Gait & Posture 39 (2014) 894–898

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Full length article

Expecting ankle tilts and wearing an ankle brace influence joint control in an imitated ankle sprain mechanism during walking

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ARTICLE INFO

Article history:
Received 28 July 2013
Received in revised form 19 November 2013
Accepted 27 November 2013

Keywords:
Ankle sprain
Injury
Kinematics
Electromyography
m. peroneus longus

ABSTRACT

A thorough understanding of the functional aspects of ankle joint control is essential to developing effective injury prevention. It is of special interest to understand how neuromuscular control mechanisms and mechanical constraints stabilize the ankle joint. Therefore, the aim of the present study was to determine how expecting ankle tilts and the application of an ankle brace influence ankle joint control when imitating the ankle sprain mechanism during walking.

Ankle kinematics and muscle activity were assessed in 17 healthy men. During gait rapid perturbations were applied using a trapdoor (tilting with 24° inversion and 15° plantarflexion). The subjects either knew that a perturbation would definitely occur (expected tilts) or there was only the possibility that a perturbation would occur (potential tilts). Both conditions were conducted with and without a semi-rigid ankle brace.

Expecting perturbations led to an increased ankle eversion at foot contact, which was mediated by an altered muscle preactivation pattern. Moreover, the maximal inversion angle (−7%) and velocity (−4%), as well as the reactive muscle response were significantly reduced when the perturbation was expected. While wearing an ankle brace did not influence muscle preactivation nor the ankle kinematics before ground contact, it significantly reduced the maximal ankle inversion angle (−14%) and velocity (−11%) as well as reactive neuromuscular responses.

The present findings reveal that expecting ankle inversion modifies neuromuscular joint control prior to landing. Although such motor control strategies are weaker in their magnitude compared with braces, they seem to assist ankle joint stabilization in a close-to-injury situation.

1. Introduction

Intensive research has been conducted to understand the occurrences and etiological constraints related to the incidence of initial ankle sprain, recurrent ankle sprains, or even chronic ankle instability [1]. There is evidence showing that ankle sprains are associated with an excessive ankle inversion combined with an extreme internal rotation of the ankle, with or without plantar-flexion [2,3]. Under distinct conditions, the joint loading may exceed the limits for joint control, which can lead to excessive stress of the lateral ligament complex [4]. It is conclusive that restricting such extreme angular displacements–for instance, by external mechanical supports like orthotics–may be beneficial in the reduction of lateral ankle sprains. In contrast, preventive exercise programs mainly address the active, neuromuscular component of ankle joint stabilization [5]. While these programs are shown to be effective in reducing ankle sprains by approximately 50% [5], the underlying mechanisms are still under discussion. Specifically, the observation that balance training was effective in reduction of ankle sprains led to the conclusion that an enhanced proprioception and reflex involvement may contribute to dynamic ankle joint control [6].

Hence, research has extensively focused on the evaluation of neuromuscular responses by means of simulating ankle inversion with trapdoors under sitting or standing conditions [7–9]. While useful fundamental knowledge was gained about the relevance of reflexes in counteracting excessive inversion, these experiments did not consider important motor control properties like pre-activation of muscles or whole-body coordination [10]. Only recently has research concentrated on simulated ankle inversion under functional conditions like walking or landing to mimic the actual injury mechanism in a more 'realistic' way [11–13].

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0966-6362/$ – see front matter
http://dx.doi.org/10.1016/j.gaitpost.2013.11.016

It is a main feature of human movement control to precisely expect the upcoming loading situation in functional movements like walking or landing. In order to evaluate how expecting the environmental situation can influence ankle joint control, three studies used the following paradigm: the subjects either knew that the trapdoor would definitely tilt and an ankle inversion would be induced (expected/anticipated tilts) or there was only the possibility that the trapdoor would tilt (potential/unanticipated tilts) [11–13]. Under the latter condition, i.e., when the subjects did not know whether the platform would tilt, the activity of the m. tibialis anterior was reduced or the activity of the m. soleus was increased prior to ground contact [11,12]. These authors concluded that these strategies might correspond to a more pronounced plantarflexion at touchdown, which "could be part of a more cautious gait, whereby the whole foot is put on the box instead of just the heel in an attempt to get more stability" [11]. Unfortunately, these studies focused only on the analysis of neuromuscular characteristics and did not incorporate a detailed assessment of joint kinematics. In a more recent study, the effect of anticipation on ankle joint kinematics during drop landings was evaluated, and it was observed that inversion angles and velocities were increased under unanticipated situations [13]. However, the induced ankle inversion was only marginal (up to 3° and 47°/s on average) and is, therefore, not close to the actual injury mechanism.

The purpose of the present study was to evaluate how expecting the environmental conditions influences neuromuscular and biomechanical characteristics of ankle joint control. We aimed to combine kinematic and electromyographic (EMG) measurements to gain a detailed understanding of the complex interaction of neuromuscular activation strategies and ankle joint excursions during an induced ankle inversion in the walking subject. We hypothesized marked differences in neuronal and in biomechanical characteristics between situations, when subjects knew that an ankle inversion would occur or when this was just a possibility. To assess the effectiveness of these neuromuscular control strategies in stabilizing the ankle joint, we compared them with the ankle-stabilizing effect of an externally applied ankle brace.

