Evaluation of human postural balance in quiet standing by direct measurement of human body center of mass acceleration

J. Griškevičius[1,a], E. Jarmalienė[1,b], A. Šešok[1,c], K. Daunoravičienė[1,d], N.Kizilova[2,e]
[1]Vilnius Gediminas Technical University, J.Basanavičiaus str. 28, 1001a, LT-03224, Vilnius, Lithuania
[2]Kharkov National University, Svobody Sq., 4, 61077, Kharkov, Ukraine
e-mail: [a]*julius.griskevicius@me.vgtu.lt* [b]*edita.jarmaliene@me.vgtu.lt* [c]*andzela.sesok@me.vgtu.lt* [d]*kristina.daunoraviciene@me.vgtu.lt* [e]*n.kizilova@gmail.com*
Phone: [a]+37052744750, +37068737782;

(Received … April 2009; accepted …2009)

Abstract. Present article deals with the evaluation of human postural balance in quiet standing by the direct measuring of center of mass acceleration. Displacements of subjects' center of mass were determined and trajectories in anterior-posterior-medial-lateral plane were obtained. Comparison of parameters between subjects with stroke and healthy subjects was performed and measurements revealed higher sway amplitudes of subjects with stroke.

Keywords: human postural balance, body sway, center of mass acceleration, accelerometry.

Introduction

Ability to hold upright standing posture is essential for human being. A seemingly simple task performed by human being is more or less automatic and a complex activity both mechanically and neurologically. Researches on balance control and postural stability are very diverse. There are many ways to evaluate human postural balance and one of the most often applied methods is experimental measurements by using force plates, for example computerized posturography [2]. Force plates are used to measure the position and path of the center of pressure (COP) – one of the parameters to estimate a postural stability [8, 9]. The COP refers to the point of application of the supportive force applied to the force plate and it is affected by the center of gravity and by the muscular forces acting on the foot. There are many others so called stabilometric descriptors like mean velocity (MV), area under COP, sway density curve (SDC) and etc., enabling identifying changes in postural control, for example with ageing [5, 10, 12]. Loss of postural stability may be caused by different disorders like stroke, because most of stroke survivors become disabled due to motor and cognitive dysfunction [3, 4, 11, 14]. Comprehensive rehabilitation of such patients can help to gain back lost functions and improves quality of life. Rehabilitation can be implemented by balance feedback training using MTD-balance system [3]. Alternatively to the traditional descriptors obtained from force plate measurements, some researchers have proposed, as parameter for the evaluation of postural control, an acceleration of center of mass (COM), estimated with force platform recordings [1, 12, 13]. Though, it is not direct measurement of COM acceleration, it could be possible indeed with the application of modern motion video analysis systems. With the successful implementation of affordable electronic sensors nowadays it is possible to perform direct measurement of human motion by accelerometry, using accelerometers [7].

An objective of present study is to evaluate human postural balance from acceleration data obtained from the direct measurement of center' of mass acceleration during the quiet standing with eyes opened and closed.

Methods

Research was carried out on volunteers, which were divided into two groups – healthy subjects as a control group and subjects with stroke. Fifteen subjects with stroke, after brain circulation disorders (13 men, 2 women; mean ± SD: age = 69±6.04, stature = 176.93±7.26 cm, and body mass = 88.13±12.36 kg) had already rehabilitative training in process and were therefore considered stable in their neurological recovery, were able to stand by themselves without support. The control group consisted of 30 healthy subjects (16 men, 14 women; mean ± SD: age = 25.97±3.88, stature = 175.37±3.88 cm, and body weight = 73.67±15.67 kg). None had any current or recent self-reported injuries, illness, or musculoskeletal disorders. All participants were informed about the conditions of an experiment and signed an agreement to participate in the study.

Each participant performed 6 trials involving a quiet upright stance. In each trial, participants stood barefoot on a MTD-balance platform and had two-axial accelerometer fixed on the center of mass, with eyes opened and eyes closed, and arms at sides were requested to stand as still as possible. Trials lasted 30 seconds, with at least two minutes of rest between each.

