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Decreased skin temperature of the foot increases gait variability in healthy young adults

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ABSTRACT

We investigated the effects of reduction in plantar skin temperature on gait. Thirty-four healthy subjects (20 men and 14 women; mean age 22.2 ± 2.5 years; mean height 166.8 ± 8.3 cm) walked 16 m under two different conditions – normal conditions (NC) with the skin at a basal temperature, and cold conditions (CC) after cooling of the plantar skin to about 15 °C. Wireless motion-recording sensor units were placed on the back at the level of L3 and on both heels to measure acceleration and angular velocity. Gait velocity and mean stride, stance and swing times were calculated. The variability of lower limb movement was represented by the coefficients of variation (CVs) of stride, stance and swing times, and that of trunk movement was represented by autocorrelation coefficients (ACs) in three directions (vertical: VT; mediolateral: ML; and anteroposterior: AP). Gait velocity was significantly lower under CC conditions than under NC ($p < 0.0001$). None of the temporal parameters were changed by plantar cooling. However, all parameters of gait variability were significantly worse under CC, and AC-VT, AC-ML, and AC-AP were significantly lower under CC than under NC, even after adjusting for gait velocity (p = 0.0005, 0.0071, and 0.0126, respectively). Our results suggest that reducing plantar skin temperature induces gait variability among healthy young adults. Further studies are now needed to explore the relationship between plantar skin temperature and gait in the elderly.

1. Introduction

Successful locomotion is supported by rhythmic motor behavior that consists of leg movements executed as the primary means of propulsion and trunk movement helping to maintain body equilibrium [1]. Increasing gait variability during walking induces instability and implies reduction in the ability to coordinate movement [2] and thus an increase in fall risk in older adults [3]. Rhythmic movement is thought to be generated by a central pattern generator and is modified by afferent feedback from various sources [4,5]. The gait of people with peripheral sensory loss is characterized by slow walking velocity, reduced step time, and shortened step length [6,7]. During walking, neuropathic patients have smaller amplitude of trunk acceleration than control subjects owing to peripheral sensory loss [6].

The plantar aspect of the foot is the only part of the body that is in direct contact with the external environment. Sensory feedback originating from cutaneous receptors, particularly in the sole, therefore plays a crucial role in walking. The effects of reduced foot sensation on gait have been investigated in not only patients with sensory loss but also healthy adults. Experimental reduction in plantar information (i.e. temporary sensory loss) leads to a decrease in gait velocity [8,9], reduced electromyography activity of the muscles of the lower limbs [10], changes in joint movement, and modification of the pressure distribution pattern in walking [8,10,11]. Although gait is believed to be modified by afferent information, the effects of reduced plantar sensation on gait – including on trunk movement – during walking are still unclear. We hypothesized that cooling of the foot would reduce foot sensation, and that the resulting change in afferent information would affect gait, including trunk movement, in the same way as occurs with sensory loss from disease.

There are various experimental ways of inducing brief sensory loss. They include induction of ischemia [12], application of local anesthesia [9], or induction of hypothermia [8,11]. Hypothermia is one causes of sensory deficit and is achieved by immersing the feet

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in ice-cold water for 15 min [13] or 30 min [8] or until the skin temperature of the plantar surface of the foot drops below 6 °C [14]. However, the conditions achieved by using these methods are fairly unlikely to occur in everyday life: even in winter, foot skin temperature naturally declines to only about 15 °C [15]. Decreasing the skin temperature reduces blood flow. Thus the function of the cutaneous mechanoreceptors declines and afferent nerve conduction velocity is decreased. Moreover, because the plantar aspect of the foot contacts the external environment – especially the floor – almost constantly, it is likely that the supporting surface conducts heat away from the foot at cold times of the year or in cold regions. However, to our knowledge, there have been no studies of the effects of the decreases in plantar skin temperature expected in everyday life on foot sensation and gait; it may therefore be useful to determine whether common decreases in skin temperature reduce plantar sensation and thus affect gait. The aim of this study was to investigate how reducing plantar skin temperature to a level common in cold environments would influence gait. Our hypothesis was that the decreases in plantar skin temperature expected in everyday life induce declines in sensory function and thus increases in gait variability, including in trunk movement.

2. Methods

2.1. Subjects

The study participants were 34 healthy subjects (20 men and 14 women; mean age 22.2 ± 2.5 years; mean height 166.8 ± 8.3 cm). All subjects reported that they were free of neurological dysfunction or disease, and of pain that might have affected their performance in the study. Ethical approval for the study was given by the Ethics Committee of the Kobe University Graduate School of Health Sciences (approval number 113). All subjects were properly informed about the study and signed written consent forms, in accordance with the Declaration of Helsinki, before their participation.

