Do Ankle Foot Orthoses Modify Postural Control during Bipedal Quiet Standing Following a Localized Fatigue of the Ankle Muscles?

Abstract

The purpose of the present experiment was to investigate the effects of wearing ankle foot orthoses (AFO) on postural control during bipedal quiet standing following a localized fatigue of the ankle muscles. To this aim, eight young healthy subjects were asked to stand upright as immobile as possible with and without AFO in two conditions of non-fatigue and fatigue of the ankle muscles. The center of foot pressure displacements (CoP) were recorded using a force platform. Larger CoP displacements in the fatigue than non-fatigue condition were observed without AFO along both the medio-lateral and antero-posterior axes. Interestingly, with AFO, these destabilizing effects were not observed along the medio-lateral axis. Altogether, the present findings suggested that the AFO allowed the subjects to limit the postural perturbation induced by a localized fatigue of the ankle muscles during bipedal quiet standing.

Key words
Balance · ankle foot orthosis · muscular fatigue · center of foot pressure

Introduction

The ability to maintain a stable upright posture is an important factor, not only in the initiation and the control of voluntary movement, but also in the prevention of injury. Under normal circumstances, the importance of an intact ankle function for maintaining upright stance was evidenced by investigating individuals with functional ankle instability, strain or trauma [9–11, 15, 20, 24] or by manipulating ankle sensory/motor systems in healthy subjects. For instance, when the reliability of ankle proprioceptive information was experimentally reduced, either by standing on a sway-referenced floor [13] or on a compliant surface [22], or by applying vibratory stimulation bilaterally to both antagonistic ankle muscles [12, 27], a decreased postural control was observed. In recent years, numerous studies also have reported that a localized fatigue of the ankle muscles, known to alter not only the functionality of the proprioceptive system [8] but also the force-generating capacity at the ankle joint [23], impaired postural control during quiet bipedal standing [3, 14, 16, 26–29]. Interestingly, this destabilizing effect, reported in the absence of vision, has been shown to be at least partially alleviated by providing additional visual information [16, 26] and haptic cues from the finger [29].

In the present study, we investigated whether postural control during quiet standing following a localized fatigue of the ankle muscles could also be modified by wearing ankle foot orthoses (AFO). Indeed, the application of AFO has previously been reported to improve postural control, under both monopodal [1, 7, 11, 25] and bipedal stance conditions [2, 21]. These stabilizing effects, mainly reported in the absence of visual information, were described in terms of increased mechanical support [4] and increased sensorimotor function offered by external ankle support [5, 6, 19] and were critically related to the physical character-

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Bibliography
Fig. 1 Photograph of the model of ankle orthosis tested (lateral view): Ligacast is a stabilizing ankle brace made of two rigid plastic shells. Two adjustable straps allow a precise fit of the shells. This model is prescribed for moderate or severe sprains, during functional or post-surgery treatment and for malleolar fractures during functional treatment in the physical therapy phase.

istics of the AFO. For instance, a recent study aimed at evaluating the postural effects of various AFO models indicated that 1) postural control was predominantly improved where the ankle movement was counteracted by the AFO, and 2) the relative rigidity determined by the model was an important factor for improving postural control [21]. In the present experiment, we hypothesized that: 1) ankle plantar-flexor muscles fatigue would yield a destabilizing effect, 2) wearing AFO would induce a stabilizing effect, and 3) AFO would limit the destabilizing effect induced by the localized fatigue of the ankle muscles. In addition, given the physical characteristics of the AFO model tested (i.e., Ligacast, Fig. 1), different effects according to the medio-lateral (ML) and antero-posterior (AP) axes were expected, with a stabilizing effect mostly occurring in the frontal plane [21].

Methods

Subjects

Eight healthy university students from the Department of Sports Sciences at the University of Siena (mean age = 21.5 ± 1.0 years; mean body weight = 62.3 ± 6.5 kg; mean height = 172.1 ± 8.3 cm) voluntarily participated in the experiment. They gave their informed consent to the experimental procedure as required by the Helsinki Declaration (1964) and the local ethics committee. None of the subjects presented any history of injury, surgery or pathology to either lower extremity that could affect their ability to perform postural control tests.

Apparatus

A force platform (Equi-M, model PF01, Aix les Bains, France), constituted of an aluminium plate (800 mm each side) lying on three uniaxial load cells, was used to measure the displacements of the center of foot pressure (CoP). Signals from the force platform were sampled at 64 Hz, amplified and converted from analogue to digital form.

Task and procedure

Subjects stood barefoot on the force platform, in a natural position (feet abducted at 30°, heels separated by 3 cm), with their arms hanging loosely by their sides and their eyes closed.

The non-AFO condition served as a control condition. In the AFO condition, subjects were required to wear a particular model of AFO, fastened by a single investigator, on each foot. Based on a recently published investigation [21], we tested the Ligacast AFO model, reported to induce a large decrease in postural sway along the ML axis. This model, manufactured by Thuaire (Thuaire, Levallois-Perret, France), is described and illustrated in Fig. 1.

