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Human Postural Response to Lower Leg Muscle Vibration of Different Duration

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Summary

Body lean response to bilateral vibrations of soleus muscles were investigated in order to understand the influence of proprioceptive input from lower leg in human stance control. Proprioceptive stimulation was applied to 17 healthy subjects by two vibrators placed on the soleus muscles. Frequency and amplitude of vibration were 60 Hz and 1 mm, respectively. Vibration was applied after a 30 s of baseline. The vibration duration of 10, 20, 30 s respectively was used with following 30 s rest. Subjects stood on the force platform with eyes closed. Postural responses were characterized by center of pressure (CoP) displacements in the anterior-posterior (AP) direction. The CoP-AP shifts as well as their amplitudes and velocities were analyzed before, during and after vibration. Vibration of soleus muscles gradually increased backward body tilts. There was a clear dependence of the magnitude of final CoP shift on the duration of vibration. The amplitude and velocity of body sway increased during vibration and amplitude was significantly modulated by duration of vibration as well. Comparison of amplitude and velocity of body sway before and after vibration showed significant post-effects. Presented findings showed that somatosensory stimulation has a long-term, direction-specific influence on the control of postural orientation during stance. Further, the proprioceptive input altered by soleus muscles vibration showed significant changes in postural equilibrium during period of vibration with interesting post-effects also.

Key words
Posture • Muscle vibration • Postural orientation • Postural equilibrium

Introduction

Human upright posture is maintained by the central nervous system via integration of complex afferent and efferent control signals, based on body orientation and motion information, which are provided by the vestibular, visual and somatosensory systems (Maurer *et al.* 2000, Peterka 2002). The human balance control system includes the sensorimotor, musculoskeletal and nervous processing components, aimed at the achievement of two behavioral goals: postural orientation and postural equilibrium (Horak and MacPherson 1996). Postural orientation refers to the position of the body with respect to gravitational vertical and it is characterized by body tilts from the vertical position. Postural equilibrium refers to body balance around equilibrium point, i.e. the configuration where all forces acting on the body are balanced in the desired

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body vertical position.

Proprioceptive inputs from postural muscles, particularly from leg postural muscles, are important information in human postural control. The balance control process can be influenced by vibratory stimulation of postural muscles (Adamcová and Hlavačka 2004). Vibration of leg postural muscles evokes kinesthetic illusion of movement in standing subjects and it results in a postural response known as vibratory-induced falling (Eklund 1973). The induced body tilt can be characterized as involuntary body lean in the direction of vibrated muscles (Hayashi *et al.* 1981). Vibration applied to a muscle increases the firing of muscle spindles which inform the central nervous system that the muscle is being stretched (Roll *et al.* 1989). Consequently, the postural system responds with a body tilt in the direction of the vibration to shorten the muscle. Effects of postural muscle vibration are diverse depending on the localization, intensity and duration of vibration (Wierzbicka *et al.* 1998, Kavounoudias *et al.* 1999a,b).

As a response to vibration of postural muscles in a freely standing person on stable support, each muscle involved in human posture control is always given the specified direction of evoked body tilt (Polonyová and Hlavačka 2001). It was proved that the response to vibration is not a local reaction limited to the joint, but a complex postural synergy that involves both legs and trunk muscles (Talis and Solopova 2000). Some authors suggested that posture is organized with respect to a body scheme, which is constructed on the common contribution of the information from eye, neck and skeletal muscles (Ivanenko *et al.* 1999, Kavounoudias *et al.* 1999a). Postural responses to calf muscle vibration were minimal in condition with subjects' eyes open, but increased when subjects' eyes were closed or when vision was inverted (Smetanin *et al.* 2002, 2004).

