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Stability in human postural control

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Abstract: In this paper the method of human posture identification is suggested. It is based on Pedotti's diagram, well known in human gait evaluation. During the experiment, undertaken by 12 healthy volunteers, ground reaction forces in sagittal plane were measured. Force vectors, with the origin in the center of pressure, oscillated in the shape of fan. By observing the characteristics of the fan information about some features of postural control were obtained.

Key-Words: System theory, postural control, ground reaction force, Pedotti's diagram

1 Introduction

Nowdays there are many commercial devices that for the measurement of the stability of human postural control, as the Balance System SD, that are relatively expensive and complicated. We used the dynamic force plate (AMTI AccuGait force plate) and an existing approach for analysis of reaction force vectors acting on measured subjects. Measured reaction forces will be the input data for estimating the postural stability. The Pedotti's diagram was used as an insight to the stability of human postural control.

Experiment was preformed by using the measuring equipment as shown in Fig. 1.

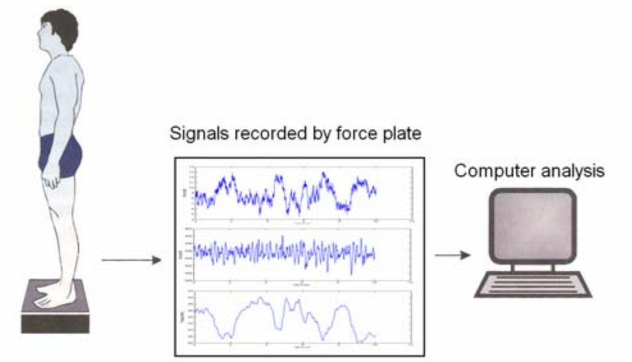

Fig.1: Schematic illustration of the measurement system

As it is known, Pedotti's diagram is a vector-diagram where each vector represents the projection of the ground reaction force into sagittal plane (x-z), with its magnitude, inclination, and point of application (Cop-center of pressure). It is illustrated in Fig. 2.

The procedure, shown in Fig. 2. was repeated for each sample of data, resulting with the Pedotti's diagram shown in Fig. 5.

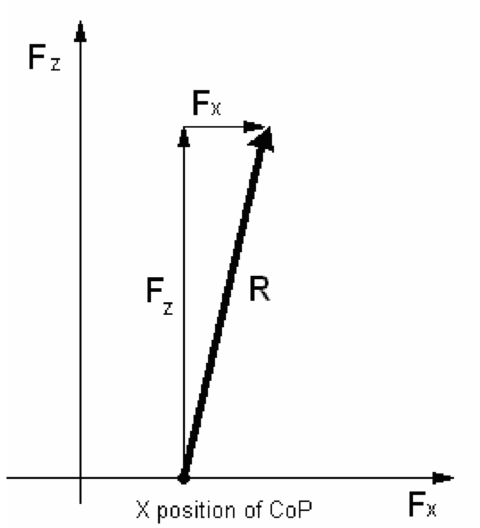

Fig.2: Vector diagram in sagittal plane

2 Description of the experiment

The experiment was done on 12 healthy subjects with no known neuromuscular or hearing disabilities. The subjects were asked to stand still on the plate, with the eyes open, during the period of 15sec. The force plate measured x, y, and z components of ground reaction force and moment. The sampling frequency was 100Hz. The force plate that has one centrally instrumented pillar which supports upper flat plate was used. Fig. 3. shows the subject standing on the plate and the coordinate system attached to the plate.

Fig. 4 shows forces that act on this instrument support. The action force of the foot F_z acts downward and anterior/posterior forces can act either forward or backward. Suppose that the direction of F_x is backward, as shown in Fig. 4.

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If we sum all moments acting about the central axis of support in y direction, we can determine the position of the center of pressure (CoP). Since the reference origin will usually be bellow the floor surface, the effect of F_x on M_y is negligible. The time-depending samples of F_x, F_z, and M_y are read from the piezo-sensors embedded into the force plate.