2. Methods

2.1. Subjects

A group of 17 physically active men with functional and mechanically stable ankles participated in this study. To assure that all subjects were free of functional limitations, they were required to score 100% in the German version of the foot and ankle ability measure questionnaire (FAAM-G) [14]. Mechanical stability of the ankle joint complex was assessed by manual examination by an experienced physician. Volunteers had no history or symptoms of neurological disorders, no acute lower extremity injury, and no previous foot or ankle surgery. On average, the tested subjects weighed 77.8 ± 7.9 kg at a body height of 181.3 ± 6.5 cm, and were 24.8 ± 2.6 years old. The study was approved by the Ethics Committee of the University of Freiburg and written informed consent was obtained from all subjects prior to participation.

2.2. Experimental setup

Subjects walked barefoot at a predefined pace (6 km/h) along a walkway with an integrated custom built tilting platform [15]. The platform was located above a force plate (OR6-7-2000, Advanced Mechanical Technology Inc., Watertown, USA), which served as a trigger for the release of the tilt platform, inducing a deflection of 24° inversion and 15° plantarflexion (Fig. 1). The instant of tilting the platform was initiated 70 ms after heel contact, ensuring that the ankle was partially loaded. As the entire tilt deflection took 82 ± 11 ms, the corresponding mean velocities of the entire tilt process reached 293°/s in a lateral direction and 183°/s in an anterior direction. Depending on the dominant (tested) leg, defined by the sensation of the subject, the tilt platform was embedded into the right or left side of the walkway. Walking trials were performed either with or without the preset information whether the platform would tilt or not (expected tilts vs. potential tilts). In the potential tilt condition, a platform tilt was randomly initiated in 50% of the walking trials. Both conditions were performed with and without a commercially available semi-rigid ankle brace (Malleoloc®, Bauerfeind AG, Zeulenroda, Germany) in order to further evaluate the functional properties of an ankle brace. A total of 15 tilting trials per experimental condition were registered.

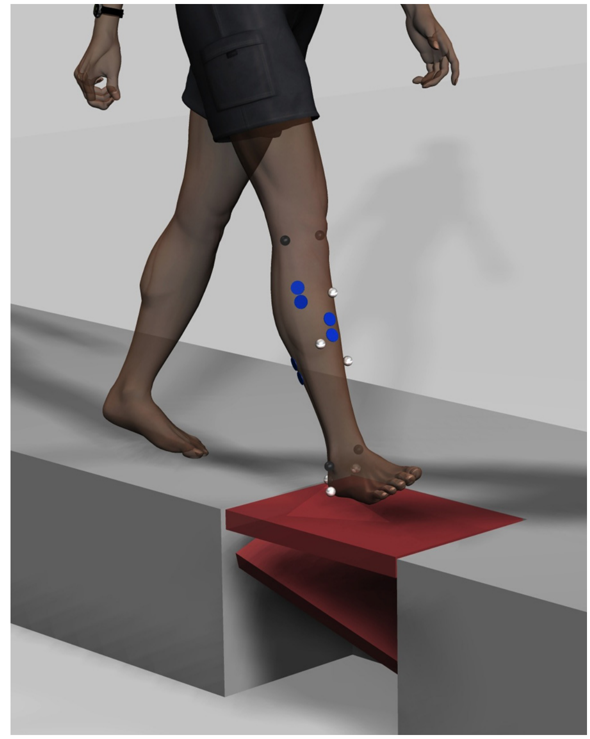

Fig. 1. Illustration of the experimental setup including the trapdoor (in the start and the end position), the reflective markers for kinematic assessment used in the dynamic trials (white spheres) as well as the additional markers in the static trial (grey spheres) and the bipolar electrode placement for EMG measurements (blue discs). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

2.3. Data acquisition and analysis

The EMG signals of the m. tibialis anterior (TA), the m. peroneus longus (PL), and the m. soleus (SOL) were recorded using wireless surface electromyography at 2000 Hz (myon RFTD-E08, myon AG, Baar, Switzerland). Before applying the bipolar surface electrodes (Blue Sensor, Ambu, Ballerup, Denmark) with an inter-electrode distance of 2 cm, the skin was prepared to assure inter-electrode impedance of less than 5 kΩ.

The raw EMG was filtered (10–750 Hz, Butterworth 4th order), rectified, and integrated over the following time intervals: during the preactivation phase 100 ms prior to heel strike (EMG_{Pre}), during the preparatory phase from heel strike until the beginning of the tilting of the platform (EMG_{Prep}), during the tilting of the platform (EMG_{Tilt}), and during the 100 ms after the tilting of the platform ($EMG_{afterTilt}$). The potential tilt condition without a brace individually served as the normalization reference (= 100%).