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ORIGINAL ARTICLE

Postural control assessed by limit of stability in obese adults

Kristína Bučková, Jana Lobotková, Zuzana Hirjaková, Diana Bzdúšková, František Hlavačka

Laboratory of Motor Control, Institute of Normal and Pathological Physiology, Slovak Academy of Sciences, Bratislava, Slovakia.

Correspondence to: Kristína Bučková, MSc., Institute of Normal and Pathological Physiology, Slovak Academy of Sciences, Sienkiewiczova 1, 81371 Bratislava, Slovakia, TEL: +421 2 3229 6051; E-MAIL: kristina.buckova@savba.sk

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Abstract

OBJECTIVES: Maintenance of body equilibrium was tested during voluntary leaning posture with the aim to determine the contribution of body weight to dynamic stability.
METHODS: Ten obese subjects (mean BMI 31.4±1.5 kg.m^{-2}) and ten subjects with normal weight (mean BMI 22.2±0.9 kg.m^{-2}) participated in this study. The balance control was assessed by evaluating centre of foot pressure (CoP) amplitude of steady leaning position, variance of CoP leaning amplitude, leaning velocity and magnitude of postural adjustment (PA). Body segments position was also measured to investigate the postural strategies used to achieve the forward stability limit.
RESULTS: We find that the ability to incline forward – limit of stability (LOS) of obese subjects was lower than in control subjects as attested by their smaller displacement of CoP. The variance of amplitude oscillations during steady leaning position was significantly higher in obese group compared to control group. Magnitude of postural adjustment had an increasing trend in obese group. The mean and maximal leaning CoP velocity was significantly slower for obese subjects. We observed significant difference between trunk and leg angles in obese group.
CONCLUSION: The reduction of limit of stability, increase of CoP oscillation during leaning and limited progression of velocity suggest that an adaptive strategy in maintaining dynamic stability of balance is accepted in obese subjects.

Introduction

Proper balance control is a key aspect of activities of daily living. Obesity mechanically increases the body mass that must be moved or control during stance and everyday motor activities. It is known that balance stability during quiet stance is strongly correlated to an increase in body weight (Hlavačka & Šaling 1979; Hue *et al* 2007). Nevertheless the biomechanical changes in balance control linked to obesity in dynamic motor activities are not completely known.

The ability to move the centre of gravity voluntarily and keep balance is fundamental for performing mobility tasks such as body leaning, transition from a seated to standing position or walking. The maximum displacement of the centre of body mass to external postural perturbations that can be controlled without a fall or a step is defined as limit of stability (Horak *et al* 2005). Maximal voluntary inclined posture reflects the self-perceived LOS and in absence of external perturbation, is used to evaluated LOS (Schieppati *et al* 1994). It is known that reduced LOS is related to risk of fall or instability during postural activities (Hue *et al* 2007). Statically holding the centre of body mass near the forward or backward limits of foot support simulates functional positions that occur in motor task as in the transition from stance to gait (Newton 2001). The degree of instability in maintaining equilibrium near such locations can be important factor for the postural control system to decide on a stepping strategy even if a leaning posture is mechanically possible. The evaluation of how is equilibrium maintained during tilt may be relevant to understand the transition between postural strategies (Duarte & Zatsiorsky 2002).

We focused on assessment of limit of postural stability by voluntary forward leaning because consequences of overweight should be more evident on dynamic stability than those on static equilibrium.

Methods

Ten overweight and obese adults (8M, mean age 30.7±1.4 years, mean height 174.4±3.5 cm, mean BMI 31.4±1.5 kg.m^{-2}) and 10 normal weight adults (4M, mean age 26.7±0.8 years, mean height 170.8±1.8 cm, mean BMI 22.2±0.9 kg.m^{-2}) participated in this study. They were free of any neurological or musculoskeletal disorders. All subjects gave informed consent prior to participation and the local Science Ethical Committee approved the experimental protocol.

The subjects stood on custom-made force platform equipped with automatic weight correction and with direct output of CoP signal. CoP data in anterior-posterior direction were sampled at 100 Hz and recorded on PC. A movement analysis system (BTS Smart DX, Italy) with six cameras and sampling frequency 100 Hz recorded the kinematics of body segments. Reflective markers were placed on lateral malleolus, femoral condyle, greater trochanter and clavicular acromion, bilaterally. We evaluated the leg (hip-ankle) and trunk segment angles with respect to vertical. Postural body alignment we assessed by difference between trunk and leg ankle (Figure 1B).

Participants were instructed to maintain an upright standing position, with arms along the body and feet parallel at their comfortable stance width. After hearing sound signal subjects were asked to lean (rotation around ankles) as far as they could at their comfortable speed without lifting heels or flexing their hips and persist in this position till the trial end. Each trial lasted 10s and was repeated 3 times. Initial stance position was consistent from trial to trial by tracing foot outlines on force plate.

