Human Movement Science 54 (2017) 240–247

Contents lists available at ScienceDirect

Human Movement Science

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

Full Length Article

The effects of foot cooling on postural muscle responses to an unexpected loss of balance

Oran W. Ferguson, Nadia Polskaia, Craig D. Tokuno*

Department of Kinesiology, Brock University, 1812 Sir Isaac Brock Way, St. Catharines, ON L2S 3A1, Canada

ARTICLE INFO

Keywords:
Foot sole sensitivity
Somatosensation
Electromyography
Balance control

ABSTRACT

The purpose of this study was to examine the role of foot sole somatosensory information during reactive postural control. Twenty young adults (22.0 ± 1.4 y) participated in this study. Baseline skin sensitivity from the foot sole was assessed using Semmes-Weinstein monofilaments. Postural muscle responses, in the form of electromyographic (EMG) onset latencies and amplitudes, were then obtained while participants recovered their balance while standing on a moveable platform that could translate in either the forward or backward direction. Following these baseline measures, the participant's foot soles were immersed in a 0–2 °C ice-water bath for 12 min followed by a 3 min re-immersion period. At the completion of foot cooling, foot sole sensitivity and postural muscle responses to the balance perturbations were re-assessed. Results indicated that the foot cooling protocol reduced foot sole sensitivity and remained reduced throughout the duration of the experiment ($p < 0.001$). The reduction in foot sole somatosensation resulted in the soleus EMG onset latency being delayed by 3 ms ($p = 0.041$) and the soleus and medial gastrocnemius EMG amplitudes increasing by 14–23% ($p = 0.002–0.036$) during the balance perturbation trials. While the magnitude of these results may suggest that foot cooling has a minor functional consequence on reactive postural control, it is likely that the results also reflect the ability of the central nervous system to rapidly adapt to situations with altered somatosensory feedback.

1. Introduction

Somatosensory and proprioceptive information are critical for maintaining an upright stance. For example, muscle spindles and joint receptors provide information about the length and position of muscles and joints, respectively, (Fitzpatrick & McCloskey, 1994), while cutaneous mechanoreceptors relay information regarding pressures against the foot sole (Kavounoudias, Roll, & Roll, 1998). These sensory inputs, as well those from the vestibular and visual systems, are integrated and processed within the central nervous system to ensure that the resulting motor output maintains the center of mass (COM) within the base of support (BOS).

Studies have attempted to isolate the importance of each sensory system through various means. For example, studies have applied different foot cooling protocols to decrease foot mechanoreceptor firing rates and reduce somatosensory information from the foot sole in order to establish its contribution to postural control. Results from these studies are conflicting, with some studies reporting a transient increase (i.e., effect only in the first trial) in the antero-posterior (A-P) root mean square center of pressure (COP) velocity (Billot, Handrigan, Simoneau, Corbeil, & Teasdale, 2013), a smaller COP excursion area (McKeon & Hertel, 2007a), or an increased time to boundary minima (McKeon & Hertel, 2007b) during quiet standing when the feet are cooled. This contrasts other

---

* Corresponding author.
E-mail address: ctokuno@brocku.ca (C.D. Tokuno).

http://dx.doi.org/10.1016/j.humov.2017.05.008
Received 30 November 2016; Received in revised form 2 April 2017; Accepted 14 May 2017

studies that have shown no changes in COP velocity, range, or sway area with foot cooling (Billot, Handrigan, Simoneau, & Teasdale, 2015; D'Hondt et al., 2011). Similar inconsistencies are observed when considering lower limb electromyographic (EMG) activity during quiet standing, with some reporting an increase (Billot et al., 2013), while others have observed no change in background EMG activity (Muise, Lam, & Bent, 2012). This has resulted in a recent systematic review suggesting that foot cooling does not significantly impact measures of standing balance in healthy young adults (Hoch & Russell, 2016).

