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Short term alteration of balance control after a reduction of plantar mechanoreceptor sensation through cooling

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HIGHLIGHTS

- ► Cooling alters plantar sensitivity.
- ► Plantar sole sensitivity reduction has a short term effect on standing balance control.
- ► Balance control alteration is compensated with increased calf muscle activity.
- ► Plantar sole mechanoreceptors contribute to standing balance control.

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ABSTRACT

Proprioceptive inputs from the plantar sole contribute to balance control during normal quiet standing. This study investigated the cooling of plantar sole mechanoreceptors through ice immersion and its effects on balance control and lower leg muscle activity. Ten healthy males participated in this study. Plantar sole sensitivity was tested using the two point discriminatory test and the Von Frey monofilaments test. Plantar sole cooling was achieved through foot immersion in ice water. Balance control was measured using a force platform with seven trials (30 s) performed before and after ice water foot immersion. Lower limb balance control muscle activity was measured with electromyography. Ice cooling reduced the plantar sole sensitivity of the foot. A short term alteration in balance control was observed with only the first trial showing significantly greater speed and RMS of the velocity of the centre of pressure in the cooling condition when compared to control trials before cooling. Muscular activity increased following the first trial. The adaptation observed after the short term alteration of balance control, could result from sensory reweighting processes. It is suggested that the muscular activity increase is evidence of sensory reweighting and contributes to the regulation of balance control when the plantar sole sensation is partially inhibited.

1. Introduction

It is generally accepted that human balance control involves complementary input from the visual [19], vestibular [1,7], proprioceptive [24], and somatosensory systems [16]. The significance of the contributions from the sensory systems depends on the population (e.g., elderly, diabetic), environmental constraints (e.g., slippery surfaces, low lighting) and task being performed (i.e., bipedal vs. unipedal). Importantly, Kavounoudias et al. [9] demonstrated that cutaneous afferents contribute to the sensory information required for human balance control. These authors suggested that the relaying of the cutaneous information from the plantar mechanoreceptors to the central nervous system contributes to body position awareness. Altering the sensations in the plantar sole of the foot could be one way to observe the contributions towards balance control.

A reduction of plantar sensation can be induced by cooling [2,3,14,17,18,20,22]. This can lead to various modifications in balance control. For instance, McKeon and Hertel [13] observed

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in eyes closed condition, a reduction of the centre of pressure (CoP) excursions area while the CoP speed (mean of three 10 s-trial) was not altered after the feet were submersed in an ice bath for 10 min. Conversely, an increased speed of the CoP in the anterior–posterior plane was observed after cooling of the feet for 20 min [12]. However, there appears to be no consensus in the literature regarding the effect of reducing the plantar mechanoreceptor sole sensitivity on balance control. In a recent review, Kars et al. [8] raised this issue and clearly mentioned that the effect of plantar sensation reduction on balance control is unclear and still controversially discussed. This disputed point could be explained by a sensory reweighting following the cooling procedure.

Therefore, the objective of this study is to investigate whether there is a time course alteration when cooling the plantar sole mechanoreceptors to measure their contributions to balance control. If so, this may explain the lack of agreement between studies. In the current study, the plantar mechanoreceptors were cooled, and balance control changes were examined from the CoP displacements (speed, root-mean-square of the velocity (RMSv) and range) and the electromyographic (EMG) activity of lower leg postural muscles using a trial by trial analysis. It is hypothesized that a reduction of plantar sole mechanoreceptor sensitivity will impair balance control and increase lower limb muscular activities. Furthermore, across trials, balance control should improve due to sensory reweighting.

2. Methods

Ten healthy young male adults (age: 24.6 ± 3.6 years, height: 176.9 ± 5.2 cm, weight: 76.5 ± 5.7 kg) participated in this investigation. Participants reported no neurological or orthopaedic disorders, no lower extremity injury or surgery, were not medicated, and had normal vision during testing. Prior to commencing, participants were briefed and provided a written informed consent. This experiment was approved by the institutional ethics review board and in accordance with the Declaration of Helsinki.

Per subject, all measurements were in one experimental session. For each trial, subjects were instructed to stand as still as possible (bipedal-barefoot stance with eyes open) on a force platform while visually fixating a target located 4 m in front of them. Feet were oriented at a 15° angle (foot position was marked) from the sagittal midline with their heels 10 cm apart and arms positioned freely along the sides of the body. The participants performed two blocks of seven 30 s trials. The first block of 7 trials was a control condition. The second block of 7 trials was performed after a cooling procedure.

