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Research article

Cutaneous afferent feedback from the posterior ankle contributes to proprioception

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HIGHLIGHTS

- We assessed ankle proprioception using a passive joint matching task.
- Cutaneous feedback from the posterior ankle was experimentally reduced.
- Reducing skin feedback increased matching error and variability.
- Findings indicate posterior ankle skin contributes to passive joint position sense.

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ABSTRACT

Cutaneous mechanoreceptors in skin surrounding joints can respond to the skin strain generated by movement, and thus provide proprioceptive cues. The objective of this experiment was to determine the contribution of skin feedback from the posterior ankle to position sense during passive movements. In 28 healthy adults (12 male), a topical anesthetized (n = 14) or placebo cream (n = 14) was applied to an area of skin on the posterior ankle that undergoes stretch and compression during ankle dorsi- and plantar-flexion. Position sense was assessed before and after anesthetization using a passive joint matching task (target angles: 6°, 12°, and 18° dorsiflexion and plantar flexion). Results showed that reducing skin feedback caused the perception that the ankles were aligned when the anesthetized ankle was relatively more dorsiflexed, suggesting that posterior ankle skin primarily signals the magnitude of skin stretch. Larger movement into dorsiflexion was likely necessary to provide enough stretch of muscle and surrounding intact skin to compensate for reduced signals from the anesthetized skin region. Reducing skin feedback also increased matching variability during larger movements. These findings suggest that skin feedback from the posterior ankle has a significant contribution to position sense during passive movement. Therefore, the sensitivity of skin surrounding the ankle could be important to consider in populations with reduced peripheral skin sensitivity as a result of ageing or neurological disorders.

1. Introduction

Tactile information is provided by four classes of cutaneous afferents that signal events at the skin, such as pressure, slippage, and contact and release. Fast adapting type I and II afferents are primarily known to signal contact and release, whereas slowly adapting type I and II afferents are primarily known to signal information about direct pressure and skin stretch. In addition to providing tactile information, evidence suggests that cutaneous afferents can respond to skin deformation to provide proprioceptive cues (i.e., information about the position and movement of neighbouring body segments) [1–4]. Single afferent nerve recordings in humans have shown that both slow and fast adapting cutaneous afferents respond rapidly and robustly to skin strain at the dorsal skin of the hand [2,5] and foot sole [6]. Furthermore, stretch imposed on the dorsal skin of the hand has been shown to evoke illusory movement [7], which indicates that this information is used when consciously evaluating joint position. Evidence also suggests that skin information can contribute to proprioception at larger joints; afferents innervating skin on the anterior and lateral thigh have been found to respond to movement at the knee joint

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[4]. Additionally, stretch applied to skin surrounding the elbow and knee has been shown to evoke illusory joint movement [8]. Furthermore, Collins et al. [8] showed that when muscle spindle stimulation was paired with skin stretch, the magnitude of the perceived movement illusions increased, indicating that combined sensory input from muscle and skin are interpreted for position sense at the elbow and knee joints [8].

Relative to the hand, less is known about the sensory sources that precisely code movements at the ankle joint – a critical joint for the control of standing balance and gait. There is strong evidence to support that muscle spindle feedback from the anterior and lateral compartments of the shin has a prominent role in signaling plantar flexion and eversion [9,10]. Cutaneous afferents from the anterior shin have been shown to provide similar population coding with respect to spindles within the underlying muscles [11]. Furthermore, interfering with cutaneous feedback from the anterior shin and foot dorsum using a topical anesthetic or vibrotactile stimulation has been shown to impair joint position sense [12,13]. Overall, it is clear that an ensemble of skin and muscle feedback from the anterior shin provides proprioceptive information primarily through coding muscle and skin stretch. To date, little is known about the movement coding properties of cutaneous afferents innervating skin on the posterior ankle, an area of skin that undergoes substantial stretch and compression during ankle rotation in every day tasks. A decline in skin sensitivity around the ankle joint as a result of ageing [14–16] or neurological disorders [17,18] might be important to consider clinically, as loss of proprioceptive feedback from skin could contribute to poor postural control and falls. The purpose of this experiment was to determine whether reducing feedback from a portion of skin on the posterior ankle in healthy young adults could impair passive joint position sense. We hypothesized that reducing skin feedback would increase joint matching error and variability.

