914. Application of accelerometry in the research of human body balance

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Abstract. This article provides methods for evaluating the parameters of human body balance by applying accelerometry and evaluates the impact of physical load on the balance parameters. The presented research work aims at assessing and comparing the parameters of static balance in comparatively healthy adults (20-25 years old) before and after physical activity.

Keywords: body balance, physical activity, accelerometry.

Introduction

Accelerometry is one of the newest and alternative methods for research and evaluation of balance. This method is related with a posturography method; however, differently from applying the posturography method in research, no laboratory conditions and expensive equipment are required. Movements of the head with respect to the trunk are recorded by means of accelerometric method even before the changes in the position of the centre of the body mass, measured by a force plate, appear [1, 2]. During accelerometry, the triaxial accelerometers are used by attaching them to the trunk and limbs of the subjects under study. Computer equipment for processing of the measured signals is used. Speeds and accelerations of the movement of the body parts are determined during these measurements [3].

Accelerometry is a tool suitable for long-term monitoring of subjects living in a free environment, as it allows execution of inexpensive, objective and reliable assessment of the changes in the parameters of motion of unrestricted objects [4]. With the use of this method, it is possible to obtain information on various aspects of interest, including movement classification and assessment of a degree of physical activity, metabolism energy input, equilibrium, gait and transition from sitting to standing position. Most of these functions can be assessed using single triaxial accelerometer fixed to the waist.

One of the main parameters predicting balance pathologies and disorders is an increase in the body oscillation amplitude in the sagittal (forward/backwards) or frontal (on left/right) body planes [5, 6]. Balance is characterized as the human ability to maintain the stable position of the body or to regain the required body position by performing various movements for separate body parts and moving the whole body at different speed [4, 5, 6].

Popularity of the systems intended for assessment of human mobility models and based on the use of accelerometers has strongly increased lately among doctors and researchers in related fields. Efficiency of the use of accelerometers is evident as compared to the traditional gait analysis measures, primarily for their low prices. In addition, tests may be performed not only in the standard laboratory environment [1, 7]. Also, by direct measurement of three-dimensional acceleration, it is possible to avoid errors related to differentiated change and speed data. An issue, studied in the literature, on how accelerometry is applied in analyzing the main space and time related parameters of standing, gait, and noticeable body acceleration, has also been reviewed [6, 7]. Data provided by the accelerometers fastened to the superior part of the body specified the useful insights into the body movement control standing in the manner of natural posture with eyes opened and closed.

The objective of the work is to assess the impact of physical load on the parameters of static balance in humans by applying accelerometric method.

Body (MC) vibrations of a group of healthy volunteers as compared to the data of volunteers after cerebral insult are stable and fall within the limits of a 10 mm circle. Fig. 1 provides posturograms of healthy people (a) and people after insult (b). Straight line represents measurements with eyes opened, and dotted line shows measurements with eyes closed [4, 5].

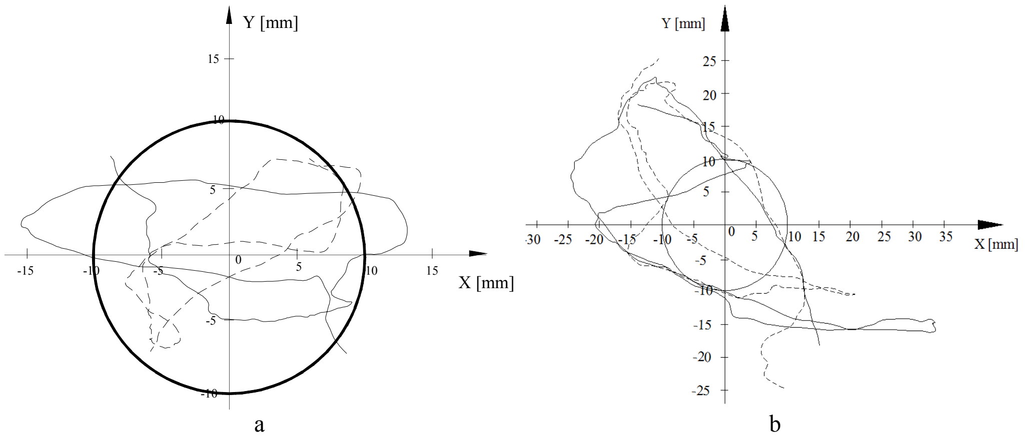


Fig. 1. (a) Posturogram of healthy people;
(b) Posturogram of people after insult with eyes opened and closed [4]

Advantages for using accelerometers [6]:

1. Low price as compared to other laboratory means for gait measurement;
2. Tests are allowed to be performed not only in the laboratory environment;
3. Accelerometers are compact, therefore they do not limit human movements and make it possible to carry out measurements with patients walking;
4. A wide choice of accelerometer constructions operating within different dynamic and sensitive ranges;
5. Direct 3D acceleration measurements eliminate errors related to the change of acceleration and speed.

