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Identification of a degradation in postural equilibrium invoked by different vibration frequencies on the tibialis anterior tendon

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***Abstract*—The aim of the study was to compare the effect of different vibration frequencies applied to the tibialis anterior tendon on the control of postural equilibrium. Sixty-three parameters were analyzed, with 44 of them showing an effect of vibration. The greatest differences were observed for those parameters related to movement in the anteroposterior direction. Such a result was due to the direction of postural sway induced by the vibration. There were no differences between the control condition and vibration at 50 Hz. However, both 70 and 90 Hz vibrations produced similar results. The method of postural perturbation presented here might be useful to test the sensitivity of parameters extracted from COP signals in terms of their capability to detect small changes in postural equilibrium.**

I. Introduction

In order to remain upright under normal environmental conditions, subjects need to resist the force of gravity acting upon them. To do so, it is necessary to use active physiological active processes that require the control of the nervous system. Standing posture is controlled using information from three types of sensory receptors: vision, the vestibular system, and proprioception. This latter class of receptors includes muscle spindles whose stimulation is thought to be crucial for maintaining static equilibrium [1]. These receptors inform the nervous system of movement direction, speed, and the position of different parts of the body in relation to each other.

The involvement of ankle proprioception has been mainly demonstrated by the use of tendon vibrations applied to those muscles in order to activate muscle spindles. Such an artificial stimulation sends erroneous information on the movement of the affected body segment to the central nervous system. For instance, vibration applied to the tibialis anterior tendon when subjects are in a static upright position creates an illusion of a backwards tilt of the body, which causes subjects to make a corresponding forward tilt of the body in order to correct the perceived tilt [1]. This motor reaction has been interpreted as motor assistance behavior associated to whole body orientation [2].

Modification of standing posture has primarily been analyzed by requiring subjects to control their posture during the application of vibration [3]. In contrast, a small number of studies have examined changes in standing posture after vibration. For instance, Wierzbicka and colleagues analyzed standing posture after vibration was applied on either the tibialis anterior or the Achilles tendons [4]. Postural modifications were observed, with subjects oscillating either forwards or backwards, depending on the tendon on which the vibration was applied. The authors concluded that these new postures, which are outside the range of the normal erect posture, are inherently less stable [4].

The sensitivity of the muscle spindle message to tendon vibration depends on the frequency of the stimulation applied. Modulation of the frequency has been studied by Roll and Vedel, who demonstrated a relation between the frequency of vibration and the illusory movement perceived [5]. This experiment was only performed on the upper limb. To this point, no studies have assessed the effect of vibration frequency on standing posture.

The aim of this study, therefore, was to analyze the post vibratory effects of different vibration frequencies on standing posture in healthy adult subjects in order to determine the frequency that provided the greatest perturbation.

II. Methodology

A. Subjects

Seventeen healthy adult subjects were tested (10 males and 7 females). Subjects' mean age, height and weight were 22.8 ± 4.0 y, 174.2 ± 8.5 cm, and 67.1 ± 10.7 kg, respectively. All subjects who participated gave their written informed consent. No subjects reported any musculoskeletal or neurological conditions that precluded their participation in the study.

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B. Experimental protocol

Subjects were tested with their eyes closed in order to increase the contribution of the proprioceptive system on balance control, and thus increase the likelihood of obtaining a modification in balance as a result of the experiment. Vibration was applied bilaterally using the VB115 vibrator (Techno Concept, Cereste, France) to the tibialis anterior tendon for 10 seconds. The vibrating components of the device were cylinders (Fig. 1.). The vibrating cylinders were attached to subjects' tibialis anterior tendons using rubber straps. The VB115 devices were controlled by the VB115 software provided with the equipment. The pulse duration of the vibration applied had a pulse duration of 0.2 ms with an amplitude of 0.4 mm peak to peak.