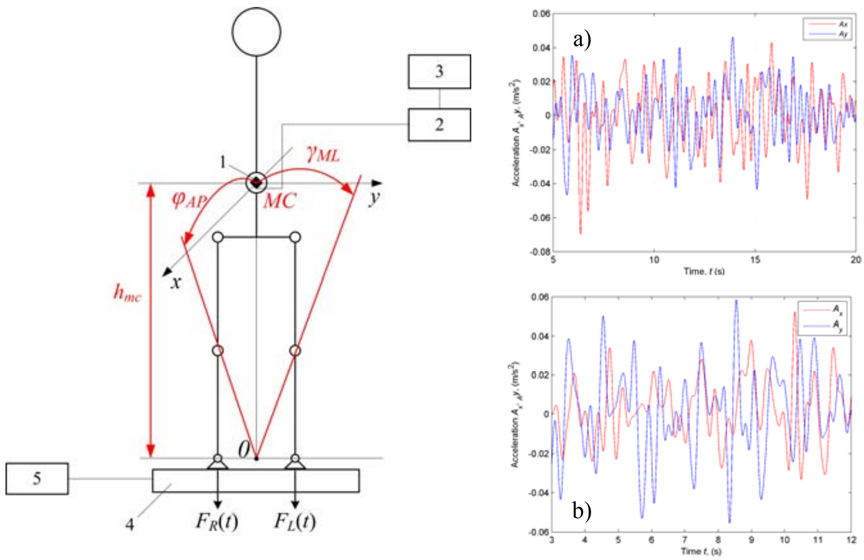

Fig.1. Experimental measurement setup on the left: 1 – two-axial accelerometer, connected to 2 – data acquisition and transfer interface to 3 – PC, 4 – MTD-balance platform, controlled by 5 – computer; and on the right an example of recorded and filtered acceleration signal: a) subjects with stroke; b) healthy subjects;

Two-axial iMEMS (®Analog Devices ADXL320, with bandwidth of 0.5 Hz to 2.5 kHz) accelerometer was fixed on the belt on subject's waist, in the height of center of mass. The height of center of mass was determined for each subject individually according to the anthropometric data [6]. Another useful feature of the accelerometer is that it can be used as a 2-axis tilt sensor with both roll axis and pitch axis when oriented so both its X-axis and Y-axis are parallel to the ground's surface (Fig.1). X-axis of the accelerometer was coincident with human body sway in anterior-posterior directions, while Y-axis was coincident with medial-lateral directions respectively.

Additionally subjects were standing on the MTD-balance platform (developed by MTD-systems), which in turn is being used not only during the rehabilitation in training the balance, but it is also capable to measure distribution of the load on both legs performing the balance test. Rehabilitation therapists often use the ratio of left and right legs pressure distribution on the platform as a stability evaluation parameter that can be expressed as follows:

$$R_{LR}(t) = \frac{F_L(t)}{F_R(t)}, \quad (1)$$

where $F_L(t)$ and $F_R(t)$ are forces of left and right legs respectively. The difference in subject's pressure on platform with left and right legs can be evaluated too [3].

Results of analysis

Recorded acceleration signal was low-pass filtered using 6th order Butterworth filter with 10 Hz cut-off frequency in Matlab software. An example of filtered acceleration signal of subjects with stroke and healthy subjects during the trials is shown in Fig.1 a) and b). Acceleration data was then numerically double-integrated in order to obtain center of mass (COM) displacements in AP (X) and ML (Y) directions (Fig.2. a and b). Few seconds in the beginning of the record were subtracted as a pre-settling time.

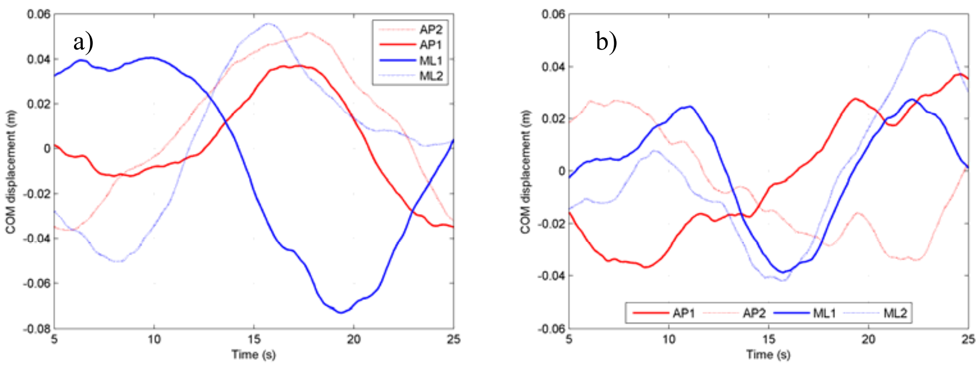

Fig.2. COM displacement – a) subjects with stroke; b) healthy subjects. Indexes 1 and 2 correspond to eyes opened and eyes closed trials respectively, and AP stands for anterior-posterior and ML for medial-lateral directions.