Placement of accelerometer.

Place of attachment of the accelerometer is a very important factor to be considered. The accelerometer is attached to the body part under examination. When movement of the leg is tested during walking, the accelerometer is fixed to the tarsus and the tibia. When testing Parkinson’s tremor, the sensor is fastened to the wrist. In many cases, however, it is important to examine the movement of the whole body and in this case, best practice is to place sensors as close to the centre of mass of a human body as possible, e.g., to the breastbone, under the hand or the waist.

The place for accelerometer attachment even if it is placed on the rigid/immovable body segment may affect the measurement precision. E.g., if the accelerometer is placed too close to the centre of rotation, the range of the obtained measurement may be reduced. The results obtained may be also affected by the assistive walking devices, like walkers, etc. [7].

Output information derived from the accelerometer depends on [5]:

- Posture where the sensor is attached;
- Accelerometer orientation;
- The body posture of the subject under study;

- Physical activity performed by the subject.

Modern technologies make it possible to design accelerometers able to measure in one axis, two axes or all three axes. If the patient under study is in the state of rest, the output data of the accelerometer are equal to the deflection from the gravitation vector. In the case where the orientation of the sensor in relation to a person is known, the human body posture in relation to the gravitation direction may be determined.

Research methods

Seeking to assess and compare the parameters of static balance in humans before and after physical load, an experimental human balance test has been conducted with the application of accelerometry. The test was conducted with 11 healthy volunteers (their characterization is provided in Table 1). Prior to starting the test, blood pressure and heart rate of the volunteers was measured. During the test, the volunteers under study stood still for 60 seconds twice with their eyes opened and twice with their eyes closed; a one-minute pause was made between measurements. At the same time, with the volunteer standing, three seismic (uniaxial) accelerometers were attached in the area of the centre of mass and they traced the oscillation amplitude of human centre of mass along axes *X*, *Y* and *Z*.

Table 1. The main parameters of the subjects under study

Number of the subjects	Age, in years	Height, cm	Weight, kg	KMI, kg/m²	Heart rate before physical load	Heart rate after physical load
11	21.83 ± 3.17	170.63 ± 13.37	66.09 ± 16.91	22.62 ± 5.02	78.54 ± 30.46	108.18 ± 29.82

After measurements, the participants of the experimental research had to work on a bicycle ergometer for 3 minutes at a constant speed of 25 km/h. After the physical load, blood pressure and heart rate was measured again and accelerometers were attached in the area of the centre of mass. After measuring the blood pressure and heart rate twice for 60 seconds, the subjects under study had to stand still for 60 seconds twice with eyes opened and twice with eyes closed; a pause between measurements was one minute.

Equipment and tools used.

During the experiment, the following main tools (Fig. 2) and supplementary equipment (Fig. 3) were used:

- Three seismic (uniaxial) accelerometers B&K Type 8344, which traced the oscillation amplitude of human centre of mass along all three axes. Technical characteristics of the accelerometer: sensitivity 250 ± 20 % mV/ms^{-2}, measurement range ± 26 ms^{-2}, frequency range 0.2–3000 Hz;
- Portable computer with B&K software package Pulse;
- Electrical signal input and processing device 3660-D;
- Bicycle ergometer;
- Wrist blood pressure monitor.

Experimental results

Accelerations were registered be means of the accelerometers. After double integration of the data a change in the centre of mass of a human body was obtained. Having a change in the centre of mass, the trajectory of the centre of mass in the horizontal plane (*XY* plane) may be obtained for the axes *X*, *Y* and *Z* (Fig. 4).

As mentioned at the beginning, the oscillation amplitude of human centre of mass may be used as one of the parameters for assessing changes in the balance.

