Available online at www.sciencedirect.com
SCIENCE @ DIRECT®
ELSEVIER
Brain Research 1062 (2005) 48 – 62
BRAIN RESEARCH
www.elsevier.com/locate/brainres

Research Report

Postural uncertainty leads to dynamic control of cutaneous reflexes from the foot during human walking

Carlos Haridas[a], E. Paul Zehr[b,c], John E. Misiaszek[a,d,*]

[a]*Centre for Neuroscience, University of Alberta, Edmonton, AB, Canada*
[b]*Rehabilitation Neuroscience Laboratory, University of Victoria, Victoria, BC, Canada*
[c]*International Collaboration on Repair Discoveries (ICORD), Vancouver, BC, Canada*
[d]*Department of Occupational Therapy, Sensory-Motor Research Laboratory, 2-64 Corbett Hall, University of Alberta, Edmonton, AB, Canada T6G 2G4*

Accepted 24 September 2005
Available online 24 October 2005

Abstract

Cutaneous reflexes evoked by stimulation of nerves innervating the foot are modulated in a phase-dependent manner during locomotion. The pattern of modulation of these reflexes has been suggested to indicate a functional role of cutaneous reflexes in assisting to maintain stability during walking. We hypothesized that if cutaneous reflexes assist in maintaining stability during gait, then these reflexes should be modulated in a context-dependent manner when subjects are asked to walk in an environment in which stability is challenged. To do this, we asked subjects to walk on a treadmill under five conditions: (1) normally, (2) with the arms crossed, (3) while receiving unpredictable anterior–posterior (AP) perturbations, (4) with the arms crossed while receiving unpredictable AP perturbations, and (5) with the hands holding onto fixed handles. Cutaneous reflexes arising from electrical stimulation of the superficial peroneal (SP; relevant to stumbling) or distal tibial (TIB; relevant to ground contact sensation) nerves were recorded bilaterally, at four points in the step cycle. Reflexes evoked with SP nerve stimulation showed marked facilitation during the most unstable walking condition in 4 of the 7 muscles tested. SP nerve-evoked reflexes in the muscles of the contralateral leg also showed suppression during the most stable walking condition. Reflexes evoked with TIB nerve stimulation were less affected by changes in the walking task. We argue that the specific adaptation of cutaneous reflexes observed with SP nerve stimulation supports the hypothesis that cutaneous reflexes from the foot contribute to the maintenance of stability during walking.

Theme: Motor systems and sensorimotor integration
Topic: Reflex function

Keywords: Postural threat; Superficial peroneal nerve; Distal tibial nerve; Locomotion

1. Introduction

Cutaneous reflexes have been shown to exhibit both task-dependent and phase-dependent modulation (for review, see Ref. [25]). For instance, electrical stimulation of cutaneous nerves in the foot has been shown to evoke reflexes in the muscles of the leg that differed according to the task performed [14]. The authors showed that during standing, the net reflexes evoked were largely inhibitory, whereas during walking, facilitatory net reflexes were observed. Additionally, cutaneous reflexes in the muscles of the legs have been shown to change both in sign and amplitude during walking according to the position of the stimulated leg within the step cycle [9,22,26,27]. It has therefore been suggested that these reflexes act in a functional manner by helping to maintain balance while encountering a perturbation during walking [22,25].

Electrical stimulation of the cutaneous superficial peroneal nerve (innervates the dorsum of the foot) has been shown to elicit a “stumbling corrective response” in the leg

* Corresponding author. Centre for Neuroscience, University of Alberta, Edmonton, AB, Canada. Fax: +1 780 492 4628.
E-mail address: john.misiaszek@ualberta.ca (J.E. Misiaszek).

0006-8993/$ - see front matter
doi:10.1016/j.brainres.2005.09.003

during treadmill walking in cats [11] and in humans [27]. In the human, this stumbling corrective response consists of an increase in knee flexion and a decrease in ankle dorsiflexion during swing. This response would allow for the smooth forward progression of locomotion by allowing the swing leg to drag over an obstacle. In addition, the effects of distal tibial nerve (innervates the plantar surface of the heel) stimulation during walking have been investigated [22, 23,27]. These studies have also suggested that cutaneous reflexes serve to assist balance during walking. Zehr et al. [27] showed that the effects of cutaneous reflexes from the tibial nerve were predominant during late stance and late swing. The responses evoked by tibial nerve stimulation were suggested to be relevant to sensation of ground contact information and also have a functional role in stabilizing balance during walking.