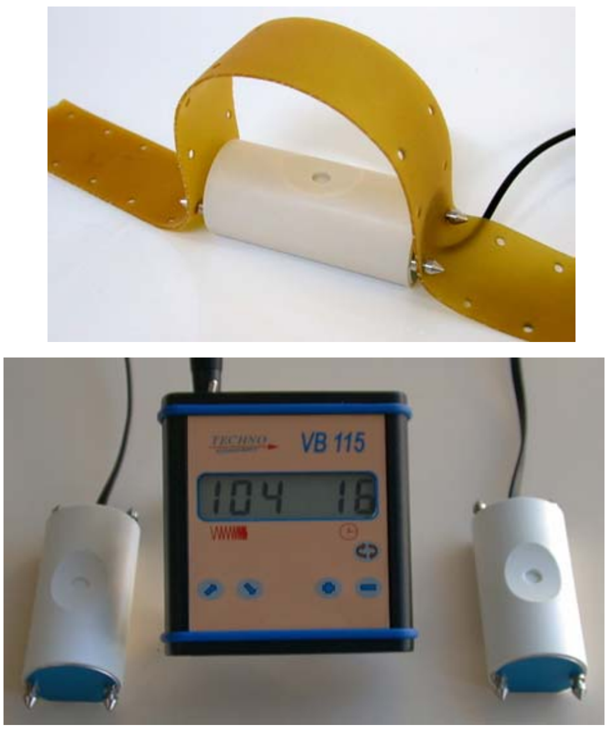

Fig. 1. The VB 115 tendon vibration system. The vibrating cylinders were attached to subjects' tibialis anterior tendons using the rubber strap shown above.

At the end of the vibration, subjects were given a verbal command to step onto a force plate (4060-80, Bertec Corporation, Colombus, OH, USA). Subjects stood quietly for 12 s with their eyes remaining closed, before stepping down backwards off the force plate after a second verbal command. Subjects were asked to remain as still as possible with their arms placed at their sides in a comfortable position throughout the protocol. No constraint was given over foot position, with subjects tested barefoot.

Measurements were repeated five times for each experimental condition, with 30 s between each test. Subjects were given a 10-min delay between experimental conditions in order to reduce any post-vibratory effect of one frequency on the subsequent experimental condition. Subjects were tested using four different vibration frequencies (0Hz: control; 50 Hz; 70 Hz; 90 Hz) that were performed in a random order. The frequencies chosen were based on those reported in previous studies [2, 3, 5].

C. Data acquisition

Data were recorded using the ProTags™ (Jean-Yves Hogrel, Institut de Myologie, Paris, France) program developed under Labview (National Instruments Corporation, Austin TX, USA). Data were sampled at 100 Hz, using an 8th-order low-pass Butterworth filter with a cut-off frequency of 10Hz. The initial COP signals were calculated with respect to the centre of the force-plate before normalization by subtraction of the mean. All calculations of COP data were performed with Matlab (Mathworks Inc, Natick, MA, USA).

D. Parameter calculation

A total of 63 parameters were calculated for the COP signals, including temporal parameters (mean, RMS), spatiotemporal (surface of the ellipse) and spectral (median frequency, deciles). An additional group of parameters that could provide insights to the state of the underlying physiological control systems was also tested. This group contains those parameters that provide information related to the trajectory of the COP signal [6, 7]. Detailed explanations of the method used to calculate all parameters can be found in [8-14].

E. Statistical analyses

Statistical analyses were performed with the Statistical Package for Social Sciences (SPSS Inc., Chicago, IL, USA). Multivariate analysis of variance was used to compare results between conditions, with COP parameters as the dependent variables and the experimental condition and the test number as the independent variables. Analysis of contrasts were undertaken to identify differences between configurations, with Bonferroni adjustments used to reduce type I error rates. Alpha level was set at $p<0.05$.

III. Results and Discussion

There was no effect of the test number on any of the parameters measured. Such a result implies that any variation in results for vibration frequencies would be entirely due to the frequency and not to any effect of a previous vibration.

