Journal of Biomechanics 42 (2009) 2268–2272

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

Wearing shoes increasing dorsiflexion improves short-term but not long-term balance control in young healthy adults

P.R. Rougier *, F. Lachaume, J. Bourse, M. Rogeon, A. Monti, S.C. Regueme

Laboratoire de Physiologie de l'Exercice, EA4338, Université de Savoie, Domaine Scientifique de Savoie-Technolac, 73376 Le Bourget du Lac cedex, France

ARTICLE INFO

Article history:
Accepted 19 June 2009

Keywords:
Ankle
Dorsiflexion
Shoes
Proprioception
Upright stance
Postural control
Posturography

ABSTRACT

Wearing sport shoes inducing ankle dorsiflexion has been shown to alter the biomechanical specificities of the stretched muscles. The possible effect over the short and long term upon the sensorial capacities induced by such stretching has not been addressed yet. Fourteen healthy individuals were involved to assess the proprioceptive repercussion and their effects upon postural control strategies. Postural control and proprioceptive assessment were measured twice: when receiving sport shoes inducing ankle dorsiflexion and 18 days later. Proprioceptive effects were assessed using an ad-hoc device through which the seated and blindfolded subjects were required to reposition their feet in a starting position after the ankles were passively displaced to dorsiflexed and plantarflexed positions. Center-of-gravity horizontal displacements (CG_v), estimated from center-of-pressure (CP) displacements, and CP–CG_v displacements were measured through a force platform during upright quiet stance maintenance. The initial session was recorded with the subjects barefoot and wearing the shoes with a set of chocks with 0° (horizontal) and −5° (dorsiflexion) tilting angles. The second session included only barefoot performance in horizontal and dorsiflexion conditions. Dorsiflexion had no immediate effect on the postural control strategies along the anteroposterior axis. In contrast, barefoot or wearing shoes, stability was increased along the mediolateral axis during the dorsiflexion conditions. No ankle proprioceptive or postural change was observed after wearing the shoes for 18 days. Wearing dorsiflexion sport shoes induces short-term effects probably by inducing a backward tilt of the pelvis. A muscular adaptation likely prevents this effect from being prolonged.

1. Introduction

Over the past few years, a new concept, ankle dorsiflexion, has been developed in the field of the sport shoes. Its principle is to lower the heels in relation to the forefeet. Wearing these shoes has been shown to increase vertical jump height (Kraemer et al., 2000; Larkins and Snabb, 1999). Recently, it has been shown that these shoes affect the recruitment of the lower limb muscles during fitness exercises, walking, and running (Bourgit et al., 2008). More specifically, increasing dorsiflexion would reorganize the motor patterns during these exercises by involving general increased muscular activity at the tibialis anterior (TA). It is likely that this increased muscular activity is related to the change in the position of the lower limb joints and of the center of gravity (CG) relative to the feet.

Even though the TA is usually not involved in the postural control organization in healthy adults when standing still on a horizontal base of support, as demonstrated by Okada and Fujiwara (1983) using electromyographic (EMG) data, one may wonder whether a slightly stretched triceps surae (TS) muscle could alone induce a change in the proprioceptive sense. An indirect way to bring this out is to investigate the repercussion of dorsiflexion on postural control by using posturographic measurements. It was recently proposed from posturographic data that improved proprioception of the TS was the most likely way to explain subjects' ability to engage their postural correction along the anteroposterior (AP) axis more rapidly after a series of successive stretches (Rougier et al., 2006). This axis specificity is explained by the biomechanical particularity of the upright posture. Whereas dorsiflexor muscles play a major role in controlling the displacements of the reaction forces along the AP axis, those occurring along the mediolateral (ML) axis result from activations at the hip (Rougier, 2007; Winter et al., 1996).

Investigations on postural effects induced by stretching some of the muscles directly involved in its control are rather scarce. Data from studies based on forward–backward leaning of the body (Schieppati et al., 1994; Rougier et al., 2001) have emphasized the disturbing effect induced by the shift of the CG. Increasing the horizontal distance between the CG and the feet has a huge effect upon muscle activity, which largely explains the

* Corresponding author. Tel.: +33 479 75 88 08; fax: +33 479 75 81 48.
E-mail address: patrice.rougier@univ-savoie.fr (P.R. Rougier).

0021-9290/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jbiomech.2009.06.044

increased center of pressure (CP) displacements along the AP axis. More recently, in an attempt to dissociate the muscle activities from the biomechanical constraints imposed by the displacements of the CG with respect to the base of support, an experimental paradigm based on an inclined surface was proposed (Mezzarane and Kohn, 2007). Compared to a horizontal position of the feet, it was shown that a position with the toe flexed up at a 14° angle (dorsiflexion) leads to an increased EMG activity of the TA without altering the TS activities. A posturographic measurement indicates that the CP displacements are greater along the AP axis with dorsiflexion. It also appears that the level of presynaptic inhibition of the soleus muscle is not really affected by the ankle position.

