior, human body, force plate.

1 Introduction

We are constantly surrounded by sounds that provide information about the objects around us. Determining the sources of sound is an important biological characteristic and our ears enable us to collect such vital information in the air.

The ear can be divided into three distinct regions based on their function and location in the peripheral auditory system. The acoustic signals manifested as pressure fluctuations in the air are collected by the external ear and transmitted through the middle ear towards the inner ear for transduction into electrical neural impulses to the brain.

A lot of sounds, many of them considered as noises, from the environment determine changes of the human behavior, and if they are combined by visual stimuli, they may finally affect the stability, balance, gait or jumps performed by the human factor.

All these manifestations may become in time, activity discomfort or may even transform in occupational pathologies if the causes, manifestation forms, their evolution and values remain unknown.

Hearing loss can be due to aging, exposure to loud noise, medications, infections, head or ear trauma, congenital or hereditary factors, disease processes and many other causes.

The vast majority of hearing problems do not require medical or surgical intervention. Some 90 to 95 percent of all cases of hearing loss can be corrected with hearing aids. For this reason it is very important to identify it in due time and prevent it by acting as much as possible upon the environmental factors.

Human hearing is at its most sensitive around speech frequencies (200 Hz – 3.5 kHz).

The full hearing range for a fit young person runs from about 20 Hz (20 cycles per second) to almost 20 kHz (20,000 cps). However, the high frequency response falls off rapidly with age, most adults can't hear much above 8 – 10 kHz.

Many industrial workers and pop music fans, etc., will have permanently damaged hearing and thus a greatly reduced hearing response (i.e. be somewhat deaf!). [5]

Temporary exposure to loud sounds, but not loud enough to cause damage, will reduce hearing sensitivity for a short while (temporary threshold shift). This is part of the human body's self-protection systems.

At lower and higher frequencies than the speech range, human hearing is not very sensitive. This is demonstrated in some ICE (In Car Entertainment) devices, stereo stacks, etc, that have a "Loudness" control in order to attempt to overcome this problem (Fletcher-Munson effect).

Below 20 Hz, sound is referred to as Infrasound, as it is really sensed as a vibration rather than heard by the ear. [5]

The most important stance of the human body is represented by the bipedal, vertical, upright and supported on a normal base (closed insteps – small base) posture, as being an initial, intermediate or even final state for the loco-motor function and also for the rest of the movement actions on any direction (jumps, bends, torsions).

The stability stance as well as the integral balance around the equilibrium position are determined by the health level of the entire human body and may constitute clear informational sources for the human behavior evaluation in any situation.

The small deviations of the human body posture around the vertical direction determine the occurrence of a torsion moment, which acts upon the entire structure and may unbalance the human body or may create a vibration state.

However, this process of corrective torque generation is not fully understood and controversy remains regarding the organization of sensory and motor systems contributing to the postural stability of the entire human body.

Balanced state of postural sway is controlled by central nervous system, and the upright stance cannot be sustained without this control. It is widely accepted that the corrective torque is generated through the action of feedback control system; the input sources include visual, proprioceptive and vestibular system [2].

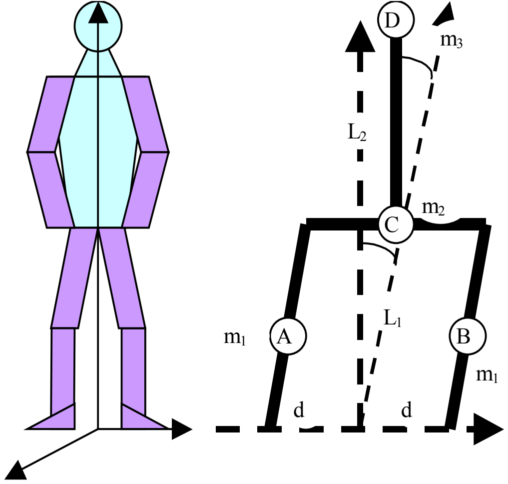


Fig.1

Figure 1 shows a simplified pelvic structural model during static upright stance. A, B are the masses of legs, C is the mass of pelvis and D is the mass of upper trunk.

Because the lumbar-sacral always sways in inverse direction of the ankle joint with the same value of θ, the upper trunk is kept perpendicular to the horizontal.