2. Materials and methods

2.1. Participants

Twenty-eight healthy young adults (12 males), age 22.6 ± 2.3, weight 74.1 ± 11.9 kg, height 173.4 ± 8.4 cm, participated in this study. Participants were free of neurological and musculoskeletal disorders. All participants provided written informed consent and all procedures were approved by the University of Guelph Research Ethics Board.

2.2. Experimental setup

A standardized area of skin on the posterior right ankle was marked on each participant; the medial and lateral borders were defined by the malleoli, the distal border was defined by the base of the calcaneus, and the proximal border was positioned at twice the distance from the malleoli to the distal border (Fig. 1). The area within the outlined region of skin was shaved and swabbed with alcohol. Baseline skin sensitivity was measured using Semmes–Weinstein Monofilaments (Stoelting, USA) at three locations within this region: (i) over the Achilles at the level of the malleoli (Mid), (ii) just medial to the lateral malleolus (Lat), and (iii) ~2 cm below the proximal border (Top). Monofilament testing was conducted using the 4-2-1 search method [19], and monofilament perceptual threshold (MPT) was defined as the smallest force perceived in at least 2/3 of trials.

Participants were seated with both feet resting on individual foot pedals. Each foot pedal could rotate the ankle into dorsi- and plantar-flexion about an axis aligned with the malleoli. Compliant Velcro straps were used to secure the feet and legs. All ankle movements were imposed passively to reduce any reliance on sense of effort and active force feedback for proprioception. Additionally, since voluntary muscle activity can bias the perception of joint position [20], participants were instructed to relax their ankle muscles and experimenters monitored surface electromyography (EMG) online from the soleus and tibialis anterior muscles bilaterally using Spike2 software (Cambridge Electronics Design, UK). EMG data were recorded through surface silver silver/chloride electrodes placed in bipolar arrangement on the soleus (distal to the medial gastrocnemius) and tibialis anterior. EMG signals were amplified (AMT-8, Bortec Biomedical, CAN), bandpass filtered (10–1000 Hz) and digitized at 2048 Hz (Power 1401 A/D board, Cambridge Electronics Design, UK). Ankle angular position was recorded in the sagittal plane using calibrated electrogoniometers (Biometrics, SG110, USA) attached across each ankle running behind the lateral malleolus (digitized at 100 Hz).

2.3. Proprioception task

Passive range of motion was measured independently for each ankle and the ankles were then aligned at the participant's perceived neutral position. Participants wore headphones and had their eyes closed to eliminate auditory and visual cues. The left (target) ankle was rotated by a servo motor (Yokogawa Electric Corporation, Japan) at a velocity of 10°/s to one of six target positions (6°, 12°, and 18° dorsiflexion; and 6°, 12°, and 18° plantar flexion) and held. An experimenter then slowly rotated the right (matching) ankle (velocity ~2°/s) in the same direction until the participant verbally indicated that they perceived both ankles were aligned [13]. Participants were allowed to make up to two additional passive adjustments (through feedback to the experimenter) to ensure they were confident in their final matching position. Participants were given six practice trials (one per angle presented in randomized order) prior to the first testing block.

The first testing block was conducted to establish baseline proprioception; this block was comprised of five repeats of each target angle (presented in randomized order) for a total of 30 matching trials. A second block of testing (30 matching trials) was repeated immediately following the anesthetization (or placebo) protocol (-see text Section 2.4).

2.4. Skin anesthetization

Fourteen participants had a topical anesthetic (EMLA, 2.5% lidocaine + 2.5% prilocaine) applied to the outlined area of skin on the posterior ankle and the remaining 14 participants had a placebo cream (unscented moisturizer) applied. The creams were covered with plastic wrap and maintained on the skin for 105 mins with heat applied by a space heater. To minimize movement, the foot and ankle were secured using a VersaForm pillow. After the removal of the cream, the skin was allowed to return to normal temperature (measured using an infrared thermometer) and dry for ~15 mins. To determine the effectiveness of the EMLA (or placebo) cream on skin sensitivity, MPTs were measured again at the three skin sites (-see text Section 2.2).

2.5. Data and statistical analyses

Root-mean-square EMG of bilateral soleus and tibialis anterior muscles was calculated for each trial during movement of the pedals. Velocity of the matching pedal (controlled by an experimenter) was calculated to ensure it remained consistent across the experiment. Directional error in ankle matching was calculated such that positive values always indicate that the matching (anesthetized) ankle was more dorsiflexed relative to the target. Variable error was