In respect to the effect of vibration, 44 of the 63 parameters demonstrated a significant effect ($p<0.05$). Due to the large number of parameters tested, only the most interesting results will be presented in the present article. In terms of the analysis of contrasts for vibration frequencies, there were no differences observed between the control condition and the 50 Hz vibration. This result is in keeping with the results of Roll and colleagues [5], who reported minimal changes invoked by low frequencies. In contrast, both 70 Hz and 90 Hz produced significant changes in a large number off parameters, with 21 and 29 parameters significantly modified for 70 Hz and 90 Hz, respectively.

The results of the three most important temporal parameters are presented in Fig. 2. For precise details of these parameters refer to [15]. It can be observed that all of these effects occurred for parameters in the anteroposterior direction.

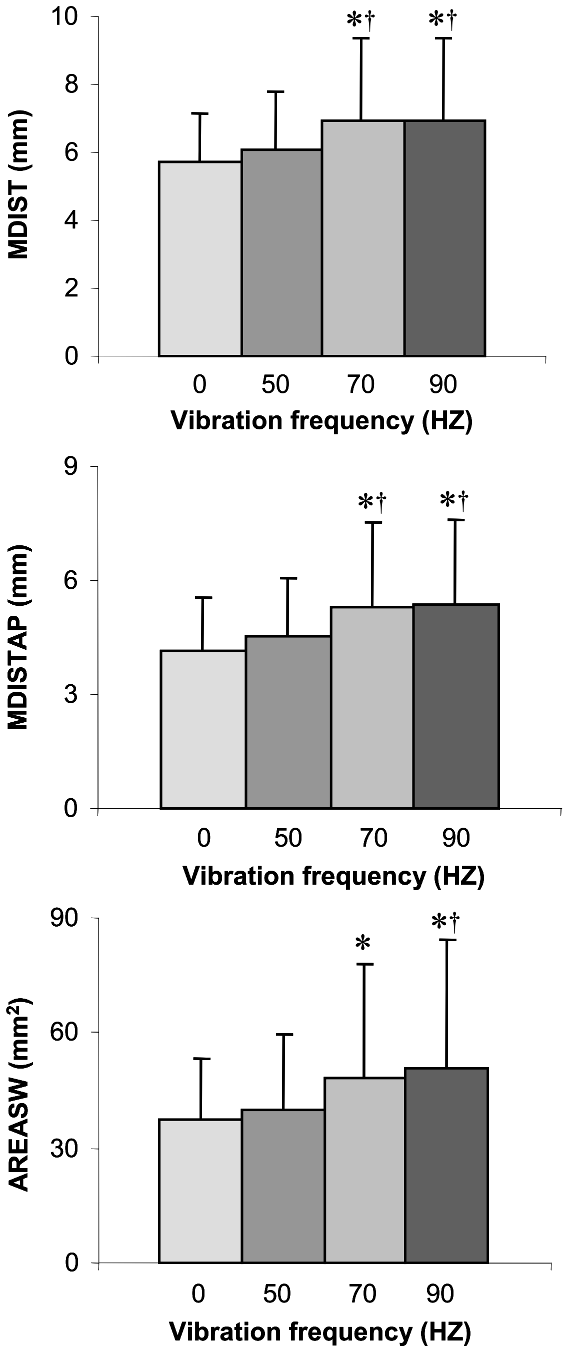

Fig. 2. The effect of vibration frequency on selected temporal paramerers. MDIST and MDISTAP are the mean distance for COP displacement for the resultant and the AP directions, respectively. AREASW is the area under the curve between two successive points. Data are means ± standard deviation. *Significant difference from 0 Hz; †significant difference from 50 Hz.

Such a result is clearly the post-vibration effect, given that the vibration was applied to the tibialis anterior tendon, which produces movement in the saggital plane. The increase in the distance the COP moved in an AP direction was significantly greater for 70 and 90 Hz. Such a result confirms the hypothesis that perturbation of proprioception would result in increased postural sway.