Analyzing graphs presented above, could be noted that maximal amplitudes of displacements of subjects with stroke are almost two times higher than in healthy subjects. Other researchers have also noted that body's sway amplitudes are increasing with ageing. When eyes are closed, amplitudes of displacements are increasing indicating, that visual perception influences the postural balance in ML direction. Fig.3 shows average ratios among the subjects with stroke (Fig.3. a, mean ± SD: $R_{LR} = 0.8393 \pm 0.128$ eyes open, $R_{LR} = 0.8367 \pm 0.127$ eyes closed) comparing to average ratios of healthy subjects (Fig.3. b, mean ± SD: $R_{LR} = 0.9599 \pm 0.03$ eyes open, $R_{LR} = 0.9581 \pm 0.03$ eyes closed). If the values of ratios (2) of pressure distribution between left and right legs are close to 1, the subject is considered as more stable. Low ratio's value could show some possible disorders of motor dysfunction.

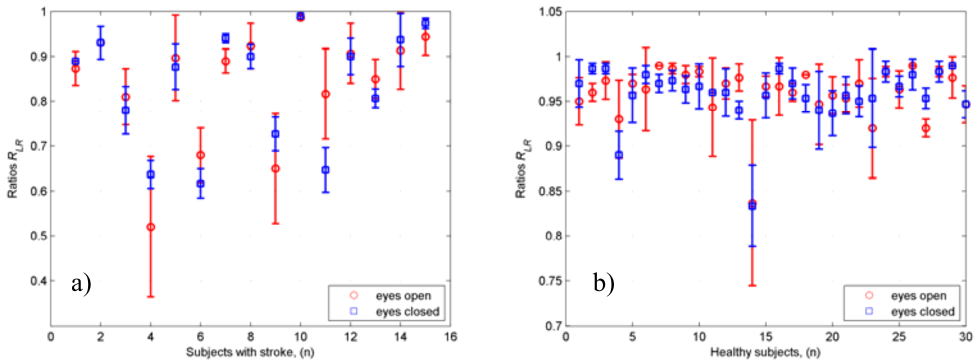

Fig.3. Average ratios of load distribution on left and right legs – a) subjects with stroke; b) healthy subjects.

When standing with eyes closed, ratios are noted slightly lower in control group consisted of healthy subjects, while ratios among the subjects with stroke are scattered more and average sizes are lower comparing with the ratios of healthy subjects. Loss of visual contact with the environment influences the stability of postural balance.

Average trajectories had been derived from COM displacements in anterior-posterior and medial-lateral plane (XY plane) are shown in Fig.4.

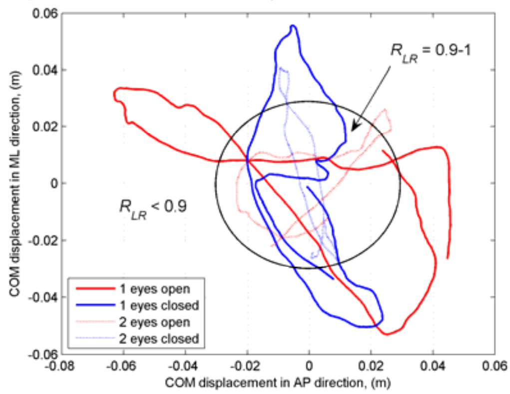

Fig.4. Average trajectories of COM in AP-ML plane – indexes 1 and 2 stand for the group of subjects with stroke and healthy subjects respectively.