In order to locate the center of mass it is necessary to establish some main principles:

- its precise location depending on individual's anatomical structure;
- habitual standing posture;
- current position;
- external support;
- location in human body;
- variations with body build, posture, age, and gender
- infant > child > adult (in % of body height from the floor);
- generally accepted that it is located at ~57% of standing height in males, and ~ 55% of standing height in females;

Location of COM remains fixed as long as the body does NOT change shape.

The maintenance of equilibrium in standing position is one of the most important activities for two main reasons: firstly, the center of mass must be located in the support area; secondly, for a major period of the standing action, the body is supported first by two legs and after a short time by a single limb with the center of mass inside the base of support but with the tendency of going outside it. In elder people especially, up to 70% falls occur during standing and of course, locomotion action. [3]

By **the static stability margin** is meant a distance of the GCOM from the edge of the support polygon, measured along a current vector of motion of the gravity center, where:

$$x_{GCOM} = \frac{\sum_{i=1}^{n} M_{xi}}{\sum_{i=1}^{n} F_{xi}} = \frac{\sum_{i=1}^{n} m_i x_{ci}}{\sum_{i=1}^{n} m_i} \tag{1}$$

$$y_{GCOM} = \frac{\sum_{i=1}^{n} M_{yi}}{\sum_{i=1}^{n} F_{yi}} = \frac{\sum_{i=1}^{n} m_i y_{ci}}{\sum_{i=1}^{n} m_i} \tag{2}$$

and m_i is mass of the *i*-th body, whereas x_{ci} , y_{ci} denotes location of the center of mass of the *i*-th body.

The motion of the first link was on ankle and the second link was on lumbar-sacral. [9]

The angular sway of the first link can be measured as the average value of the two legs and the angular sway of the second link can be calculated indirectly as shown in Fig. 2, where point O is the ankle joint, point A is the lumbosacral joint, point P1 represents the marker of legs and P2 represents the marker of subject's back. [2]

Angular sway θ_2 of lumbar-sacral joint is expressed as Eq. (3)

$$\theta_2 = \left(\frac{x_2}{L_1 + l_2} - \frac{x_1}{l_1} \right) \left(1 + \frac{L_1}{l_2} \right) \tag{3}$$

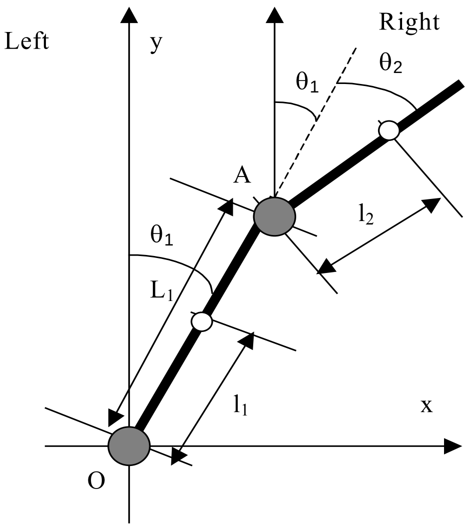


Fig.2.

2. Experimental setup for investigation

In order to start the investigation we analyzed and realized a data acquisition structure based on an assembly of measuring human physiological parameters controlled by a computer unit. [11,6]

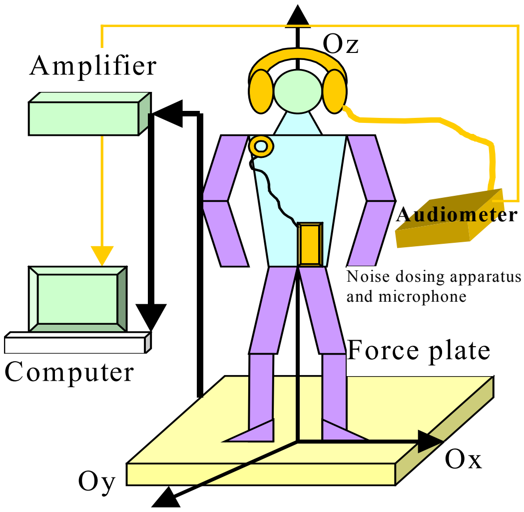


Fig.3.

The main measuring element is the Kistler force plate, which allows the values acquisition for the forces and moments developed by the human body, along the three directions (X, Y and Z), during an established period of time according to the experiment requirements.

The analysis performed upon the subjects started by establishing an investigation protocol, which aimed at a large range of measuring the bipedal stability (big support base with different polygons, small support base trapeze shaped, open eyes and arms along the body, in the same moments of the day – morning) and with different levels and sort of noises or acoustic stimulus.

