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Effects of bilateral Achilles tendon vibration on postural orientation and balance during standing

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Abstract

Objective: Altering proprioceptive information in the lower limbs by vibration produces direction-specific falling and postural instability, which can persist after vibration stops. The objectives of this study were to describe the changes in trunk and lower limbs postural orientation and muscles activities during and after the end of bilateral Achilles tendon vibration (TV).
Methods: Twelve healthy young subjects were exposed to 30 s periods of TV while blindfolded. Whole-body kinematics, kinetics and EMG of eight lower limb and trunk muscles were recorded prior, during and 5 or 25 s after TV.
Results: TV during quiet standing produced a whole-body backward shift characterized by greater extension in the trunk and lower limbs. Five seconds after TV, two trends of recovery could be observed, either an overcorrection or undercorrection of the initial position.
Conclusions: A continuum of postural orientations are adopted during and after vibration and the movements are not restricted to the ankle joints, despite the local nature of the proprioceptive stimulation.
Significance: The widespread influence of vibration as a proprioceptive stimulation when assessing its effects on posture and balance needs to be considered. Further studies should include whole-body analyses to document more thoroughly the postural strategies for balance maintenance during vibration.

Keywords: Posture; Proprioception; Post-effect; Muscle spindles; Sensorimotor integration

1. Introduction

The behavioral goals of orientation and equilibrium that underlie postural control can be challenged in everyday life by environmental perturbations. Maintenance of equilibrium during standing depends on both the descending commands from the central nervous system (CNS) and the availability as well as accuracy of somatosensory (muscle, joint, skin and pressure receptors), visual and vestibular inputs (Collins and DeLuca, 1993; Horak and Macpherson, 1996). Tendon vibration is a powerful stimulus that is known to activate mainly the muscle spindles' primary (Ia) afferents. Indeed, when exposed to bilateral vibration (50–160 Hz; 1.5–1.8 mm) of the calf or pretibial muscles or tendons (Eklund, 1969, 1972, 1973; Hayashi et al., 1981; Polonyova and Hlavacka, 2001) subjects standing with eyes closed increased their postural sway and experienced vibration-induced falling reactions in the direction of the applied vibration (Eklund, 1972; Hayashi et al., 1981) as demonstrated by directional shifts in CoP and CoM positions. The directional shifts of the CoP and CoM are attributed to an increased Ia afferents discharge

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during vibration, which is interpreted as lengthening the vibrated muscles. Hence, a perceived lean in the direction opposite to the applied vibration is compensated by tilt in the direction of the applied vibration (Goodwin et al., 1972; Hayashi et al., 1981; Kavounoudias et al., 1999; Polonyova and Hlavacka, 2001). An increased tonic activity in the Soleus muscle during vibration, referred to as a tonic vibration reflex (TVR), was also shown to contribute to the tilting of the body in the direction ipsilateral to the vibration (Hayashi et al., 1981). Vibrating other leg muscles, for example the hamstrings, also produces changes in the trunk, hips, knees and ankles orientation that are consistent with a typical backwards inclination of the body (Ivanenko et al., 2000).

The effects of vibration on various sensorimotor functions, such as the Soleus H-reflex (Heckman et al., 1984; Hayward et al., 1986; Thompson and Bélanger, 2002) and position sense (Rogers et al., 1985), are also known to persist even after the stimulation stops; however, the exact duration of its effects is unknown. Postural responses also remain affected for some time after the end of vibration (Martin et al., 1980; Hugon et al., 1982; Gauthier et al., 1983; Wierzbicka et al., 1998). Increased postural oscillations provoked by 30 min of vibration to the whole-body or legs (18 Hz; 0.25–0.5 g) have been shown to persist for up to half an hour after the end of vibration (Martin et al., 1980; Hugon et al., 1982; Gauthier et al., 1983), whereas Wierzbicka et al. (1998) reported that 30 s of bilateral Achilles tendon vibration (80 Hz; 0.2 mm) altered postural sway and orientation for 1 min to 3 h after the end of vibration.

Studies that examined the effects of tendon vibration on postural control during stance have by and large focused mainly on postural sway measured by the CoP excursions and ankle angles associated with the body-oriented displacements. However, it is still unclear whether vibration has widespread effects involving postural strategies from the joints and muscles distant to the vibrated area, as well as if those changes are still present after vibration has stopped. We therefore hypothesized that bilateral Achilles tendon vibration would affect the position and orientation of joints and segments remote to the vibrated sites, as suggested by the work of Ivanenko et al. (2000), and as such would be accompanied by consistent modifications in muscle activity. Therefore, the first objective of the present study was to determine the changes in postural equilibrium, orientation and muscle activities in the sagittal plane in the last 5 s of a 30-s exposure to bilateral Achilles tendon vibration during quiet standing. The second objective was to describe the post-vibratory postural orientation and muscle activities at two distinct moments of the recovery period (5 and 25 s after tendon vibration offset) to gain insight into the duration of these post-vibratory effects. The novelty and originality of the present study lies in the demonstration that the body adopts a continuum of postural orientations at the ankles as well as more proximal joints and segments (knees, hips, pelvis and trunk) that are aimed at compensating the backwards leaning. These new postural orientations might be consistent with the building of a new referent configuration or an altered perception of postural verticality. As well, this study is to our knowledge the first to report two distinct trends in the magnitude of recovery at offset of tendon vibration, termed overcorrection and undercorrection, which might be dependent on the position taken during vibration.

2. Methods

2.1. Subjects

Twelve subjects (7 females, 5 males; 25.3 ± 6.2 years old) voluntarily participated in this study. They were recruited from the university and research center population and were all free of any neuromuscular or musculoskeletal disorders. The project was accepted by the Comité institutionnel d'éthique de la recherche chez l'humain (CIÉR) (Université du Québec à Montréal) and the CRIR (Centre de Recherche Interdisciplinaire en Réadaptation) Ethics Committee and has been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. An informed written consent was obtained from all subjects prior to the beginning of testing.

2.2. Procedures

All subjects were assessed in the Posture and Gait Research Laboratory at the Jewish Rehabilitation Hospital. They were asked to stand on two triaxial force plates (AMTI OR6-7), mounted in a moveable support surface, with their feet shoulder width apart, one foot on each force plate and with their arms at their sides. The feet positions on the force plates were marked in order to ensure a constant feet placement throughout the experiment. The subjects' vision was occluded by an opaque eyeband and for safety reasons, they were secured in a body harness affixed to the ceiling without providing weight support. Subjects were instructed to try to maintain their balance at all times, whether vibration was applied or not.

Two custom-made vibrators consisting of a motor equipped with a small eccentric mass were strapped around the subjects' two ankles above the malleoli, with the motors placed directly over both Achilles tendons (Fig. 1a). The vibrators stayed in place for the duration of the experiment. Prior to the onset of data collection, subjects were presented with two or three bouts of vibration in order to familiarize themselves with the sensation as well as to verify if they could remain standing when vibration was applied. After this familiarization and a short delay (about 10 min), participants were subjected to 30 s periods of bilateral Achilles tendon vibration (TV), at a frequency of 80 Hz and approximate amplitude 1.5 mm. This vibration frequency and amplitude have already been shown to be optimal for eliciting postural responses during quiet standing (Kavounoudias et al., 2001; Polonyova and