Assessment of Human Balance during Stance using Accelerometer Sensors

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Abstract. *The paper describes a system for assessment of postural activity during stance with data acquired from two biaxial accelerometer sensors and from a force platform. We examined balance in healthy subjects during the quiet stance under the static conditions: at stance on a firm surface or on a foam surface with eyes either open or closed. Body sway was evaluated from the centre of pressure (CoP) positions and outputs of 2D accelerometers attached to the backside of lower and upper trunk during a 50 sec interval. The parameters from CoP and from accelerometers were evaluated to assess quiet stance in two age groups: juniors and seniors. For better presentation, power spectral densities of CoP displacements and outputs of both accelerometer sensors in forward-backward direction were compared. We found that most of CoP parameters were significantly different when comparing juniors and seniors. The useful insight into the balance control during quiet stance was provided also by the rate of change of acceleration (jerk) at lower and upper trunk levels in forward-backward direction. Our results showed that data acquired from accelerometers placed at trunk during quiet stance may indicate small balance impairment due to age.*

Keywords: human balance, accelerometer sensor, age-related posture control.

Introduction

Stabilometry based on recording of the magnitude and direction of the resultant ground reaction force (CoP) by the force platform during stance is an objective method often used for assessment of the human balance in experimental and clinical studies [1]. In recent years the interest in using accelerometer-based systems for measurement of body segment tilts has increased [2]. They range from simple monitoring of daily activities to integrating miniature sensors to enhance the function of devices to perform motor tasks [3]. Because of small dimensions and light weights, these accelerometer sensors can be easily attached to the upper body segments. Its output signals provide useful insight in balance control and gait in healthy subjects [4] and also in patients with balance disorders [5].

Subject and Methods

Fifteen young subjects within the range of 22-29 years (6 men and 9 women, mean age 25.4 years, mean height 172 cm) and sixteen elderly within the range of 64-85 years (7 men and 9 women, mean age 72.1 years, mean height 166 cm) participated in the study. None of the subjects reported previous or present disease or injuries associated with gait and/or balance impairments. All subjects gave written informed consent prior to participation and the local Science Ethical Committee approved the experimental protocol.

The balance control of juniors and seniors was measured during the quiet stance in four conditions: stance on a firm surface with eyes open (EO); stance on a firm surface with eyes closed (EC); stance on a foam surface (thickness 10 cm) with eyes open (FEO) and stance on a foam surface with eyes closed (FEC). The participants were informed to stand upright and relaxed on the force platform barefoot with heels together and feet displayed at angle of about 30º. Before the onset of measuring in each condition, the subjects stood in the same central position of the feet related to the force platform. In conditions with eyes open, the subjects were instructed to keep eyes open fixing to a black point with a diameter 2 cm placed on a white scene in front of them at a distance of 2 m. Each trial lasted 50 s and 1-3 min rest period was allowed between trials.

The body sway was quantified by displacements of the center of pressure (CoP) in the forward-backward (FB) and left-right (LR) direction. We used custom-made force platform with automatic subject's weight normalization.

Trunk tilts in FB and LR directions were measured by two ADXL203 dual-axis accelerometers with signal conditioned voltage outputs. Sensors measure both dynamic and static acceleration with a full-scale range of ±1.7 *g*. The acceleration output was low-pass filtered with cut-off frequency of 5 Hz and the output (trunk inclination) was calibrated in stationary conditions for a ±10 degrees range of body tilt. The accelerometers were positioned (see Fig.1) at the spinal column of the upper trunk at the level of the fourth thoracic vertebra (Th4) and the lower trunk at the level of the fifth lumbar vertebra (L5).

The CoP displacements and the angle of trunk tilts were sampled at 100 Hz and recorded on MacPC. Obtained data were evaluated and analyzed with MATLAB program. For each subject, the CoP displacements and the trunk tilt angles were averaged for each experimental condition. Group averages were calculated from the individual subjects' averages.

The differences between juniors and seniors in the parameter the rate of change of acceleration (Jfb) were statistically analyzed using t-test and p values < 0.05 were considered significant.