For evaluating the ability to control participant´s balance, several variables were extracted from CoP signal (Figure 1A): amplitude of LOS in forward direction (A, calculated as average of steady-state position of CoP displacement during lean), variance of amplitude (Var), average CoP velocity (V) during leaning phase and maximal CoP velocity (Vmax) during leaning phase. Since CoP displacement reflects not only displacement of the body centre of mass (Blaszczyk & Klonowski 2001), but also anticipatory postural control (Corriveau *et al* 2004), we evaluated also magnitude of postural adjustment in anterio-posterior direction.

Velocity values were normalized for subject´s height, other values for foot length. Data were evaluated with MATLAB programs. For each parameter one-way ANOVA was used to detect differences between the control and obese group.

Results

The results showed that obesity influenced postural stability. Statistical analysis revealed that CoP displacement during body tilt was significantly lower in obese group ($p<0.01$); (Figure 2A, 2D). Magnitude of PA was increased in obese group but we observed only increasing trend of values of this parameter (Figure 2B). Higher variance of amplitude oscillation was characteristic for obese group in the leaning position ($p<0.05$); (Figure 2B, 2D). We were also interested in velocity of CoP during leaning phase. Mean CoP velocity was reduced in obese group ($p<0.05$); (Figure 2C), similarly the maximum CoP velocity was smaller in obese group ($p<0.05$); (Figure 2C). The analysis of body segment alignment revealed no differences between control and obese subjects while quiet stance. During forward lean we observed smaller leg inclination in obese subjects and trunk alignment had also decreasing trend (Figure 2E). Although our subjects were instructed to

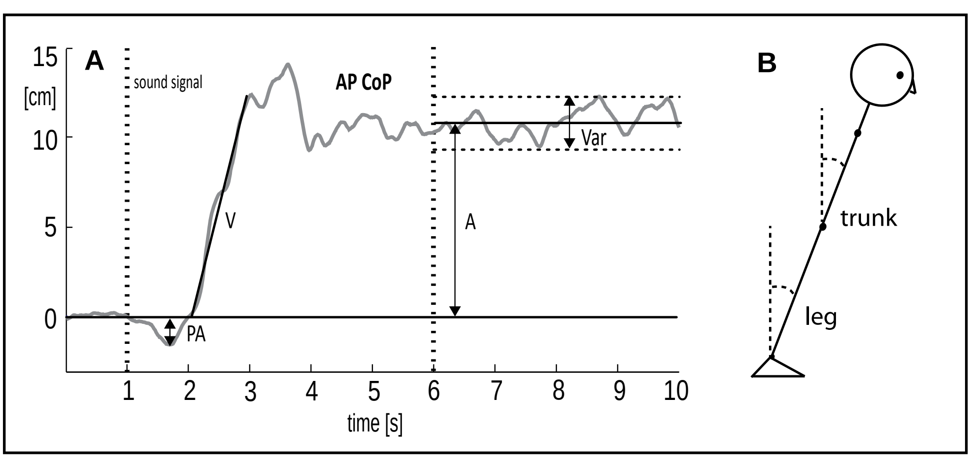

Fig. 1. A Parameters considered in data analysis: **A**- averaged value of CoP amplitude in AP direcion (steady leaning, the last 4s of the trial); **PA**- magnitude of postural adjustment in AP direction; **Var-** variance of A; **V**- average CoP velocity during leaning phase; **Vmax**- maximal CoP velocity during leaning phase. **B** Angles that characterize the forward leaning.