The corresponding soft for the values acquisition is Bioware, which allows the recording of the forces and moments values, measured along the three directions by help of some piezzo-electric sensors of the force plate.

Fig.4.

We also aimed at the fact that the bipedal position of each subject is centered on the plate, with no high heels shoes, arms relaxed along the body, open eyes and the eyes oriented straight ahead.

In first stage of the experiments we established and kept the parameters of the laboratory environment.

Temperature into laboratory was 25^0C, air humidity 80% and atmospheric pressure 755 mmHg.[4]

In the second stage we measured the physiological parameters of the human subjects (weight, height, age, pulse, blood pressure) in relaxed stance, without any health problems and with a good metabolism (example: blood pressure 155/82 mmHg, pulse 91, face temperature $36{,}7^0$C, height 175 cm, weight from 50-125 kg).

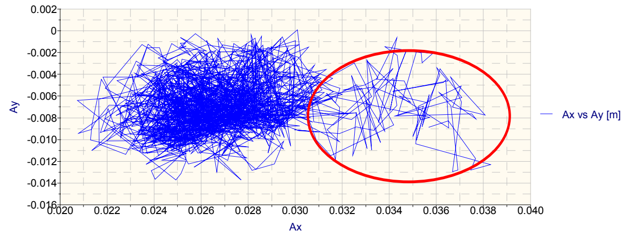
All these parameters are necessary to establish a common modeling base to measure and to evaluate the human body stability behavior in the same noisy conditions. [7]

Fig.5

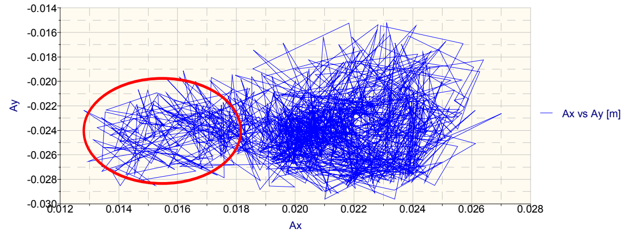
The subjects were subjected to various sounds perturbations, continuous or briskly, with different intensities and along various time intervals, with or without hearing protection (fig.5).[8]

3. Results and conclusions of investigations

Thus, for example, in fig.6 we present the data acquisition concerning the stability of a human subject, female, height 1,7m, age 53, no health problems, wearing far sighted glasses, weight 80kg, for which we analyzed the stability area and the moments of forces evolution along Ox and Oy axis, in the morning time, without any source of additional effort induced to the organism. [8]



Stability area for big base of support, with acoustic stimulus on left side



Stability area for big base of support, with acoustic stimulus on right side

Fig.6.

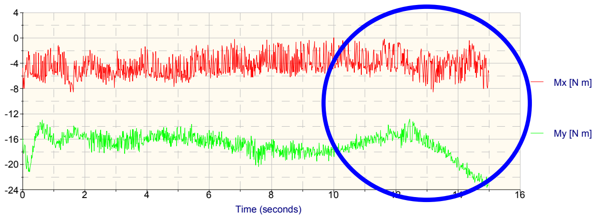
Also she is wearing a noise dose measure apparatus with microphone and recording system.

As we can notice from the diagrams analysis in fig.3, the evolution of the stability area in this case presents a compact and asymmetrical surface for the recorded human subject reactions subjected to an unilateral acoustic stimulus, short duration (5 sec) coming from the left side. Thus, the human subject try to self re-equilibrate by changing and extending the area of stability of center of mass (COM) projection on the right side (to the opposite side with the acoustic stimulus), increasing in this manner the support surface, but setting off through small oscillations the instability rate of the whole human body.

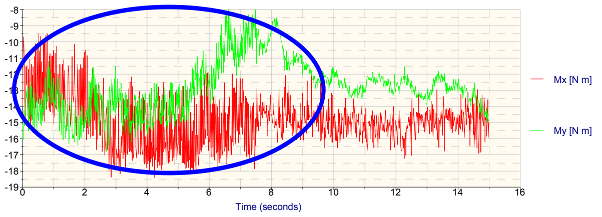
In the diagram from fig.6 we presented the similar situation for the same human subject (standing on a big base of support-BOS), when using an acoustic stimulus coming from the right side, having the same duration and amplitude. We can observe the same sort of instability (manifested to the opposite side with the stimulus direction), the area of stability having now a shape much more compact and compensated by a sustaining support of the right leg and having a higher level of instability (the selected areas are more dense).