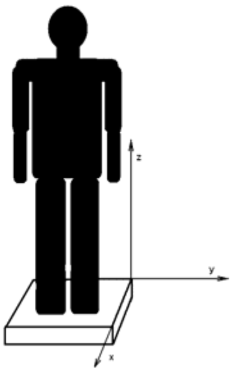

Fig. 3: Coordinate system attached to the plate

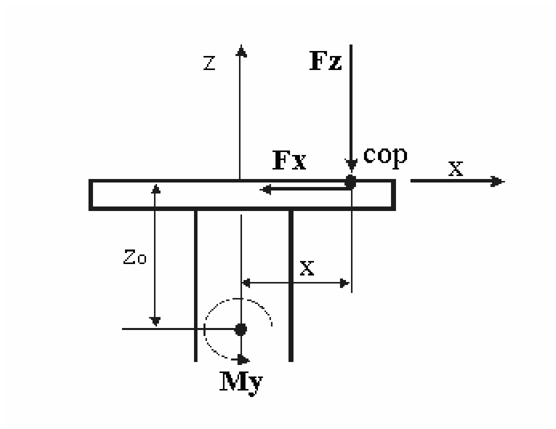

Fig. 4: Forces and moments acting on force plate

The position of the center of pressure, x_{cop} will be calculated according to the following formula:

$$My - Fz\cdot x_{cop} + Fx\cdot z_0 = 0 \quad \Rightarrow \quad x_{cop} = \frac{My + Fx\cdot z_0}{Fz} \qquad (1)$$

Where:
F_x, F_z, and M_y are data measured by force plate
z_0 is the distance from support axis to force plate surface, z_0=0.044m

2.1 Data processing

The first step was the evaluation of Pedotti's diagram for all 12 subjects. Fundamental parameter that was introduced is the inclination of boundary vectors, α and β, as shown in Fig. 5.

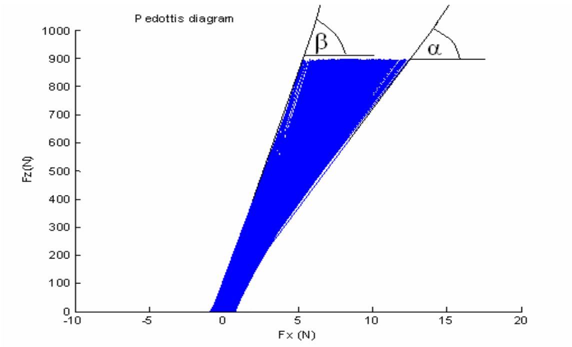

Fig. 5: Pedotti's diagram; Inclination of boundary vectors is denoted as α and β

By subjective estimation, subjects were grouped into 3 typical classes, regarding the forward-backward slope of the observed person.

Three main classes, based on angels α and β, are:

I. Forward slope, 45°<α, β <90°
II. Center slope 45°<α, β <135°
III. Backward slope 90°< α, β <135°

Figures 6, 7, and 8. show the examples of the Pedotti's diagrams for forward, centrally, and backward sloped person, respectively.