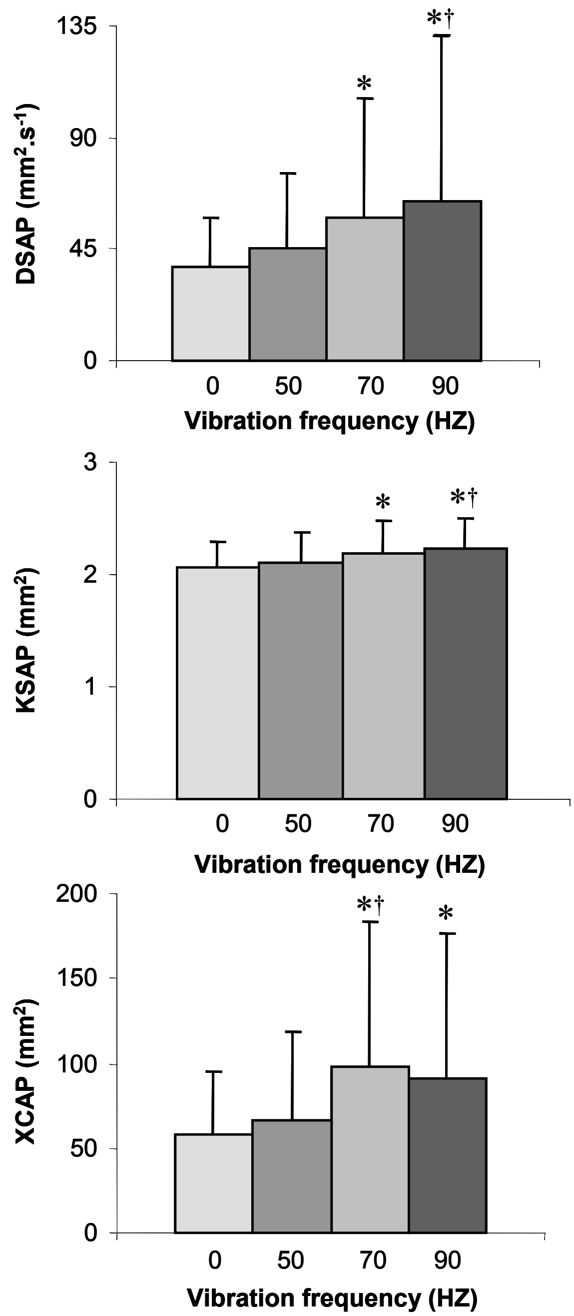

Fig. 3. The effect of vibration frequency on selected stabilogram diffusion analysis (SDA) parameters. DSAP is the short-term diffusion coefficient of COP displacement in the AP direction. KSAP is the intersection of the open-loop postural control mechanism at $\Delta t = 1$ s. XCAP is the variance of the SDA curve at the critical time R. Data are means ± standard deviation. *Significant difference from 0 Hz; †significant difference from 50 Hz.

The results of three stochastic parameters are presented in Fig. 3. For precise details of these parameters refer to [16]. These results are in agreement with those of the temporal parameters in Fig. 2. Once again, the most important changes were observed for the AP direction, with significant increases observed for 70 and 90 Hz.

IV. Conclusion

The results of this study demonstrate that vibration of the tibialis anterior tendon results in a marked perturbation of proprioception. The biggest changes were all for parameters related to movement in the anteroposterior direction. The vibration frequencies that most perturbed postural equilibrium were 70 and 90 Hz, in keeping with previously reported work. This method of postural perturbation might be useful to test the sensitivity of parameters extracted from COP signals in terms of their capability to detect small changes in postural equilibrium. To this end, it is envisaged to test the effect of smaller increments in vibration frequency, particularly between 50 and 70 Hz in order to refine the technique.

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