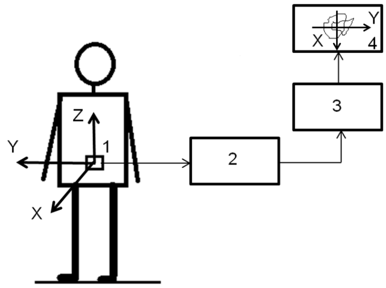


Fig. 2. Experimental measurement scheme: 1 – place of fixing of B&K accelerometers 8344; 2 – B&K signal input and processing device 3660-D; 3 – computer; 4 – trajectory of oscillation of the mass centre

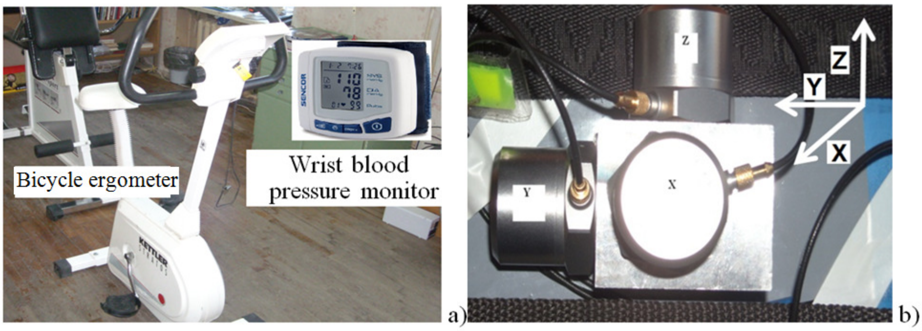


Fig. 3. Equipment used in the experiment: a) bicycle ergometer, wrist blood pressure monitor, b) three accelerometers, which registered oscillations of human centre of mass along axes *X*, *Y* and *Z*

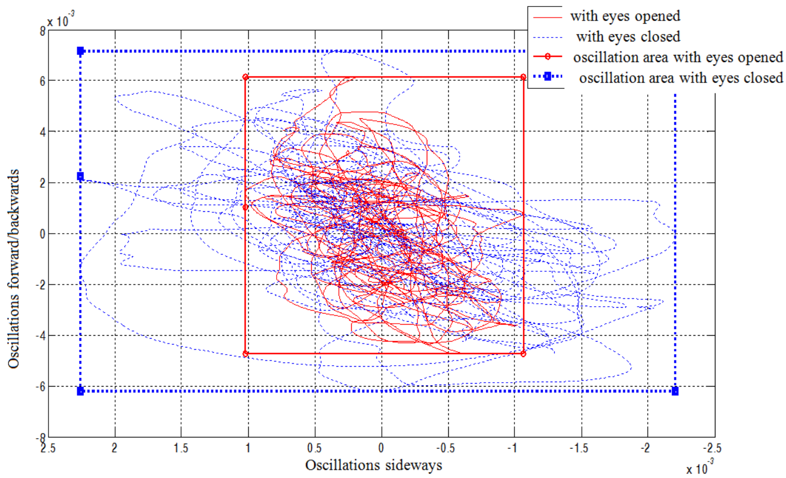


Fig. 4. Accelerograms before physical activity (with eyes opened/closed)

By direct measurement of the oscillations of the centre of mass with an accelerometer, the human balance in the horizontal plane may be assessed.

In Fig. 4 straight line represents the oscillations of the centre of mass with eyes opened, and dotted line represents the same with eyes closed, before physical load. The square marked with straight line is the area of oscillations of the centre of mass with eyes opened, and the square marked with dotted line is the area of oscillations of the centre of mass with eyes closed, before physical load.

Presented diagram indicates that amplitude of oscillations rises up with eyes closed and the area of oscillation of the centre of mass increases, on the average, by two times.

In Fig. 5 straight line represents the oscillations of the centre of mass with eyes opened, and dotted line represents the same with eyes closed, after physical load. The square marked with straight line is the area of oscillations of the centre of mass with eyes opened, and the square marked with dotted line is the area of oscillations of the centre of mass with eyes closed, after physical load.