These manifestations can be found in all the analyses performed on the selected subjects allowing a unitary evaluation of the stability area.

The recordings presented in fig.7 represent the forces' moments evolution, measured on *Ox* and Oy directions for the same human subject, in the two variants of acoustic stimulation. After the process of analyses of the graphs presented in fig.7 we can observe that the stimulus coming from left side establishes a much equilibrated behavior of the human body on two directions Ox and Oy, and his instability can be induced only because the appearance of the acoustic stimulus is random, the human subject having a good and natural capacity for recovering the standing position on this side (right leg).



Moments on Ox and Oy axis for big BOS, with acoustic stimulus on left side



Moments on Ox and Oy axis for big BOS, with acoustic stimulus on right side

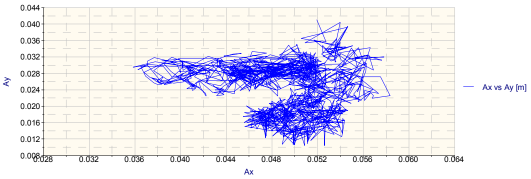
Fig.7.

Opposed to this situation, when the acoustic stimulus is coming from the right side, this develops a strong balance of the human body on the opposite side (left), on both directions Ox and Oy, at the moment of appearance and during acoustic stimulus (selected zone on fig.7).

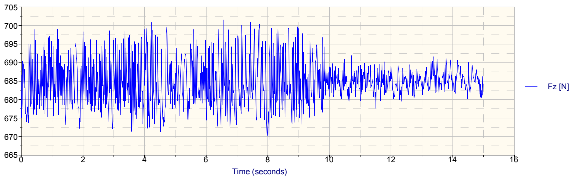
The recording time was each time the same – 15 sec and the data set was stored in the measurements database used for evaluation. In the case of force evolution analysis we observe the same type of manifestation for the recording performed in the evening, emphasized by an increase of the variation limits of the force along Oz, but also by a higher frequency of their occurrence, values that indicate an increased instability of the human body and a fatigue state at the inferior limbs level.

In this situation and correlating with the age and the influence of the poor sensorial system we may confirm that the installation of the fatigue state or an instability behavior of the human body as a follow of a normal daily activity takes place in the second part of the day determining a motor activity deficit and the diminishing of the orientation perception increasing the balance and the sway at different acoustic stimulus.

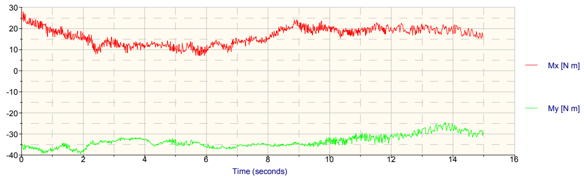
In the case of a male subject age 24, no health problems, not wearing glasses, weight 68kg and height 1,79m, the evolution of stability area in the three moments of measurements indicates a more compact but asymmetrical shape around the theoretical equilibrium position and the forces variation diagram is changing towards the diminishing of the oscillations number for the recordings situation related to those in the morning time.



Stability area, big BOS, right side acoustic stimulus



Force on Oz direction, acoustic stimulus in first 5 sec. from right side



Moments on Ox and Oy axis

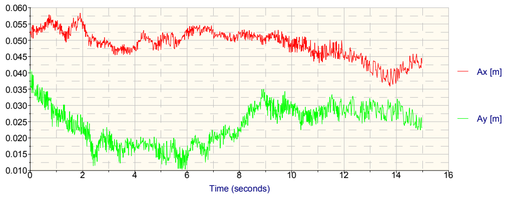
Fig.8.

As we can see from fig.8 the human subject is much less stable on the support surface due to restless and tensional state.

Also the fact that the human subject chosen for these tests is tall but thin and shows a very strong sensibility, over the medium values, on sounds and noises is very important.

Even though the duration of acoustic signal was only 5 sec, on the beginning of the experiments, the reaction of human subject on the acoustic stimulus was almost 9 sec, manifested through a strong oscillation of the force on *Oz* direction. .

Measuring and recording the moments developed on *Ox* and *Oy* directions confirm this strong instability at the start moment of recording and also on 9 sec interval, but show a good attenuation and recovery of human body standing position immediately after this period and until the recording finishes.