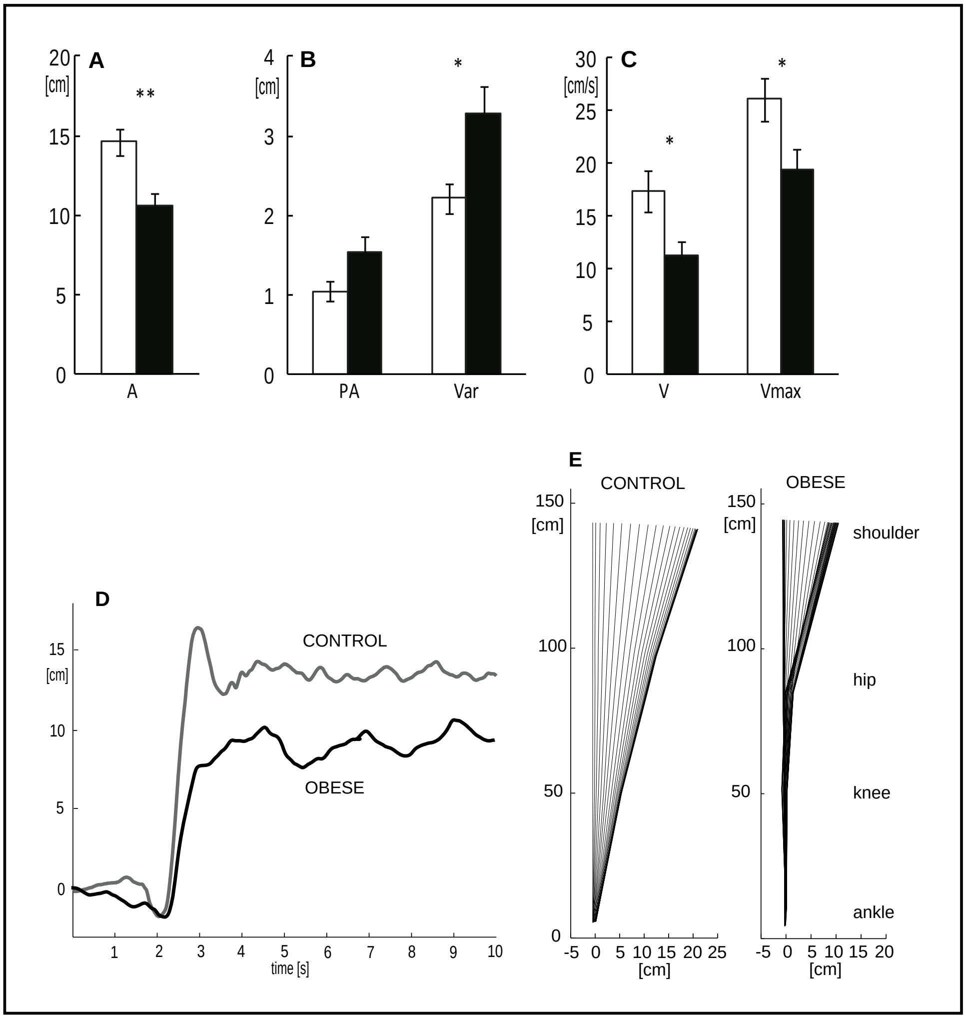

Fig. 2. A, B, C Normalized mean values±S.E.M. ***p*<0.01, **p*<0.05; white-control group, black-obese group. **D** CoP time-series during forward leaning for representative control and obese subject. **E** Postural strategies in control and obese subject represented by stick diagrams for representative control and obese subject.

move without flexion of hip, both groups were not able to use a pure inverted pendulum-like behaviour. For this reason, we evaluated the difference between trunk and leg ankle, which was significant in obese ($p<0.05$). In controls, the trunk and legs angles were more or less equal and their ratio was not statistically different.

Discussion

The goal of this study was to describe the maintenance of postural equilibrium in obese and normal weight humans during forward leaning. The ability of obese to incline forward is obviously lower than in control subjects as attested by their smaller CoP displacement while leaning. The reduced amplitude of CoP displacement could be related to limitation of muscular force available in these subjects relative to their weight (Colné *et al* 2008).

Results also showed increased variance of CoP amplitude oscillation in obese group. Few factors can contribute to increased amplitude oscillation. A small sway deviation from a perfect vertical position leads to a torque due to gravity that moves and accelerates the body further away from the upright position. A corrective torque exerted by feet counteracts this destabilizing torque (Hue *et al* 2007). Keeping the body with small amplitude oscillations offers certain advantages, less muscle activity is necessary, which therefore requires less energy. In mathematical model (Corbeil *et al* 2001) by comparing obese and normal weight humanoid an increase in the magnitude of stabilizing ankle torque was found. Authors suggest that increased body weight and resulting forward shift of centre of mass is responsible for this change. Greater ankle torque could add more noise to feedback control system as greater muscle force is related to greater motor variability (Jones *et al* 2002).

The increased CoP variance in leaning position may be due to higher instability in this position as well as to the subsequent greater necessity of postural correction to maintain a leaning position. It means in daily living obese people may be at higher risk of falling because they have to generate ankle torque with higher rate of torque development to recover balance.

During the leaning position the pressure distribution on the sole is localized on the anterior part of sole. Kavounoudias *et al* (1998) hypothesized that the cutaneous afferent messages from the main supporting zones of the feet have sufficient spatial relevance to inform the CNS about the body position with respect to the vertical reference and consequently to induce adapted regulative postural response. The change of pressure distribution by leaning could modify/diminish this information.

When we compared postural stability of these two groups we tried to find out if the factor of obesity could lead to some adjustments necessary to control body inertia and preserve balance. We noticed increasing trend of PA in obese group, but no significant differences between groups were found.

Analysis of postural kinematic strategies in leaning position suggest that obesity contributed to reduced forward limit of stability. Significant difference in angles ratio likely showed that obese subjects reduced leg alignment and used more commonly trunk flexion during inclination. This could be concluded as indication that overweight of subjects influence the kinematic strategy of postural movements, which are in direction away from optimal vertical posture. It looks like that maintaining of stance equilibrium during body leaned position are more difficult for subjects with overweight. Therefore for improvement of impaired posture control in obese subjects is perspective to use visual biofeedback during leaned posture (Halická *et al* 2011, 2012).

The instruction for leaning was 'lean as far as you could at your comfortable speed', we were curious if the voluntary strategy of choosing progression velocity will be different between groups. The obese leaned significantly slower than subjects from control group. Limiting speed of tilt can be part of the strategy how to maintain equilibrium. Similarly as in the study of Colné *et al* (2008) who focused on mean velocity of progression in gait initiation in obese adolescents, results indicate that obesity acts as a slowing factor.

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