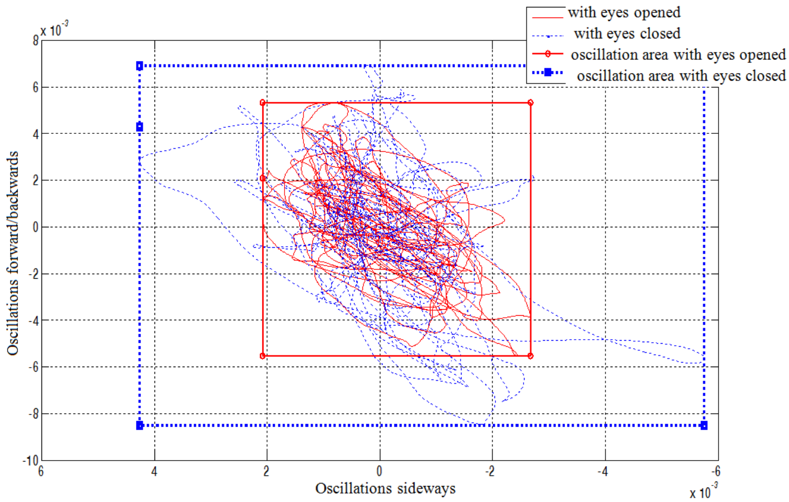


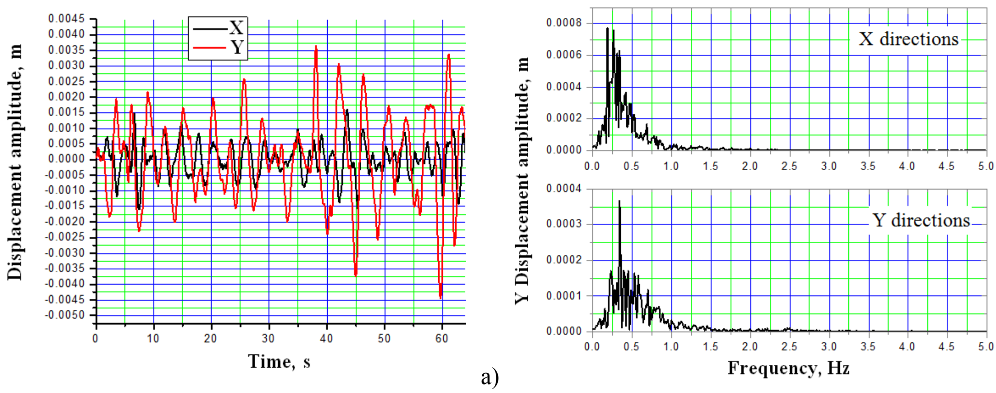
Fig. 5. Accelerograms after physical activity (with eyes opened/closed)

After the tests it was noticed that balance becomes more disturbed after physical load.

Visual perception of the environment has an impact on the human balance stability. As in examining the human balance with eyes closed, the amplitudes of oscillations have increased.

Balance disorders are affected not only by the gait or health disorders but also by the anthropometric data of each individual.

Fig. 6a presents a diagram of the typical shift amplitude for X (black color) and Y (red color) directions of the lower part of a person's spine (Point 1, Fig. 2). Fig. 6b provides spectral densities of typical shift amplitudes for X and Y directions of the lower part of a person's spine (Point 1, Fig. 2).



a) b)

Fig. 6. A diagram (a) and spectrum (b) of the typical shift amplitude for X (black color) and Y (red color) directions of the lower part of a person's spine (Point 1, Fig. 2)

Fig. 6 reveals that displacement amplitude of the lower part of a spine (Point 1, Fig. 2) in X direction is by 2-3 times lower than in Y direction. A spectrum diagram indicates that dominating displacement amplitudes are at 0.16 and 0.26 Hz (X direction) and 0.35 Hz (Y direction).

Conclusions

The sensory organization, based on visual, proprioceptive and vestibular information, is responsible for synchronization, movement direction and amplitude. It has been established that information, necessary for movement control, is received from visual views and also from proprioceptive information on the specific positions of eyes. Therefore, the existence of static and dynamic balance requires several senses, one of which is sight.

After performance of experimental research of human balance with the application of accelerometry methods, it has been established that:

a) comparing the amplitude of oscillations forward/backwards with eyes opened before and after physical load, it has been detected that the amplitude of oscillations after physical load with eyes opened increased by 22.48 %. Comparing the amplitude of oscillations forward/backwards with eyes closed before and after physical load, it may be noticed that the amplitude of oscillations after physical load with eyes opened increased by 14.99 %.

b) comparing the amplitudes of oscillations forward/backwards and sideways experimentally received from accelerometers it is possible to state that central vision enables to identify the surrounding objects, parts of the body and their parameters. Peripheral vision makes it possible to identify the changes in the position of the surrounding objects and parts of the body reciprocally, providing with consciously intangible and inapprehensible information, which is of great importance in motor control. Central and peripheral vision interacts in balance control. Peripheral vision has a greater impact on oscillation forward/backwards than on left/right. Meanwhile, central vision participates in oscillation control of both motion modes.

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