MEASUREMENT AND ANALYSES OF POSTURAL STABILITY

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Abstract: This paper deals with measurement and analyses of postural stability using dual-axes accelerometer and force plate. All the data have been collected with NetForce and EMGWorks software and stored in computer memory. Using Matlab data has been analyzed and plotted. Postural stability test was performed for at least 50 seconds during which patient with closed eyes quite stands on a force plate with a accelerometer attached on their back. Equilibrium score, standard deviation of sway angle, shape ration and Pedotti diagram, estimates postural stability in both lateral and sagittal plane. The measurements of postural stability using accelerometer were performed on 10 healthy patients and statistically processed.

Introduction

Measurements of postural stability or sway may be used in a number of health related applications, ranging from strictly medical, to athletic, to everyday or recreational activities. With respect to medical applications, postural stability measurements may be used as biomarkers for geriatric studies. In addition, measurements may be used in analyzing the progress of amputee patients, persons undergoing chiropractic care, or individuals who have lost various degrees of vestibular function. Similarly, in the case of athletes either in training or recovering from injury, measurements of postural stability would be useful in evaluating their growth and development. Finally, in a more daily or recreational setting, measurements of postural stability may help improve guidelines for heavy-lifting safety as well as sobriety tests [1].

When standing still any person will still sway a little. These movements are characteristic of the physiological balance system. The swaying can be measured using a force plate on which the person stands, and which records forces (F_x, F_y, F_z) and moments (M_x, M_y, M_z) of the GRF [2]. According to collected data using Matlab it can be calculated how the center of pressure shifts with swaying. Combining center of pressure in sagittal plane (x_{cop}) with F_x and F_z components of GRF, vector diagram, called Pedotti diagram can be plotted.

Measurement of postural stability can also be performed using dual-axes accelerometer which simultaneously measures acceleration along two different axes. Accelerometer is attached on the back of a patient and connected via A/D card to computer which acquires data. Using Matlab deviations in angle and equilibrium score in both the lateral and sagittal planes can be calculated. As it can be seen this paper presents two different methods for postural stability measurement and analyses.

Postural stability measurement

Equipment used for postural stability measurement is notebook (Intel Celeron 600 MHz, 64 Mb RAM, Windows 98), force plate (AccuGait, AMTI), dual axes accelerometer (ADXL 203, Analog Devices), A/D converter card (68 PIN E Series, 16 AI channels, National Instruments), acquisition software (EMGWorks Acquisition and NetForce) and Matlab 6.1.. Postural stability measurements have been based on a traditional Romberg type test that last at least 50 seconds. It is advisable to add extra 10 seconds period at the beginning of the test during which the person can "settle down". The person has to be in a relaxed state with hands on the side. For the feet position it is recommended a 30 degree angle between medial sides of the feet, and a heel to heel separation of 2 cm because this position provides about equal support in both the anterior-posterior and the medial-lateral directions.

Figure 1: Postural stability measurement based on traditional Romberg test in LABACS

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Sampling frequency adjusted by acquisition software is 50 Hz both for data measured with force plate and accelerometer.

Data measured with force plate

According to measured forces (F_x, F_y, F_z) and moments (M_x, M_y, M_z) of the GRF, center of pressure in sagittal plane has been calculated by Matlab using following equation:

$$x_{cop} = \frac{My + Fx \cdot z_0}{Fz} \qquad (1)$$

Pedotti diagram presents a complete space-temporal representation of the evolution of the ground reaction forces during Romberg test of postural stability.

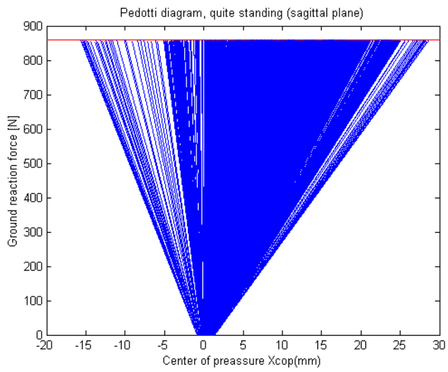

Figure 2: Pedotti diagram for quite standing (Romberg test)

On Pedotti diagram each vector represents the projection of the ground reaction force on a sagittal plane, with its magnitude, inclination and point of application. Information about shape of Pedotti diagram is very useful to calculate the measure of postural stability using following equation:

SR= (botton range/top range)*100 (2)

where
SR=**S**hape **R**ation

botton range=x_{cop}(max)- x_{cop}(min) (3)

top range=projection of max GRF on x_{cop} axis- projection of min GRF on x_{cop} axis (4)

Data measured with accelerometer

The analog output voltage of ADXL203 accelerometer can be converted by Matlab in acceleration in g's using the following equation:

$$a = \frac{V}{S} - \frac{offset}{S} = \frac{V}{S} - K \qquad (5)$$

where

a - acceleration in g's, V - output in Volts, S-scale factor in Volts/g, K- offset in g's

The scale factor and offset values are provided on the calibration data sheet of ADXL203 accelerometer. The DC output voltage of the accelerometer converted in acceleration in g's represents acceleration due to gravity. This value can be converted to determine inclination angle using the following equation:

Θ=arscin(a) (6)

where Θ=angle in degrees.

To quantify the results in a standardized form, the equilibrium score (**ES**) is used.

Equilibrium **S**core = 100 – 8*Θ (7)

The angle θ represents the peak angle sway along the axis. However, this equation assumes that the axis of the body about which θ is measured is perpendicular to the ground. For many of our trials the subjects' bodies were not perpendicular due to the different stances. To correct for this, the ES calculation had to be modified. Instead of taking peak-to-peak angle sway for θ, the standard deviation of the mean sway angle was used. This way, the angle is taken with respect to the actual body axis. The standard deviation was doubled to account for sway in both directions in the same plane. This method is also more accurate since the standard deviation corresponds to the average sway during the trial [1].

Θ= 2*(Angle Std. Dev.) (8)

Equilibrium Score = 100 - 8*(2*Angle Std. Dev.) (9)

Results

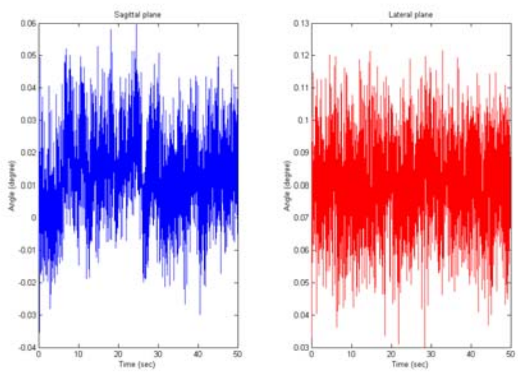

Figure 3: Angle inclination in sagittal and lateral plane

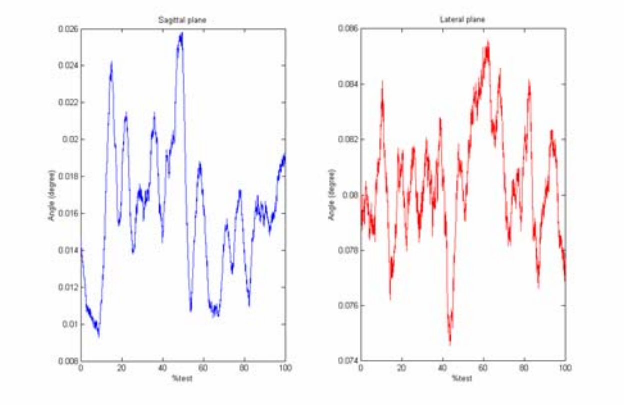

Figure 4: Average linear envelope for angle inclination in sagittal and lateral plane

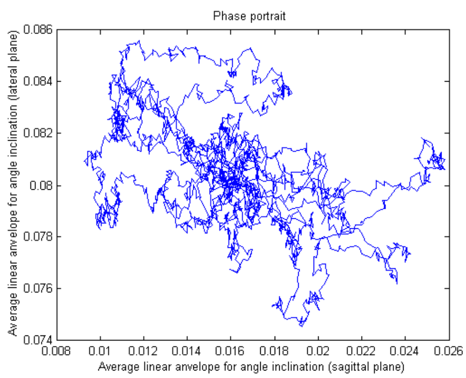

Figure 5: Phase portrait of average linear envelope

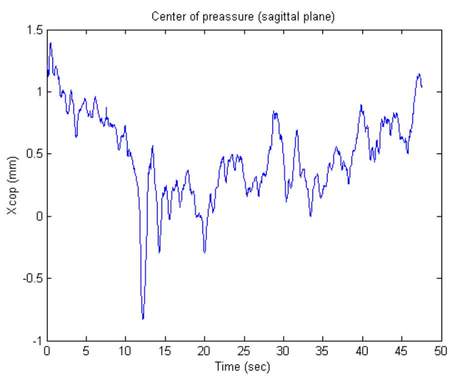

Figure 6: Center of pressure (sagittal plane)

Difference in Pedotti diagram for stable quite standing and simulated unstable standing (lost of balance) are shown on Figure 7. and Figure 8. It can be seen that Pedotti diagram for stable quite standing has regular shape, unlike for simulated unstable standing.