Accordingly, if cutaneous reflexes do serve a role in the maintenance of balance during locomotion, one would expect that they would be modulated during locomotion in an environment in which balance is challenged (e.g., walking on an unstable surface). To date, there are no studies that have specifically investigated cutaneous reflexes during locomotion in such an environment. Burke et al. [6] demonstrated that cutaneous reflexes evoked in leg muscles were more prominent when standing in unstable conditions. Llewellyn et al. [15] compared the soleus H-reflex during walking on a treadmill and balance beam. The authors found that the amplitude of the H-reflex decreased on average 40% during balance beam walking. This finding supports the idea that a change in environment (with regard to balance) contributes to reflex regulation. Similarly, the amplitude of cutaneous reflexes would be expected to be modified during locomotion in an unstable environment. This type of environment would be defined as one in which balance is threatened in a predictable or unpredictable manner.

Recently, we have developed a method to disturb balance during treadmill walking [16]. This method involves applying random forward and backward pulls on a padded belt secured around the hips of a subject. The force of the pulls is strong enough to cause instability, but not enough to result in a fall. Furthermore, having the arms crossed during walking produces a more demanding task in which balance is challenged. Crossing the arms in such a fashion restricts the use of the arms for balance recovery. We have shown that restricting the use of the arms in this way increases the amplitude of compensatory reactions in muscles of the leg during walking [17]. The implication is that restricting the use of the arms results in a shift in postural set, by placing a greater emphasis on reactions in the legs. Indeed, it has previously been shown postural control is scaled to the level of postural threat in both quiet standing [1,7] and walking [5].

In this study, we tested the hypothesis that the amplitude of cutaneous reflexes is altered when walking in an unstable environment. We speculated that any effect on reflex control should be largest for effects related to the greatest instability (e.g., stumbling and falling). Thus, we further hypothesized that any effect related to perceived stability should be larger for SP than for TIB nerve. Instability was created by delivering unexpected forward and backward perturbations, as well as having the arms crossed while walking on a motorized treadmill. Portions of these results have been reported in abstract form [13].

2. Materials and methods

2.1. Subjects and protocol

Eleven subjects between the ages of 20 and 35, with no history of neurologic, orthopedic or metabolic impairment participated with informed, written consent in a protocol approved by the Human Research Ethics Board (Health Research) at the University of Alberta. In this study, we examined cutaneous reflexes evoked with electrical stimulation of two nerves, the superficial peroneal (SP) and distal tibial (TIB) nerves. Subjects visited the lab on two different occasions, once for each nerve stimulation protocol. All eleven subjects participated in the SP nerve stimulation protocol, and ten also participated in the TIB nerve stimulation protocol. The order of presentation of nerve stimulation was randomized across subjects.

Subjects were asked to walk on a motorized treadmill at a self-selected speed (typically between 0.8 and 1.2 m/s). Cutaneous reflexes were elicited during 5 walking conditions: (1) normally, with the arms free (Normal); (2) with the arms crossed across the chest (Arms Crossed); (3) with the arms free, but while receiving unpredictable anterior–posterior perturbations applied at the waist (AP); (4) with the arms crossed and receiving unpredictable anterior–posterior perturbations (Arms Crossed + AP); (5) while holding onto stable fixed handles (Handles). The order of presentation of the walking conditions was randomized across subjects. The purpose of the anterior–posterior perturbations during walking was to create an environment in which stability was unpredictable. Therefore, cutaneous reflexes were not elicited during such perturbations, but rather during periods of steady walking between the perturbations. Subjects were instructed that they were free to grab for safety rails located in front and to the sides (~45 cm from lateral edge of the arms, ~75 cm in front of the subject) if they felt the need to do so to prevent falling. The purpose for having the arms crossed was to produce instability during walking, by constraining the arms from assisting in balance recovery. In contrast, we asked the subjects to hold onto fixed handles during walking in order to create a task with increased stability. In previous studies, we have shown that holding onto handles in this way eliminates compensatory reactions evoked in the leg muscles by a perturbation [17,18]. Subjects were informed before performing each walking condition as to whether perturbations would be elicited.