Trajectories of center of mass in area enclosed by an ellipse (Fig.4) correspond to the ratios of pressure distribution in range from 1 to 0.9, while trajectories outside an ellipse correspond to ratios below 0.9. Ratio's values of the most of healthy volunteers lie within the bounds of encircled area, thus resulting in lower body sway amplitude or in other words, the subject's postural balance is normal. In order to distinguish particularities of subject's individual anthropometry influence on the sway amplitude, body mass index was calculated according to the most popular expression $I_{BM} = \frac{m}{h^2}$, where m is a body weight and h is a height of subject. Relations between calculated body mass index (BMI) and the ratio R_{LR} were derived for every group, for subjects with stroke as well as for healthy subjects, and are presented in the Figure 5.

Thus, interconnection between anthropometrical subject's parameters and pressure rations was found.

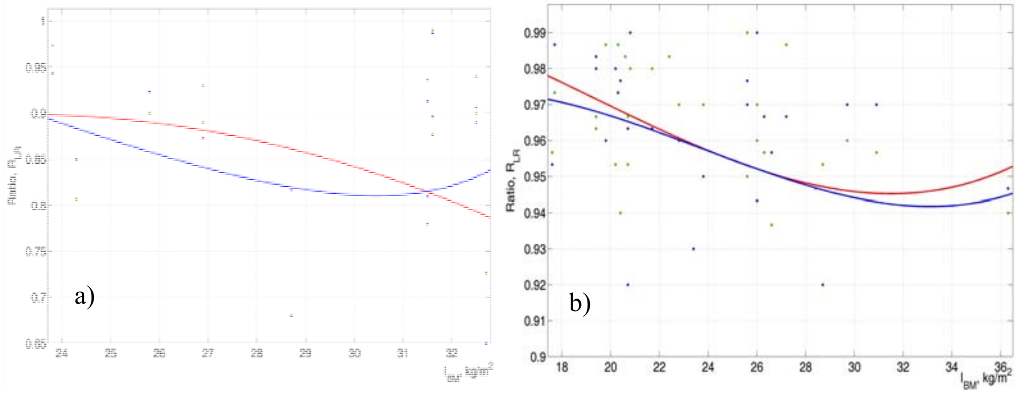

Fig.5. Relations between average ratios of load distribution on left and right legs and body mass index – a) subjects with stroke; b) healthy subjects.

From figures above can be noted, that the higher is body mass index of a subject, the lower are ratios and therefore arises presumption that the accumulation of fat tissue can reduce body balance and contributes towards larger sway amplitudes. Since the height of subjects' mass center was calculated, the relations between ratios and COM height were found and presented in figure 6 below.

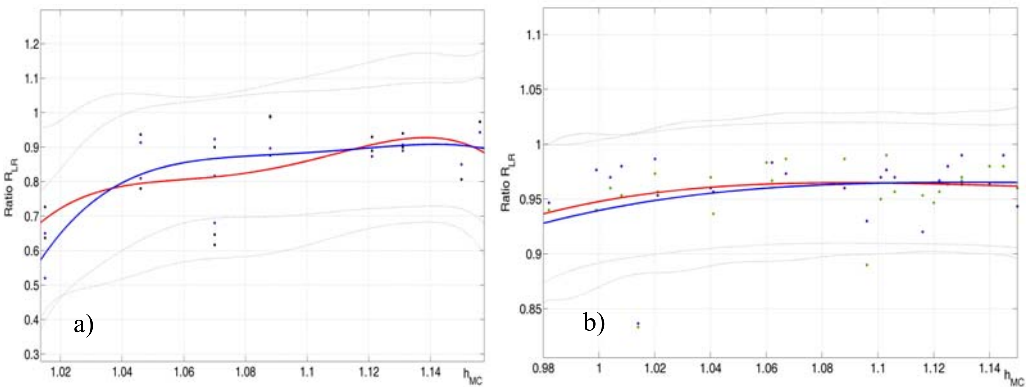

Fig.6. Average ratios of load distribution on left and right legs dependencies on height of body mass center, with bounds of prediction – a) subjects with stroke; b) healthy subjects. Red line corresponds to eyes opened and blue line – eyes closed.

Results in the figures above show, that with the increase of the height of center of mass, the ratios' values also increases, resulting in lower sway amplitudes for the taller persons. The mechanical factor provided by the inertia of the body mass and mass height above the ground, and the attempt to balance it against the gravity force through muscular action is an important indicator of ability to maintain posture.