The postural responses to bilateral vibration of soleus muscles were investigated in order to better understand the influence of proprioceptive input from lower leg in human stance control. In particular, the aim of this study was to determine the influence of duration of proprioceptive stimulation on postural orientation and postural equilibrium. We hypothesized that postural orientation during lower leg muscle vibration will be directly related to duration of stimulation. Furthermore, we hypothesized that postural equilibrium (i.e. body sway around equilibrium point) evoked by muscle vibration will be also determined by duration of muscle vibration.

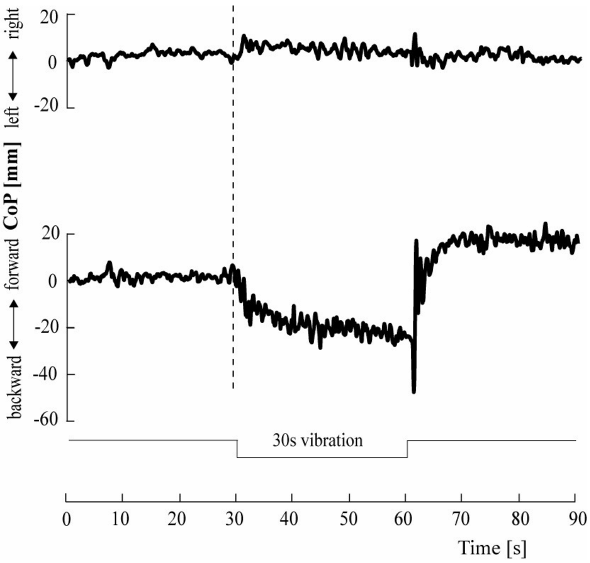

Fig. 1. The raw CoP responses to soleus vibration with duration 30s, in one subject.

Methods

We tested 17 healthy subjects (7 men and 10 women, age range 19-64, mean age 26.5 (SD=10.7) years) who gave their informed consent and the executions were approved by Local Committee. Proprioceptive stimulation was applied by two mechanical vibrators consisting of small dc motors with excenters (Polonyová and Hlavačka 2001). The vibrators were attached to the subject by elastic cuffs over both soleus muscles. Vibratory stimulus with a frequency of 60 Hz and amplitude 1mm was administrated to subjects.

Subjects stood relaxed on a force platform, with their arms along the body and their feet parallel, 15 cm apart. During all trials, subjects kept their eyes closed. Each trial began with a 30 second baseline period with no stimulation, followed by period of vibration (10, 20, or 30 sec) and a final period of 30 second with no stimulation. The experimental session consisted of six trials and each vibration duration was repeated for two trials. Conditions were presented to the subjects in random order by dividing the 6 trials into two blocks of 3 trials. After each trial, subjects relaxed for about 2 minutes. The complete duration of each trial was 70 sec, 80 sec or 90 sec, depending on duration of muscle vibration (Fig. 1).

Postural responses to vibratory stimuli were quantified by displacements of the center of pressure (CoP), measured by the force platform. Before starting each block of trials, subjects were required to realign the location of the CoP to the initial position, which was checked on a monitor. The initial CoP location was

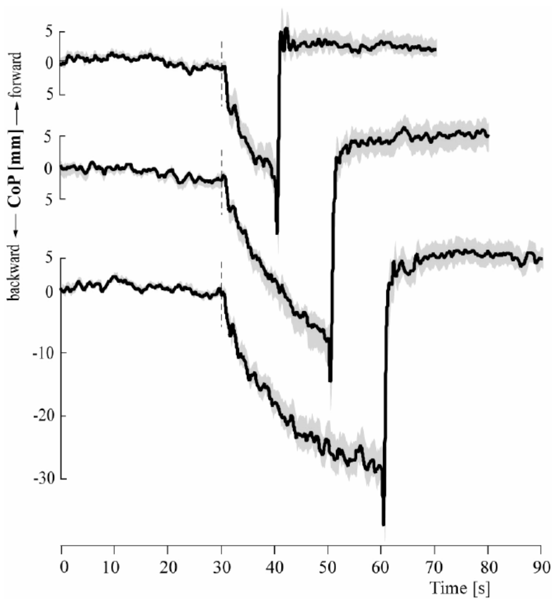

Fig. 2. Group average from all subjects of CoP responses in AP direction to bilateral soleus vibration with duration 10s, 20s and 30s. The gray area represents standard errors of mean (SEM).