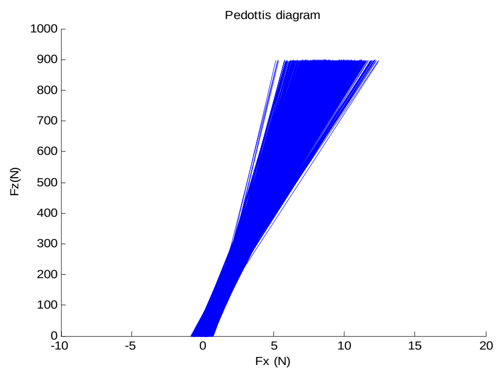

Fig. 6: Pedotti's diagram for forward sloped person

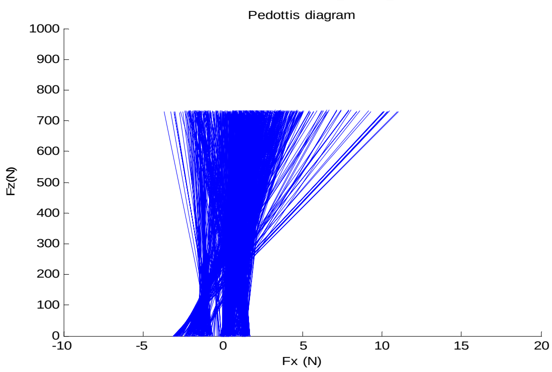

Fig. 7: Pedotti's diagram for centrally sloped person

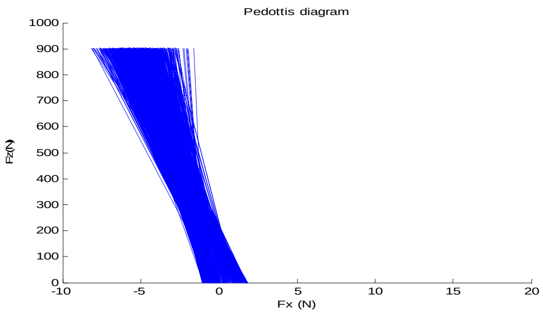

Fig. 8: Pedotti's diagram for backward sloped person

3 Data analysis

Tables 1, 2, and 3. show the results of subjects clustering into different classes, according to the angles α and β.

Table 1: Forward sloped subjects, class I

	Height [cm]	Sex [m/f]	α[°]	β[°]	X_{cop} [cm]
1	172	f	69.6	89.4	2.21
2	173	f	63.3	80.3	2.67
3	174	m	59.7	81.3	2.95
4	178	f	68.4	80.0	2.10
5	185	m	67.6	81.2	2.64
6	197	m	72.2	85.3	1.40
7	199	m	64.0	80.3	1.54

Table 2: Centrally sloped subjects, class II

	Height [cm]	Sex [m/f]	α[°]	β[°]	X_{cop} [cm]
1	168	f	71.8	95.4	2.70
2	179	f	57.2	97.6	4.83
3	185	m	74.0	90.0	1.53
4	187	m	82.9	99.7	1.92

Table 3: Backward sloped subjects, class III

	Height [cm]	Sex [m/f]	α[°]	β[°]	X_{cop} [cm]
1	188	m	91.4	110.1	2.89

By analyzing the data presented in Tables, it can be seen that in state of balance, most of the subjects are slightly inclined in forward direction (7 subjects out of 12). Four subjects are centrally sloped, and only one shows the backward inclination. This leads to the conclusion that standing balance implies the slight forward inclination.

Figures 9. and 10. show the mean values of the angles α and β, as a function of the subjects height.

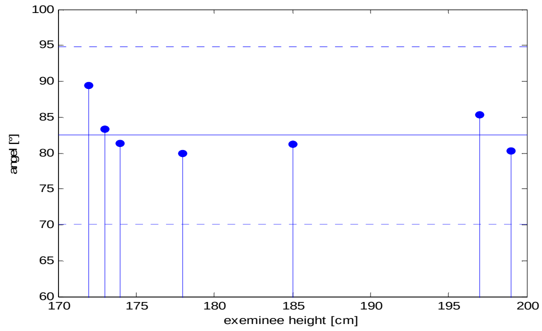

Fig. 9: Angle α; full line represents α_{mean}, and dashed lines represent α_{mean}±15%

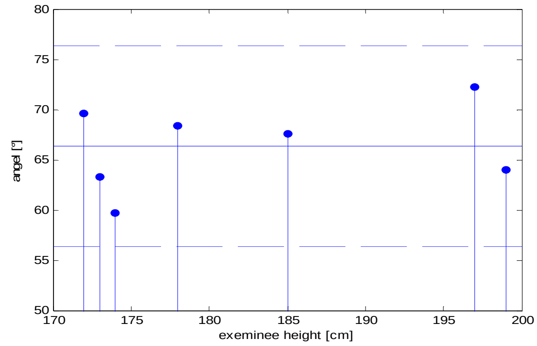

Fig. 10: Angle β; full line represents β_{mean}, and dashed lines represent β_{mean}±15%

4 Conclusion

The results imply that the majority of the healthy population tend to incline slightly forward during the stable standing. In order to validate this finding, we plan to perform the experiment on a much larger group of healthy population (at least 100 subjects) by which it would be possible to establish the normative for stable standing. We believe such a normative could be usefull in analysis of balance of patients with the hearing impairment.

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