Results

The results showed that data from accelerometer sensors placed at trunk levels during quiet stance indicated small balance differences between young and elderly subjects. We found that time courses of CoP displacement were quite similar to trunk tilts characterized by outputs of accelerometer sensors at L5 and Th4 levels. The data indicated that body during quiet stance is often swaying as inverted pendulum around ankle (ankle strategy). This is noticeable on fig. 1 in time interval from 15 to 20 s where both trunk segments moved in the same direction as CoP displacement.

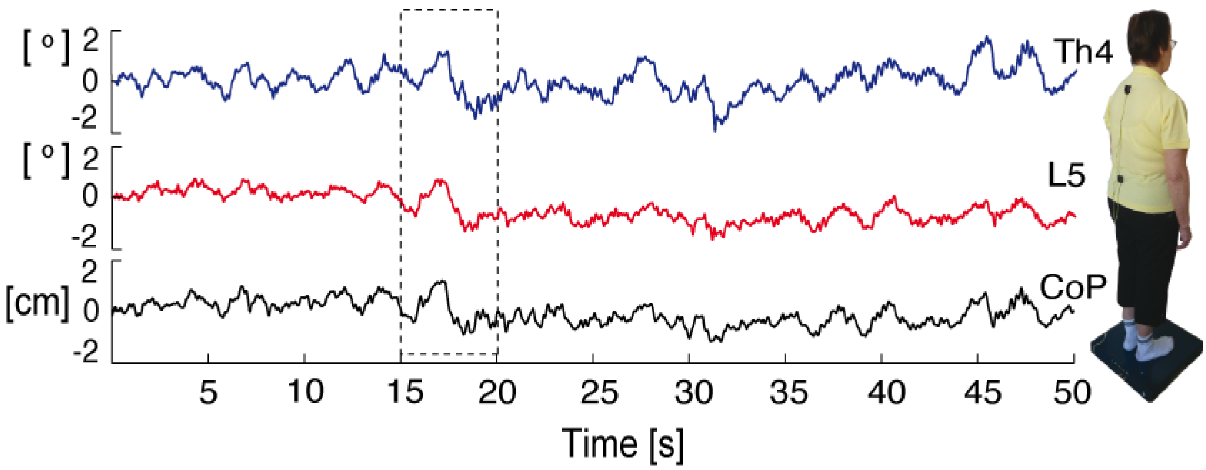

Fig. 1. Time courses of body sway in forward-backward direction recorded by the force platform (CoP) and by accelerometer sensors at lower trunk (L5) and upper trunk (Th4). The outputs of accelerometers were calibrated in degrees – body segment tilt toward vertical line.

The frequency spectrum of CoP displacements and trunk tilts showed very similar curves, which were not so much influenced by age. These frequency profiles indicated that the tilting of trunk during quiet stance oscillated with low frequency (lower than 1 Hz). Results from fig. 2 supported our idea that the calibration of output of accelerometer sensors in degree related to vertical line is acceptable for measurement of the trunk tilts during quiet stance.