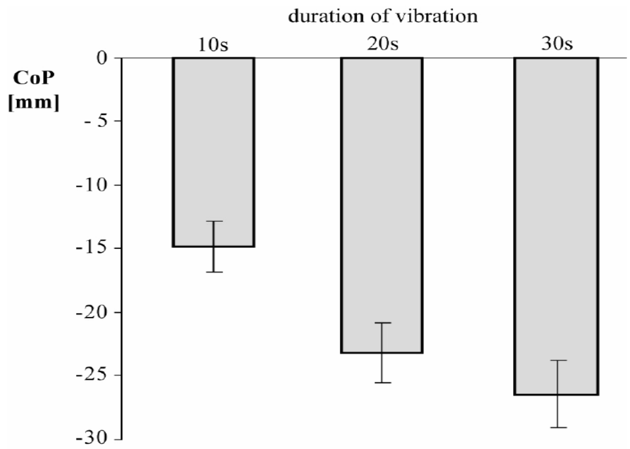

Fig. 3. Group averages of final CoP shifts during 10s, 20s and 30s lasting vibration. The error bars represent standard errors of mean (SEM).

arbitrary assigned to a value of zero.

The CoP was analyzed only in the anteroposterior (AP) direction, since vibration of soleus muscles induced body perturbations mainly in such direction.

Postural orientation was estimated by the shift of CoP position quantified during the last 4 s – final period of vibration. Effect of duration of vibration on CoP final position was investigated by one-way ANOVA with Tukey test.

Postural equilibrium (represented by body sway) was quantified by CoP-AP group-average from each stimulus recording and in particular by: 1) amplitude (A) defined as [A=4*(SD of CoP)] and 2) velocity index (V) defined as V=mean (abs (velocity of [CoP])) before, during and after vibration. Amplitude and velocity during and after vibration were computed after transitory effects were extinguished (i.e. 2 s after onset of vibration and 3 s after the termination of vibration). Comparison of A and V was obtained by repeated measures ANOVA followed by post-hoc Bonferroni tests: 3 vibration durations x 3 periods (before, during, after). Effect of duration of vibration and post-effect of vibration were also investigated.

Results

The influence of muscle vibration on postural orientation

During baseline period a minimal CoP-shift forward and backward were registered. When somatosensory afferent information from both soleus muscles was altered by onset of vibration a gradually increased backward body tilt occurred (Fig. 2).

The vibration stimulation with duration 10 s, 20 s and 30 s evoked body tilt with similar characteristics, but different final CoP backward position. There was a clear dependence of the magnitude of final CoP shift on the duration of vibration. Vibration termination was followed by a small increase of CoP tilt in backward direction. The body then returned to the initial vertical position, often overshooting the initial position. The body stabilization was usually reached after 2 s of transitory period.

The one-way ANOVA with Tukey test that compared the final CoP position induced by soleus vibration in cases of different duration of vibration (10 s, 20 s and 30 s) showed significant effect of duration ($q=13.2$, $p<0.05$) of muscle vibration (Fig. 3).

The influence of vibration on postural equilibrium

The averaged amplitude of body sway (A) from all subjects increased during vibration and was significantly modulated by stimulus duration of soleus muscles vibration (Fig. 4). The repeated measures ANOVA that compared A during vibration revealed significant effect of the duration of vibration ($F=11.954$, $p<0.001$).

Velocity of body sway (V) in AP direction during vibration clearly increased in relation to condition before vibration, but was not significantly influenced by different durations of muscle vibration (Fig. 5).