Along with these postural effects, other studies have focused on the physiological effects induced by prolonged muscular stretching. Tabary et al. (1972) investigated the long-term changes in the muscular properties of the cat's soleus muscles after 4 weeks of stretching performed by immobilizations. They observed changes in the number of sarcomere in series and length–tension relations aimed at preventing the muscle from being overstretched. More recently, Fowles et al. (2000) found that repetitive muscular stretching decreases voluntary strength, whereas Robinson et al. (1982) showed that reflex excitability, as reflected in the H-reflex, was decreased by stretching. However, to our knowledge, no postural or physiological data have been reported for longer term adaptations in humans. Along these lines, wearing dorsiflexion shoes for approximately 3 weeks might cause adaptation in these physiological effects and therefore in postural control organization. Interestingly, Rougier et al. (2006) have suggested that repetitive triceps surae stretching improves the sensitivity to proprioceptive inputs and therefore postural control capabilities along the AP axis.

The purpose of this study was multifold. At the onset, it can be hypothesized that dorsiflexion could induce short-term and long-term effects on proprioceptive sensitivity and therefore on postural control performance. These changes could be related to the TS stretch and to a possible CG displacement. To test this concept, our protocol included both a postural task (upright quiet stance) and a specific proprioceptive task where the subjects had to reposition their ankle after it had been displaced. Since wearing sport shoes a priori could attenuate the transmission of the reaction forces produced in the foot to the force plate sensors, the postural protocol was carried out in two conditions: wearing the shoes and barefoot. Lastly, to highlight a possible adaptation stemming from prolonged dorsiflexion, all subjects were required to wear their shoes consistently for a period of 3 weeks before being retested.

2. Methods

Fourteen healthy male subjects, ranging in age from 20 to 26 years (body weight, 72 kg ± 8.4; height, 175.9 cm ± 5; mean ± standard deviation) with no known visual or balance pathology gave their written informed consent and were included in this study. All the subjects were students in sports and physical education and participated in sports regularly. To prevent a possible interaction with fatigue, they were asked not to do any physical activity before the tests on each testing day.

Since one of our objectives was to assess the long-term effects induced by a prolonged slight stretching of the plantar flexors (dorsiflexion), the subjects were asked to wear a specific model of sport shoes manufactured by Springboost (B-Train model) for 3 weeks. The subjects were tested twice: once when receiving the shoes for assessing the short-term effects and 18 days later to assess the long-term effects. To better assess the possible adaptation, the subjects were required to note the number of hours per day the shoes were worn and the level of dorsiflexion. The sports shoes used are sold with three pairs of insoles (−1, −3, and −5°) to allow a progressive adaptation to this new position. Each subject was free to decide how long each insole was successively used. The subjects reported wearing the shoes as follows: total time: 68.6 ± 39.3 h for 18 days; −1° insoles: 3.1 ± 2 days; −3° insoles: 3.3 ± 3 days; −5° insoles: 11.6 ± 6.5 days.

At each testing session, two protocols were carried out based on posturographic measurements and ankle proprioceptive assessment. The goal was to use the data to assess the short-term and long-term effects on postural control strategies and the long-term effects on ankle proprioception. Therefore, the posturographic data at the second testing session only involved barefoot conditions on horizontal and tilted supports.

2.1. Posturography

The subjects stood on a dual force platform (PF02, Equi+, Aix-les-Bains, France) with the inner boarder of the feet parallel and were asked to standstill with their arms at their sides. The signals from the load cells under the plate were amplified and converted from analog to digital form before being recorded on a personal computer with a 64 Hz sampling frequency.

The experimental protocol included four experimental conditions performed in random order and consisting of various inclinations of the feet with respect to the horizontal position. Precisely, in addition to a reference condition (REF) where the feet were horizontally positioned using a set of wooden wedges laying on the force platform (Fig. 1), the feet were tilted upward (dorsiflexion) with a 5° angle This value corresponded to the maximal angle induced by the shoes. To assess the postural effects independently of shoe wear, these two conditions were performed twice: barefoot and wearing the shoes. Each condition was composed of three trials lasting 64 s, with a rest period of a similar duration allowed between each trial. The rest time period between each condition lasted at least 5 min.

2.2. CG_v and $CP–CG_v$ movement estimation

From a biomechanical point of view, the CP displacements can be considered as containing the CG horizontal displacements they control and also as the difference between CP and the vertically projected CG ($CP–CG_v$). The former is generally viewed as the main controlled variable during human upright stance, whereas the latter expresses the horizontal acceleration communicated to the CG (Brenière et al., 1987) and is a fair expression of the overall muscular activity of the lower limbs (Rougier et al., 2001). As highlighted in the latter study, the two movements do not vary systematically in similar ways, legitimating splitting the complex CP into two basic components, that is CG_v and $CP–CG_v$.

These movements were estimated through an amplitude ratio, displayed graphically for instance in Fig. 1 of the article by Rougier et al. (2001), involving the vertically projected movements of the center of gravity (CG_v) on the horizontal plane and CP movements (CG_v/CP) as a function of CP displacement frequencies (Brenière, 1996). The CG_v estimation consists in multiplying the FFT of the CP signal by the relation $\Omega_o^2/(\Omega^2+\Omega_o^2)$ where Ω is angular frequency in rad/s and Ω_o is a value determined from the anthropometric data of the experimental subject (Brenière, 1996). The CG_v time domain description is then obtained by an inverse FFT. All of these data were automatically processed using the Equi+-PROG02

Fig. 1. Photograph showing the force platform device, the wedges, and the shoes used in this study. Note that the displayed wedges position causes a plantarflexion instead of a dorsiflexion.