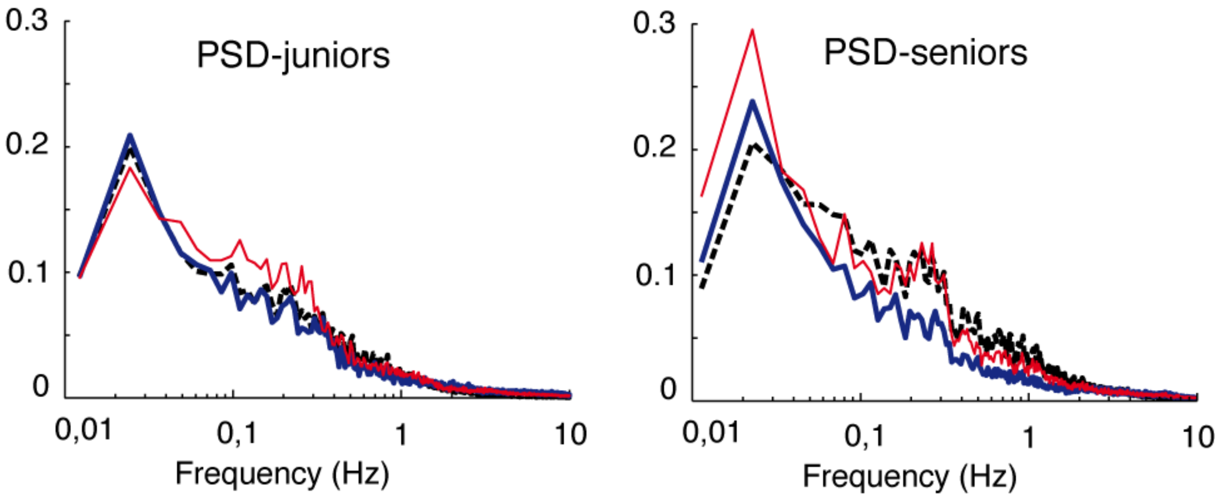

Fig.2. PSD – power spectral density of CoP displacements (dashed line) and accelerometer outputs at lower trunk (thick line) and upper trunk (thin line) in forward-backward direction.

Data analysis of outputs from accelerometer sensors at trunk levels during quiet stance showed the small imbalance in elderly subjects. A first derivation of acceleration - the rate of change of acceleration (jerk-Jfb) at lower trunk in forward-backward direction was considered as a sensitive parameter. The value created by the mean of jerk at lower trunk was the most sensitive to age-related changes in balance of the quiet stance.

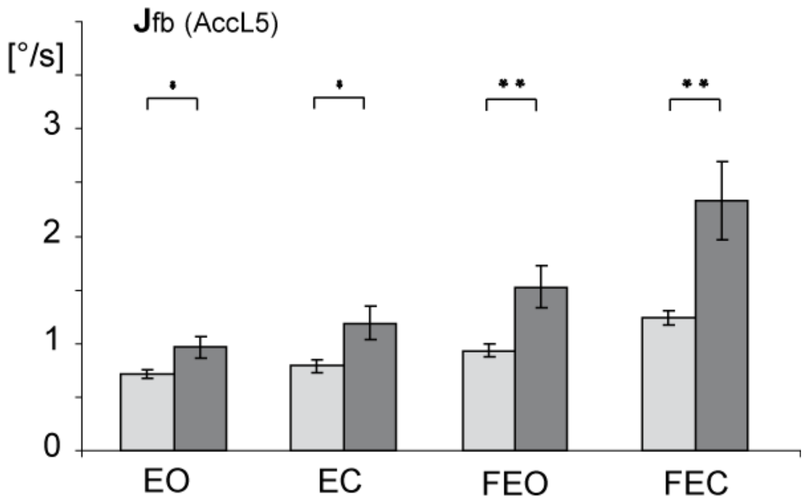

Fig. 3. Comparison of jerk (derivation of acceleration) at lower trunk in forward-backward direction between juniors (white) and seniors (black) in all experimental conditions. The asterisks denote significant differences * P<0.05; ** P<0.01 between the young and elderly subjects. The values of jerk are expressed as group averages ± standard error of mean.

Discussion

Our results showed that data acquired from accelerometer sensors at trunk levels during quiet stance provided useful information about balance control. The jerk parameter created as the first derivation of acceleration was also appropriate for assessment of differences in balance between juniors and seniors. Similar conclusion about age-related changes in CoP parameters was found in all static conditions [1]. It was reported that the most sensitive view on postural steadiness during quiet stance was provided by CoP amplitude and velocity in FB direction.

If we assume that the acceleration at the level of L5 has a similar time course as the CoP displacement in the same direction, then it is obvious that the rate of change of acceleration in time should be sensitive indication of age-related changes in balance control. This conclusion is supported by the findings of authors [1] concerning about the velocity of CoP as a good indicator of postural changes due to age.

Our data confirmed also the inverted pendulum prediction that forward-backward and left-right accelerations of the trunk were related to the subsequent CoP displacements. These findings are in agreement with those of Zijlstra and Hof [4]. Furthermore, the accelerations show a more complex pattern than is expected based upon an inverted pendulum movement alone. Accelerometers afford opportunity to differ between ankle and hip strategy.

Both stabilometry and accelerometers provide valid information about postural control, but different information about postural strategies. The body-mounted sensors are accurate, inexpensive and portable and allow long-term recordings in clinical, sport and ergonomics settings. The body-mounted sensors do not hinder natural movement [2], because they can be unobtrusively attached to the body or can be part of clothing items [3]. Stabilometry is less sensitive in differing between ankle and hip strategy and also in assessing slight changes in postural control. For these reasons we advise using accelerometers as supplement or alternation of stabilometry in postural control research.

Acknowledgements

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