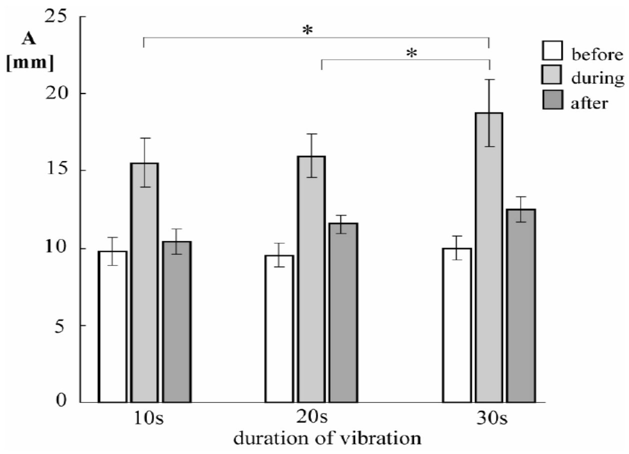

Fig. 4. Group averages of amplitude (A) recorded before; during and after vibration stimulation with duration 10 s, 20 s and 30 s. The error bars represent SEM.

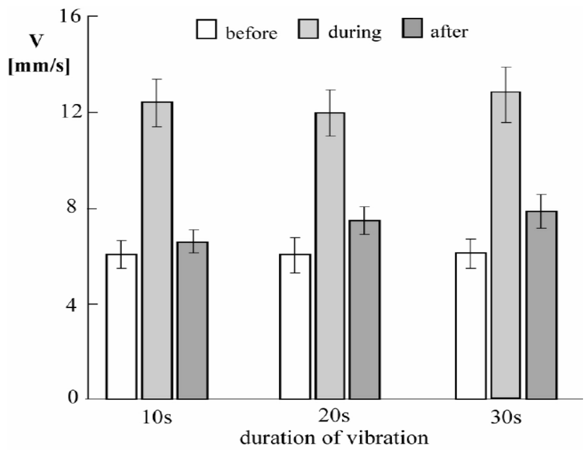

Fig. 5. Group averages of body sway velocity (V) in antero-posterior direction before, during and after muscle vibration with duration 10 s, 20 s and 30 s. The error bars represent SEM.

The post-effects of muscle vibration

To evaluate the post-effect of muscle vibration we compared A and V of body sway in condition before and after muscle vibration.

The repeated measures ANOVA that compared body sway A between conditions before and after vibration stimulus showed that post vibration effects were significantly sensitive to the stimulus duration (F=21.249, p<0.001). In the comparisons within the factor "duration of vibration" ANOVA showed significant differences for A between before and after vibration intervals for both 20 s (t=3.877, P<0.05) and 30 s (t=4.689, P<0.05) lasting vibration (Fig. 4).

The repeated measures ANOVA that compared body sway velocity V between conditions before and after vibration stimulus showed that post vibration effects were significantly sensitive to the vibration duration (F=17.140, p<0.001).

There was no significant difference between body sway amplitude and velocity before and after vibration for the 10 s lasting muscle stimulation. This indicates that 10 s soleus vibration is a proprioceptive stimulus probably not effective enough to induce significant post stimulus effects.

Discussion

In this study we analyzed how the different duration of proprioceptive input from lower leg muscles affects human balance control and postural responses to muscle vibration. We found a significant influence of bilateral soleus vibration on parameters of body sway and body lean during vibration and a post-effect of 30 s period of vibration. Hence, our results showed that different duration (10 s, 20 s and 30 s) of proprioceptive stimulation could modulate postural orientation and postural equilibrium, even after the vibration has terminated.

Proprioception can be altered in normal subjects using several techniques. Vibration techniques have become widely employed in studies of muscular proprioception. The sensitivity of muscle spindles to vibration stimulation depends on various mechanical characteristics, such as the intensity, displacement, frequency and duration of the stimulus (Cordo *et al.* 1993, Wierzbicka *et al.* 1998). Primary endings of ankle muscle spindles play a significant role in the control of posture and balance during locomotion by providing information on the movement of the body's center of mass with respect to the support foot (Sorensen *et al.* 2002). Many studies showed that vibration activates Ia afferents predominately (Roll *et al.* 1989, Gilhodes *et al.* 1992).

