Plantar insensitivity and reduced cutaneous reflex strength: potential risk factors for balance impairment?

Sensory input arising from skin receptors of the foot sole provides important information for controlling standing balance: a finding demonstrated by blocking the neural activity of skin receptors in young adults. As we age, our skin receptors undergo a reduction in number, as well as alterations in the physical shape of their specialized receptor endorgans. The skin becomes less elastic, and there is a decline in the speed at which sensory nerves conduct information into the central nervous system. All of these factors are predicted to negatively impact both the quality, and quantity of balance-relevant sensory information available from the foot soles in healthy adult aging.

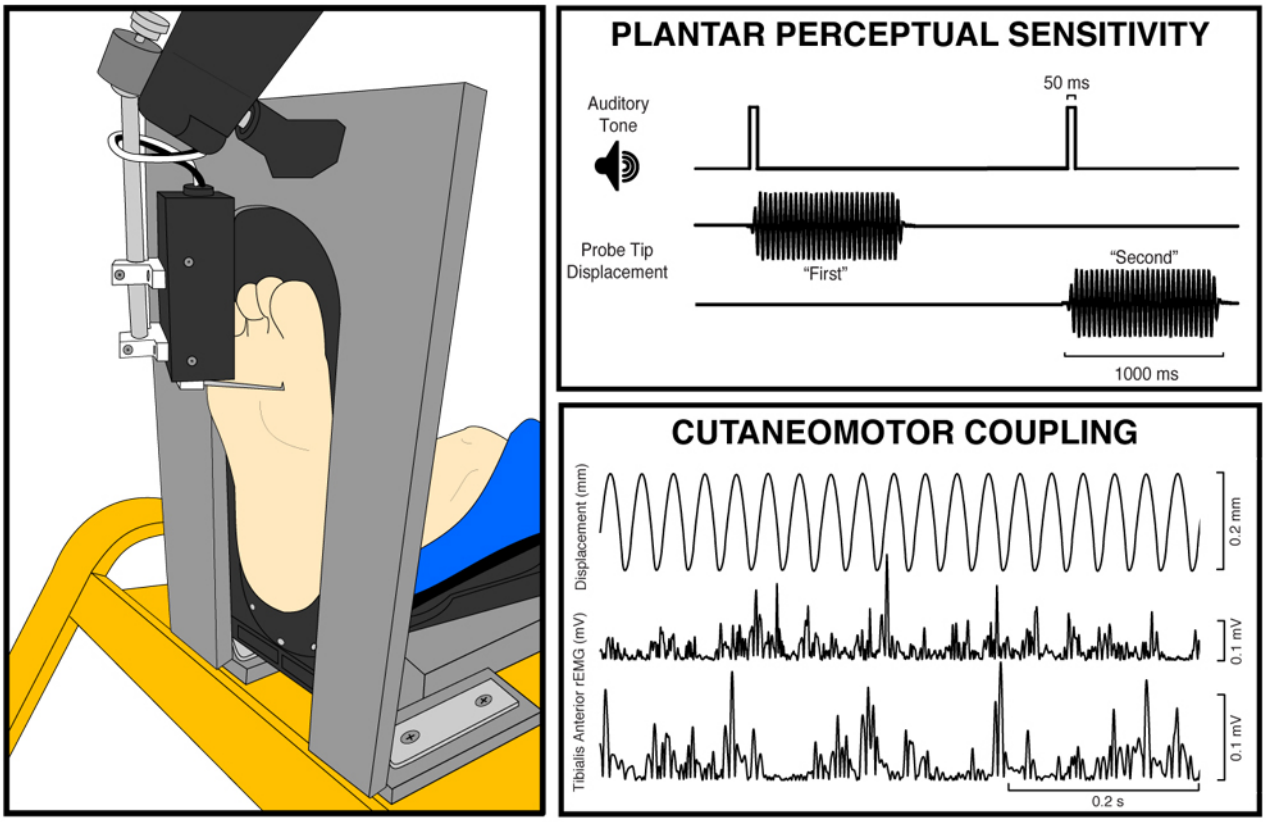

Fig. 1. Experimental setup and plantar function assessment. Right: front view of the exposed plantar surface of the foot, as well as the motor used for delivering vibrations. Left Column: Top, timeline depicting the series of events that occurred on each two-interval two-alternative forced choice vibrotactile trial. The participant was presented with sequential 50-ms auditory tones denoting the 2 stimulus intervals. A 1-s vibration was delivered randomly during either the first or second interval, and the participant was required to determine which interval contained the stimulus. Bottom, Example of continuous 30 Hz sinusoidal vibration and rectified EMG traces

(upper trace from young adult, lower trace from older adult) used for spectral cutaneomotor coupling analysis. Modified from Figure 1 in Peters et al., 2016.

It is known that perceptual sensitivity to stimulation applied to the foot sole declines with age, yet standing balance control and plantar perceptual sensitivity had never been measured in the same cohort of healthy young and older adults. Additionally, there is a different aspect of foot sole sensory information that had yet to be investigated altogether in older adults, namely, the neural connection strength, through spinal reflex circuitry, between plantar cutaneous sensory receptors and the motor neurons that control lower-limb muscles. This so-called cutaneomotor coupling strength could also potentially change throughout the lifespan, and contribute to balance dysfunction.