Displacement on Ox and Oy axis of center of mass (COM)

Fig.9.

The displacements of COM on the support surface are more accentuated on *Oy* direction, that means a balance from front to back of the human body, partial compensated by a less accentuated balance from left to right, which can not strain in a special way the joints of the human locomotor system, but only the hip joint.

The recovery of the correct balance and equilibrium of human body is achieved after 9 sec of stimulation and post-stimulation, observing the symmetry of the displacements on two directions *Ox* and *Oy*.

This behavior indicates a normal state of reaction, but with a relative low acoustic sensitivity level, which limits the capabilities of human subject to perform the working activities with a high concentration and coordination power.

This fact proves a more non-equilibrated behavior as the fatigue due to daily activity can influence the motor capacity and also can reduce the resistance to effort and attention for different sounds or acoustic stimulus for young people.

For these situations it is necessary to improve the health performance and to train the abilities to adapt the human body at different environmental conditions.

In the diagrams shown in the figures we presented the analysis of the evolution of parameters during these investigations, made by statistical methods.

From these recordings and according to the initial conditions and the demands of the researches we can conclude: that the most important force values are the components on the direction **Oz** because they can establish the amplitude of the balance (moments) in other two directions Ox and Oy.

Also the changes in foot position have been found to affect measurements of standing balance, force and stability surface and in normal conditions the size of the support is a primary determiner of stability.

Other influences were the light stimulus on the visual system because they are the most important stimulus inducing the instability that will be bigger in the open and fixed oriented eyes position than free gaze even if the optical stimulus was the same.

This situation is due of the unknown visual external stimulus reactions and concentration on the periodic activities with automated movements.

Also the different shape of acoustic stimulus like duration, amplitude and way of appearance are sources of analyses of human subjects' reactions and especially analyses of stability rate and the size of human body balance.

By future researches we are going to analyze the influences of the visual stimuli correlated with acoustic stimuli, upon the human body equilibrium in order to obtain a complete evaluation of the human subjects' stability, subjects involved in technological activities.

4 Acknowledgment

These researches are part of the Grant nr. PNII-IDEI 722 and 744 with CNCSIS Romania and we've developed the investigations with apparatus from Research Department "Advanced mechatronics systems" from University Transilvania of Brasov

References:

[1] A. Tozeren, Human Body Dynamics: Classical mechanics and Human Movement*, 2000 Springer-Verlag New York, Inc.ISBN 0-387-98801-7*

[2] Y. Jiang, S. Nagasaki, M. You, J. Zhou, Dynamic studies on human body sway by using a simple model with special concerns on pelvic and muscles roles, *Asian Journal of Control, Vol. 8, No. 3, pp. 297-306, September 2006;*

[3] J. Mrozowski and J. Awrejcewicz, ZMP and GCOM criteria as a base of assessment of the human gait stability, Department of Automatics and Biomechanics, Technical University of Łódź,

[4] Baritz M., Cotoros D., Cristea L., Rogozea L. Analyze of human body bipedal stability for neuromotors disabilities, *BICS'2008, Tg.Mures, Nov.6-7, 2008, ISSN 2065-0418.*

[5] A. M. Nakashima, The effect of vibration on human performance and health: A review of recent literature, *Technical Report DRDC Toronto TR 2004-089 July 2004*;

[6] S. Mota, R. W. Picard, Automated Posture Analysis for detecting Learner's Interest Level, MIT Media Laboratory 20 Ames Street Cambridge, MA 02139, USA, 2007;

[7] F. Hlavačka, Human Postural Responses to Sensory Stimulations. Measurements and Model, *MEASUREMENT SCIENCE REVIEW, Volume 3, Section 2, 2003;*

[8] M. Baritz, L. Cristea, D. Cotoros, L. Rogozea, Human body biomechanical stability evaluation affected by automated movements*, 3rd International Conference "Optimization of the Robots and Manipulators" OPTIROB 2008 - PREDEAL Romania, 30 May- 1 June 2008* ;

[9] Kui Fu Chen Standing Human - an Inverted Pendulum, *Lat. Am. J. Phys. Educ. Vol. 2, No. 3, Sept. 2008,* ISSN 1870-9095;

[10]http://www.tech5.nl/products/acoustics/humanvibration

[11] J. Polechonski, J. Blaszczyk, The Effect of Acoustic Noise on Postural Sway in Male and Female Subjects, *Journal of Human Kinetics volume 15, 2006, 37-52*