However, it is possible that the effects of foot cooling on postural control are complex and are influenced by several factors. For example, it is possible that the lack of postural changes with foot cooling may be due to the minimal requirements of quiet standing, where the loss of foot sole sensitivity can be compensated by prioritizing the remaining sources of sensory information (e.g., inputs from the vestibular system or the muscle spindles). To determine whether foot somatosensory information becomes more important as the postural task becomes more difficult, previous studies have investigated how foot cooling affects dynamic postural control. During reactive postural tasks, where an unexpected loss of balance is experienced, it has been found that individuals rely more heavily on multiple rather than single steps for balance recovery when less foot somatosensory information is available (Perry, McIlroy, & Maki, 2000). Similarly, when foot sensitivity is reduced through the application of a local anesthetic, there is a shift in compensatory torque production from the ankle to the hip joints in order to recover balance from a medio-lateral perturbation (Meyer, Oddsson, & De Luca, 2004). While it appears that there are distinct adaptations in postural strategies when somatosensory information from the foot is reduced, few have investigated whether the underlying postural muscle responses that may be responsible for these kinematic and kinetic adaptations are altered. This is important because foot sole somatosensation has been associated with the triggering and scaling of postural muscle responses during fall recovery (Inglis, Horak, Shupert, & Jones-Rycewicz, 1994; Kavounoudias et al., 1998).

The purpose of this study was to examine the effects of foot cooling on the response of lower limb postural muscles following an unexpected loss of balance. Based on findings of impaired postural reflexes in individuals with poor somatosensory feedback (e.g., diabetic neuropathy patients) (Inglis et al., 1994), it was hypothesized that reduced foot sole somatosensation due to foot cooling would result in delayed and reduced muscle responses following an unexpected balance perturbation.

2. Methods

2.1. Participants

Twenty healthy young adults (14 males, 6 females) with a mean ± one standard deviation (SD) age of 22.0 ± 1.4 y, height of 1.72 ± 0.09 m and mass of 68.8 ± 5.3 kg participated in this study. None of the participants reported any history of recent injury as well as any neuromuscular, vestibular, or cardiovascular impairments that could affect their balance. All participants provided informed consent prior to participating in the study and the experimental protocol was approved by the university research ethics board.

2.2. Participant set-up

The skin over the right and left tibialis anterior (TA), medial gastrocnemius (MG), soleus (SOL), and the left tibial tubercle was shaved using a disposable razor and cleaned with rubbing alcohol and abrasive gel. Pairs of surface electrodes (10 mm diameter, 2 cm inter-electrode distance, Kendall™, Mansfield, MA, USA) were placed over each of the six muscle sites, with a single ground reference electrode on the left tibial tubercle. The decision to solely record EMG activity from muscles surrounding the ankle joint was based on the assumption that an ankle strategy, characterized by a distal to proximal muscle recruitment order, would be most commonly observed in response to the chosen balance perturbation parameters (Tokuno, Cresswell, Thorstensson, & Carpenter, 2010).

2.3. Experimental protocol

Once the electrodes were in place, participants performed the following series of tests (Table 1). First, cutaneous sensitivity of the right foot sole was assessed using a set of Semmes-Weinstein monofilaments (Baseline Tactile Semmes-Weinstein Monofilament Sensory Evaluator Set, Fabrication Enterprises Inc., White Plains, NY, USA). Participants lay supine on a table with their eyes closed and with their feet over the edge of the table. Beginning with the thinnest monofilament, the monofilaments were applied

Table 1
General time course of the experimental protocol.

Time	Task(s)
0–5 min	Foot sole sensitivity test (pre-cooling)
5–20 min	Pre-cooling trials: quiet standing (2 trials); balance perturbation (20 trials)
20–32 min	Ice-water immersion (12 min duration)
32–37 min	Foot sole sensitivity test (post-cooling #1)
37–40 min	Ice-water immersion (3 min duration)
40–50 min	Post-cooling trials: quiet standing (2 trials); balance perturbation (8 trials)
50–55 min	Foot sole sensitivity test (post-cooling #2)