The postural orientation has two aspects: to orient the body to the biological significant environmental variables and aligning various body parts along a specific orientation with respect to each other (Horak and MacPherson, 1996). When some of the sensory information is altered, typical changes in postural orientation and equilibrium occur. Our results showed that the vibration of soleus muscles resulted in body lean oriented in the direction of vibrated muscles, i.e. in backward direction. Immediately after the start of vibration rapid CoP shift in the backward direction occurred. With the persistence vibration, the relative increase of CoP shift gradually reduced (i.e. there is not a linear relationship between vibration duration and corresponding CoP shift). Similar time course was presented by Hayashi *et al*. (1981) and Polonyová and Hlavačka (2001). We found that during the 4 s before end of the 30 s vibration, the final CoP position reached a sort of plateau. We hence hypothesized that the maximum body lean of subject was achieved. The significant relation between the final CoP position and the duration of vibration (Fig. 3) clearly showed that postural orientation depended on duration of vibration stimulation of soleus muscles.

Postural equilibrium involves the coordination of movement strategies to stabilize the center of body mass (Horak 2006), which is also characterized by amplitude, and velocity of body sway. In our study we focused how the 10 s, 20 s and 30 s lasting vibration affected the amplitude and velocity of body sway in the AP direction. Figure 4 shows that amplitude of body sway during vibration significantly increased with prolonged duration of vibration. Body sway oscillation increased mainly during 30 s lasting vibration. This increase of amplitude is likely due to the fact that during vibration is the subject's actual body position tilted from the usual vertical equilibrium position. This is consistent with previous findings that in unusual body posture the sway area increases markedly during long lasting body inclination (Schieppati *et al.* 1994). Such study suggested that the increased sway area in tilted posture is the effect of many small movements deliberately issued in order to seek balance and keep the requested inclination despite the changes of gravity load (average inclination plus instant body sway). The velocity of body sway significantly increased during vibration but contrary to amplitude of body sway it was not sensitive to duration of vibration. Our data provided evidence that postural equilibrium was altered by soleus muscles vibration and depended on activation and duration of proprioceptive stimulus.

It is likely that postural effects evoked by muscle vibration are present not only during vibration; indeed pattern of postural responses may remain altered for some time after the stimulus was terminated. Such alterations were indeed observed in previous studies (Feldman and Latash 1982, Wierzbicka *et al.* 1998, Gilhodes *et al.* 1992, Kavounoudias *et al.* 1999a). It was demonstrated that the Ia sensory discharge due to muscle vibration produces powerful prolonged effects on the motor system at the postural level. It is possible to think of post effects on the motor system as reflecting long-lasting consequences of motor actions (Wierzbicka *et al.* 1998). Also Kavounoudias *et al.* (1999b) observed the similar postural reaction after the sudden stop of vibration, as 'oriented whole body tilt in opposite side as stimulated one'. It is interesting that the area of short latency response of soleus muscle significantly decreased during vibration and almost returned to control value immediately after vibration termination (Bove *et al.* 2003). Contrary, medium latency responses were even more reduced during post-vibration period. It was suggested that the post vibratory phenomenon is not local and results of Gurfinkel *et al.* (1989), Rogers *et al.* (1985) and Ribot-Ciscar *et al.* (1996) supports the involvement of supraspinal pathways.

To summarize, the present findings clearly indicate the influence of duration of soleus muscles vibratory stimulation on postural orientation and postural equilibrium. The postural orientation – body lean during lower leg muscle vibration was related to duration of stimulation. Postural equilibrium - amplitude of body oscillation was larger during muscle vibration and remained altered even after the termination of soleus vibration. These facts could be applied as the method for testing of muscle proprioceptive information in human balance control in medicine practice.

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