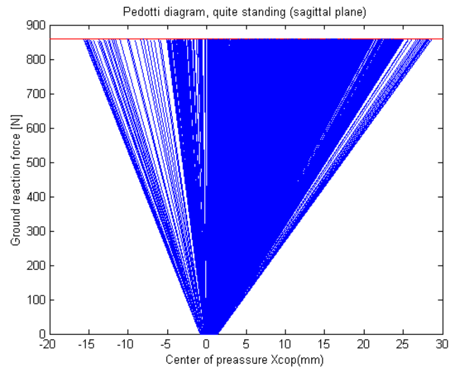

Figure 7: Peddoti diagram - stable quite standing

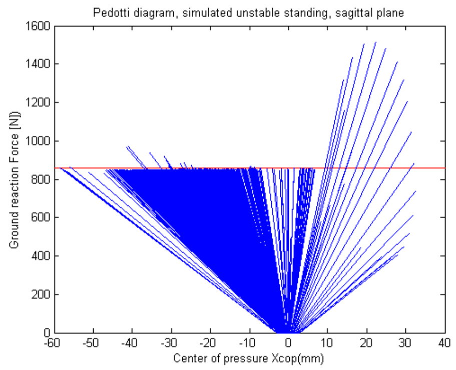

Figure 8: Peddoti diagram - simulated unstable standing, lost of balance

Measurement was performed on healthy male (age 23).

Table 1. Equlibrium Score in sagittal and lateral plane

Plane	**Stable quite standing (ES)**	**Simulated unstable standing (ES)**
Sagittal	99.7765	99.6562
Lateral	99.7618	99.686

For stable quite standing:

$$\text{Shape } \mathbf{R}\text{ation} = 4.9934\ \% \qquad (10)$$

Results of postural stability measurements on 10 healthy persons (5 male and 5 female) using dual axes accelerometer are shown on Figure 9.

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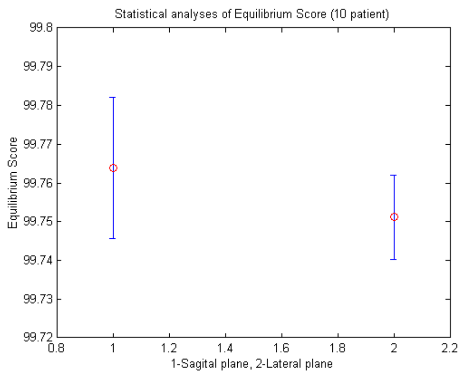

Figure 9: Statistic analyses of **E**quilibrium **S**core (5 male, 5 female)

Conclusions

In this work it is shown how to measure and analyze postural stability using two methods. For both methods, measure of stability has been defined (Shape Ration and Equilibrium Score). First method is based on measurement of postural stability using force plate. It can be concluded that regular shape of Pedotti diagram refer to stable quite standing of observed person. Second method use accelerometer for postural stability measurement. Comparing results it can be conluded that person has higher postural stability if the Equilibrium Score is lower, both for sagittal and lateral plane.

Statistical analyses of Equilibrium Score performed on 10 healthy patients (5 male, 5 female) shown that average mean of Equilibrium Score in sagittal plane is 99.7638, while the std is 0.0183. In lateral plane average mean of Equilibrium Score is 99.7511 with the std 0.0109. Future work is to measure and analyze postural stability of ill and old patients and compare it with the results of healthy.

References

[1] KASTNER M., KOWSHIK A., SHOMAKER J., WONG E., "Testing Postural Stability in the Lateral and Sagittal Positions", projct report, SEAS, spring 2002

[2] BORG F., HERRALA M., "The Pilot Stabilometric System", biosignals project, Jyvaskyla University, Chydenius Institute, version 3/24/03.

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