Pre-cooling procedure. Baseline skin temperature and sensitivity measurements were taken. Two measures were used to quantify the plantar foot sole sensitivity. The first test consisted of a tactile discrimination [20]; a two-point aesthesiometer (Lafayette Instrument Company, model 16011, IN, USA) was used to find the acuity discrimination at the first metatarsus. The two prong tips of the aesthesiometer touched perpendicular to the test site simultaneously and the subject simply stated if a touch was perceived as a single point or two separate points. The experimenter started with 30 mm between the aesthesiometer tips and would vocally verify with the subject if a pressure was felt on the respective test site. This method continued in a progressive manner with 1 mm adjustments of the tips until the subject perceived only one point of application. This was repeated three times.

A Von Frey monofilaments test (Lafayette Instrument Company, model 16013, IN, USA) was also used as a measure of plantar sole sensitivity [11]; the sites of application on the sole were at the first metatarsus, fifth metatarsus and heel. The monofilament was applied perpendicular to the test site with enough pressure to bend the monofilament for one second. The eight filaments that were used exerted 46.8, 19.9, 14.7, 10.2, 5.8, 4.6, 2.4, and 1.7 g, for the largest to the smallest filament, respectively. The subjects were asked if they perceived the pressure or did not. Both tests were carried out while subjects were seated comfortably with eyes closed pre and post cooling procedure. As for the two-point discrimination, three repetitions were realized at each test site.

For the cooling procedure, participants feet were immersed in water maintained between 0 and 2 °C. Water depth was adjusted to obtain total immersion of toes without immersing the ankle joint. Water temperature was maintained by adding ice. Participants' feet were immersed in water for 10 min before post cooling tactile testing. After the tactile testing, a further 2 min foot immersion occurred to maintain foot cooling. After the total 12 min of cooling, the participants moved to the force platform for balance control data collection. After four balance control trials, the participants' feet were re-immersed in the water for 2–3 min in order to avoid a rewarming. Skin temperature was measured on the plantar surface below the 1st metatarsus with a thermistor thermometer (Cole-Parmer model 8402-00, Cole-Parmer Canada Inc.). Measurements were taken before cooling, after 10 min of cooling, after the additional 2 min cooling period and after the first four balance control trials in the cooling condition (Fig. 1). In a previous study, the sole sensitivity measured with the two-point discrimination test did not change from 10 min to 25 min of a cooling period [3].

CoP parameters were evaluated using a force platform (AMTI, model OR6-5-1, Watertown, MA, USA). Force and torque components were amplified (AMTI, model MSA-6) prior to being fed to a computer (12-bit A/D conversion) and the signals were recorded at 200 Hz. Prior to computing the CoP displacement, the moments and force data were digitally filtered (Butterworth fourth-order, 7 Hz low-pass cut-off frequency with dual-pass to remove phase shift). In the cooling condition, CoP parameters (speed, antero-posterior (A/P) and medio-lateral (M/L) range, RMSv A/P and RMSv M/L) were compared on a trial by trial basis with the mean of the seven trials of the control condition. The speed of the CoP corresponds to the cumulative distance over the sampling period. The range of the CoP displacement indicates the average minimal and maximal excursion of the CP from the base of support. RMSv is analogous to the standard deviation of the signal within a trial and is often taken as

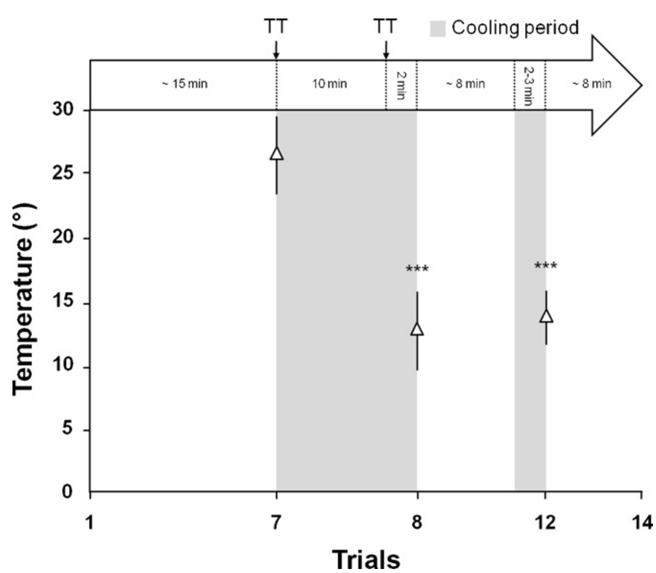

Fig. 1. Time course of temperature after period cooling. Tactile test (TT) were performed pre and post 10 min cooling. Significant difference between temperature at rest and after cooling period, $^{***}p < 0.001$.