Conclusions

The main conclusions of the present research are formulated below:

1. Direct measurement of body center of mass sway acceleration enables to evaluate human postural balance by analyzing the center of mass displacements and trajectories

in horizontal plane. It was noted, that amplitudes of subjects with stroke were larger almost two times than control group's of healthy subjects.

2. Ratios of pressure distribution on both left and right legs are in range from 1 to 0.9 for healthy subjects, and ratios below 0.9 are common for subjects with stroke. Ratios of healthy volunteers are related with body sway lower amplitude or in other words, the subject's postural balance is normal.
3. Loss of visual contact with the environment influences the stability of postural balance. When subjects were standing with eyes closed, sway amplitudes were higher and the ratios of load distribution on left and right legs were lower.
4. Postural balance is influenced not only by the presence of motor and cognitive disorders, but also by individual anthropometric parameters of subjects. Larger body mass index tends to increase human body oscillations.

References

[1] **Yu E., Abe M., Masani K., Kawashima N., Eto F., Haga N., Nakazawa K.** Evaluation of Postural Control in Quiet Standing Using Center of Mass Acceleration: Comparison Among the Young, the Elderly, and People With Stroke. Archives of Physical Medicine and Rehabilitation, 2008, Vol. 89, 1133-1139.

[2] **Karpinsky M., Kizilova N.** Computerized posturogprahy for data analysis and mathematical modeling of postural sway during different two-legged and one-legged human stance. Journal of Vibroengineering, 2007, Vol. 9, Issue 3, 118-124.

[3] **Juocevičius A., Zigmantavičiūtė I., Janonienė D.** A comparison of comprehensive rehabilitation and comprehensive rehabilitation with feed-back balance training for acute stroke patients. Journal of Vibroengineering, 2007, Vol. 9, Issue 3, 55-57.

[4] **Jurgelevičienė D., Janonienė D., Juocevičius A.** Physical capacity and balance ability after lower limb amputation. Journal of Vibroengineering, 2007, Vol. 9, Issue 3, 62-64.

[5] **Vieira TdMM., Oliveira de L.F., Nadal J.** An overview of age-related changes in postural control during quiet standing tasks using classical and modern stabilometric descriptors. Journal of Electromyography and Kinesiology, 2008, doi: 10.1016.j.jelekin.2008.10.007.

[6] **Winter D.A.** Biomechanics and Motor Control of Human Movement. 2nd edition, John Wiley & Sons, New York, 1990, 277 p.

[7] **Godfrey A., Conway R., Meagher D., ÓLaighin G.** Direct measurement of human movement by accelerometry. Medical Engineering & Physics, 2008, Vol. 30, 1364-1386.

[8] **Hæggström E., Forsman P., Wallin A., Toppila E., Pyykkö I.** Evaluating sleepiness using force platform posturography. IEEE Transactions on biomedical engineering, 2006, Vol. 53, No. 8, 1578-1585.

[9] **Juras G., Słomka K., Fredyk A., Sobota G., Bacik B.** Evaluation of the limits of stability (LOS) balance test. Journal of Human Kinetics, 2008, Vol. 19, 39-52.

[10] **Schmid M., Conforto S., Camomilla V., Cappozzo A., D'Alessio T.** The sensitivity of posturographic parameters to acquisition settings. Medical Engineering & Physics, 2002, Vol. 24, 623-631.

[11] **Rougier P.** The influence of having the eyelids open or closed on undisturbed postural control. Neuroscience Research, 2003, Vol. 47, 73-83.

[12] **Jeka J., Kiemel T., Creath R., Horak F., Peterka R.** Controlling human upright posture: velocity information is more accurate than position or acceleration. Journal of Neurophysiology, 2004, Vol. 92, 2368-2379.

[13] **Masani K., Vette A.H., Kouzaki M., Kanehisa H., Fukunaga T., Popovic M.R.** Larger center of pressure minus center of gravity in the elderly induces larger body acceleration during quiet standing. Neuroscience letters, 2007, Vol. 422(3), 202-206.

[14] **Niam S, Cheung W, Sullivan PE, Kent S, Gu X.** Balance and physical impairments after stroke. Archives of Physical Medicine and Rehabilitation, 1999, Vol. 80, 1227-1233.