The two non-AFO and AFO conditions were executed the same day before (non-fatigue condition) and after a designated fatiguing exercise for ankle plantar-flexor muscles performed without AFO (fatigue condition). The non-fatigue condition served as a control condition in which three 32-s trials for each condition of non-AFO and AFO were presented randomly. In the fatigue condition, three trials for each condition of non-AFO and AFO were executed randomly 1 min after a fatiguing procedure. Note that this 1-min rest period was automatically managed by the recording program (software PROG01; Equi-M, Aix les Bains, France); 1) to allow the AFO to be applied after completion of the fatiguing exercise whenever required (i.e., in the AFO condition); and 2) to ensure a similar time-lag between the exercise-induced fatiguing activity and the postural measurement for both the non-AFO and AFO conditions. The ankle plantar-flexor muscle fatigue of both legs was induced until maximal exhaustion was achieved by instructing the subjects to perform toe-lifts as many times as possible following the beat of a metronome (40 beats/min). Verbal encouragement was given to ensure that subjects worked maximally. The fatigue level was reached when subjects were no longer able to complete the exercise. To ensure that balance measurement in the fatigue condition was obtained in a real fatigued state, the fatiguing exercise was repeated prior to each trial [16,28–29].

Data analysis

Variances of positions of the CoP calculated along the ML and AP axes were used to describe the subject's postural behavior.

Statistical analysis

The means of the three trials performed in each of the four experimental conditions were used for statistical analyses. Two fatigues (non-fatigue vs. fatigue) × 2 AFO (non-AFO vs. AFO) analyses of variance (ANOVAs) with repeated measures on both factors were applied to the data. Post hoc analyses (Newman-Keuls) were used whenever necessary. Level of significance was set at 0.05.

Results

Analysis of the variance of the CoP displacements along the ML axis showed a significant interaction of fatigue × AFO (f [1.7] =
28.38, p < 0.01) (Fig. 2A). The decomposition of this interaction into its simple main effects showed larger CoP variance in the fatigue than non-fatigue condition in the non-AFO condition (p < 0.001), whereas no significant difference was observed in the AFO condition (p > 0.05). The ANOVA also confirmed main effects of fatigue (F[1.7] = 68.47, p < 0.001) and AFO (F[1.7] = 10.55, p < 0.05).

Analysis of the variance of the CoP displacements along the AP axis showed a main effect of fatigue (F[1.7] = 6.35, p < 0.05), yielding larger CoP variance in the fatigue than non-fatigue condition (Fig. 2B).

**Discussion**

The purpose of the present experiment was to investigate the effects of wearing ankle-foot orthoses (AFO) on postural control, during bipedal quiet standing, following a localized fatigue of the ankle muscles. To this aim, eight young healthy subjects were asked to stand upright as immobile as possible with and without AFO in two conditions of non-fatigue and fatigue of the ankle muscles.

Larger CoP displacements in the fatigue than non-fatigue were observed along both the ML and AP axes, suggesting that ankle muscle fatigue impaired postural control. Since ankle muscle fatigue is known to alter both the sensory proprioceptive side [8] and motor output [23] of the postural control system, this result was expected (hypothesis 1) and was consistent with previous results [3,14,16,26-29]. Furthermore, the Ligacast AFO model yielded decreased CoP displacements, along the ML axis, suggesting an improved postural control. This result also was expected (hypothesis 2), corroborating those of Rougier et al. [21]. More interestingly, as clearly indicated by the significant interaction fatigue × AFO (Fig. 2A), this stabilizing effect was more accentuated in the fatigue than non-fatigue condition, hence confirming our third hypothesis. In other words, along the ML axis, the application of AFO allowed the subjects to suppress the postural perturbation induced by the localized fatigue of the ankle muscles. As stated above, these results could stem from 1) the mechanical and neuromuscular features induced by the application of AFO [4,5,19], and 2) the physical characteristics of the Ligacast AFO model adding structural support mainly to the medial and lateral sides of the ankle-foot complex (Fig. 1) [21].

Postural control is known to require the interaction of multiple sensory inputs from either the same or different sensory systems [17]. When a sense is missing or altered, cooperation and the gathering of sensory information to regulate posture may be reweighted. Interestingly, these adaptive capabilities of the postural control system have recently been highlighted during bipedal quiet standing following ankle muscle fatigue, known to impair ankle neuromuscular function [8,23]. As mentioned above, it was observed that, to some extent, vision [16,26] and a light finger touch [29] could compensate for a muscular fatigue applied to calf muscles, hence reflecting a reweighting of sensory cues in balance control following ankle muscle fatigue by increasing the reliance on visual information and haptic cues from the finger, respectively. Results of the present experiment also argued in favor of such a sensory reorganization of postural control characterized by reweighting of sensory contributions as a function of the neuromuscular constraints acting on the subject. Indeed, assuming that the application of AFO enhanced afferent input from cutaneous mechanoreceptors in the foot and shank (stimulated by the pressure and traction of the material on the skin) [6], it is possible the reliance on cutaneous sensory cues from the foot and shank, for controlling posture to increase when sensory information of other systems was unavailable and/or unreliable [18]. Along these lines, although the exact mechanism inducing postural stabilization with the application AFO following the fatiguing exercise is rather difficult to answer, proprioception at the ankle joint, altered following the fatigue protocol [8], might have been facilitated through the increased cutaneous feedback at the foot and ankle supplied by the AFO, which in turn leads to an improved postural control. Without direct measures of the ankle proprioceptive function, such a proposal is yet speculative. However, a study investigating whether additional cutaneous sensory input modifies the position sense at the ankle following muscular fatigue may provide more insight on this issue and thus, included in our immediate plans.
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References