2.2. Gait measurement procedure

Subjects were instructed to walk at preferred speed along a 16-m smooth, horizontal walkway. A 12-m section of the walkway was marked off by two lines, one positioned 2 m from each end, to allow space and time for acceleration and deceleration. Walking time over the middle 10 m was measured with a stopwatch (a reliable method for measuring time [16,17]), and gait velocity was expressed in meters per second. Trunk and lower limb movement during gait was measured by using three wireless motion-recording sensor units (MVP-RF8; 45-mm width, 45-mm depth, 18-mm height; weight, 60 g; MicroStone Co., Ltd., Nagano, Japan; Fig. 1), one fixed to a belt at the level of the L3 spinous process and the others attached to the posterior surface of each heel with surgical tape. Acceleration and angular velocity could thus be measured without restricting the subject's movement. All signals were sampled at 200 Hz and synchronously wirelessly transferred to a personal computer via a bluetooth personal area network.

2.3. Experimental reduction of plantar skin temperature

Plantar skin temperature was monitored with a digital thermometer (PT-201, Unique Medical Co., Tokyo, Japan) that had a temperature resolution of 0.1 °C and was equipped with a wired thermosensor (PTP-50, Unique Medical Co., Tokyo, Japan). Before data collection the subjects were given a 20-min equilibration period to adjust to the room and floor temperatures (26.9 ± 1.4 °C and 28.3 ± 1.9 °C, respectively). Plantar skin temperature was measured at three anatomical locations (heel, first

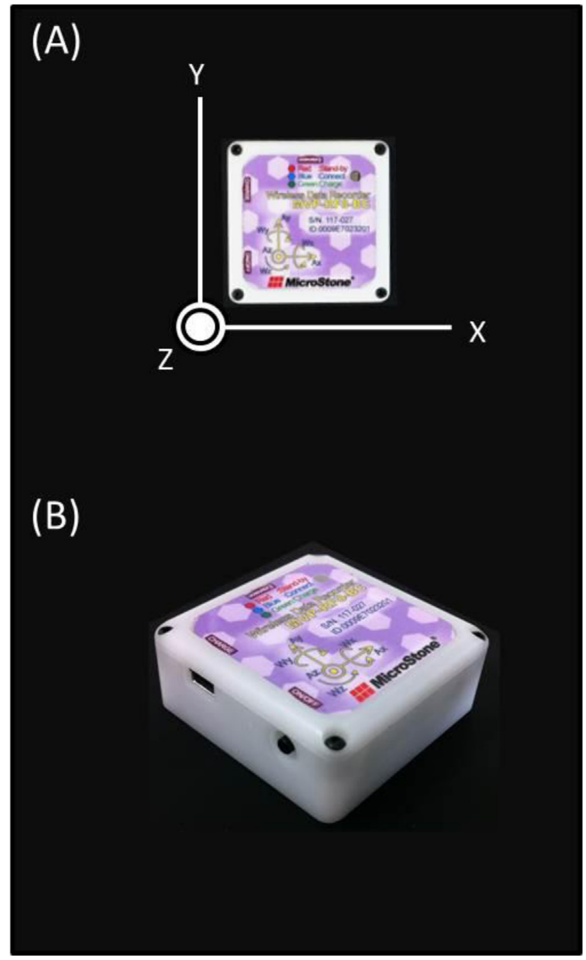

Fig. 1. Wireless motion-recording sensor (MVP-RF8; 45-mm width, 45-mm depth, 18-mm height; weight, 60 g).

metatarsal head [1st MTH], and hallux) on the plantar aspect of the foot to determine the baseline plantar skin temperature. The conditions after the subject's plantar skin had adjusted to the floor temperature after removing their shoes were defined as normal conditions (NC). To alter plantar skin temperature, the subject's feet were placed on a block of ice with a plate-like surface. The temperature at each anatomical location on the foot was checked every 3 min to ensure that the skin was cooling. When the temperature at each anatomical location on the foot was below 15 °C, the conditions were defined as cold conditions (CC).

2.4. Plantar sensation testing

Before and after the cooling procedure, the plantar cutaneous sensation threshold was determined by using Semmes–Weinstein monofilaments (North Coast Medical Inc., San Jose, CA, USA). Each filament had a specified diameter and a known buckling force. Each test began with the 2.83 filament to evaluate the plantar cutaneous sensation thresholds at the three anatomical locations on the plantar aspect of the foot (i.e. the heel, 1st MTH, and hallux). Each monofilament was applied for 1 s perpendicular to the skin of the foot being tested [18]. Before the test, the testing procedure was explained to the subjects and they were instructed to respond verbally when they felt the stimulus; they were also familiarized with the sensation produced by being touched with the monofilament. Testing at each anatomical location was repeated with monofilaments of increasing diameter until the subject responded to the stimulus.