To investigate the influence of plantar perceptual sensitivity and cutaneomotor coupling strength on standing balance control, we measured each of these variables in nineteen healthy young (25.7 ± 5.5 yr, mean ± SD) and twenty-two older (68 ± 6.9 yr, mean ± SD) adults. To assess perceptual sensitivity we used monofilament and vibrotactile (30 and 250 Hz) detection tasks. Cutaneomotor coupling strength was assessed by applying continuous sinusoidal vibration at either 30 or 250 Hz for 5 min while recording muscle activity in the Tibialis Anterior muscle, the primary dorsiflexor of the ankle. Participants were instructed to hold 10-15% of their maximal voluntary contraction during the reflex testing to control for muscle activation level. Sensory and cutaneomotor coupling strength testing was performed bi-laterally at the same skin site (Fig. 1), near the head of the first metatarsal (0.8 x foot length heel-to-toe, 0.8 x foot width across the ball of the foot), and data were collapsed across legs (as well as testing sessions for the older adults). Afterwards, we had all participants complete two 2-minute quiet standing trials on a force plate with their eyes closed, and their feet one-foot-length apart. We computed the amplitude and the frequency content of their postural sway in the medial and lateral planes over each 2-min trial (data were averaged across trials).

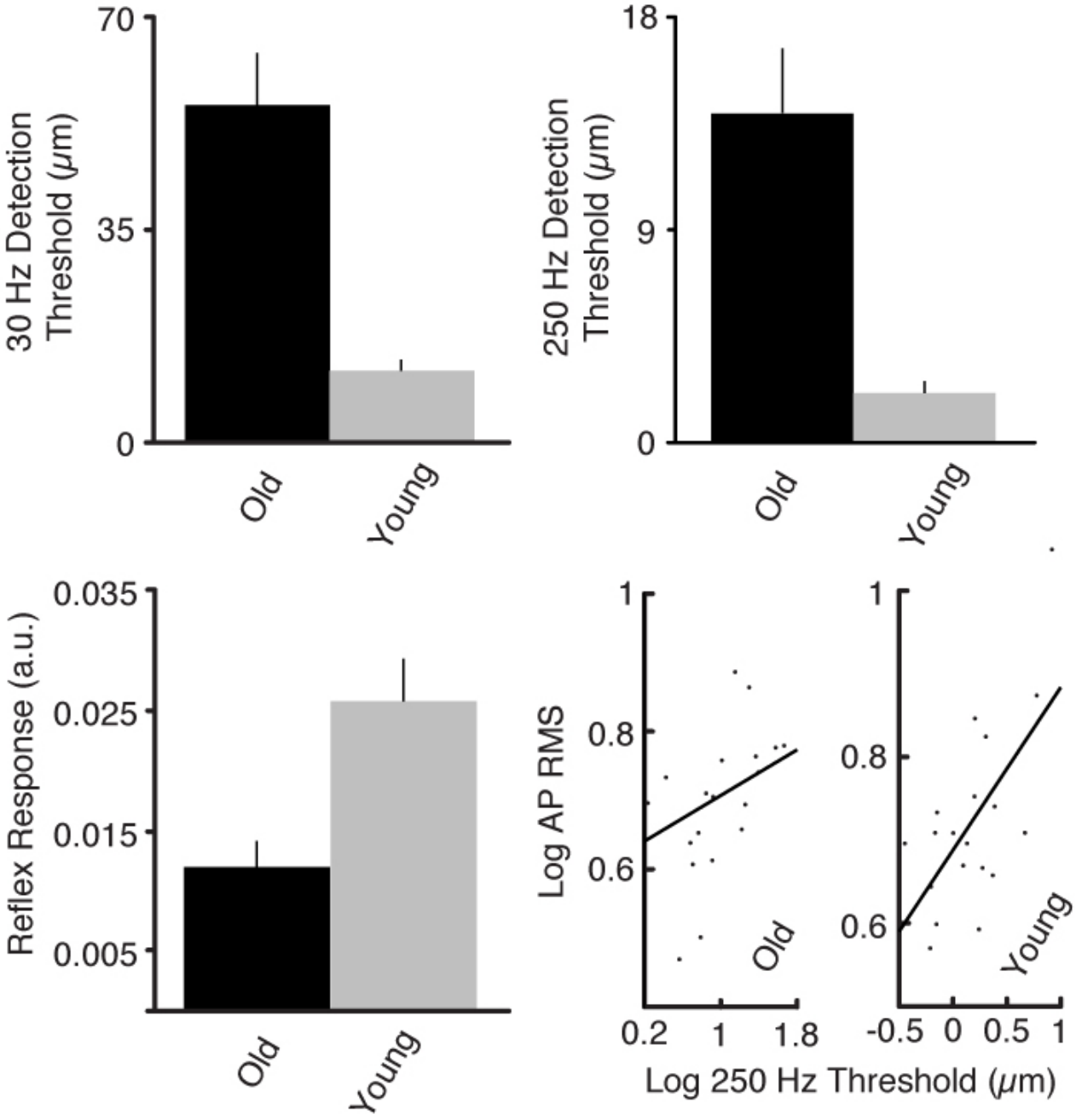

Fig. 2. Changes in plantar perceptual sensitivity and cutaneomotor coupling, and the relationship with standing balance. Top row, 30 Hz (Left), and 250 Hz (Right) detection thresholds for young and older adults. Bottom row, mean reflex response amplitudes (peak-to-peak cumulant density) (Left), and correlations between 250 Hz detection thresholds and the RMS amplitude of centre-of-pressure excursions measured during quiet standing (right) in both age groups.

We observed an age-related decline in sensitivity to monofilaments and vibration (30 and 250 Hz) in healthy young and older adults (Fig. 2, top row). With 30 Hz vibration, cutaneomotor coupling was observed in 95% of young adults but in only 53% of older adults, and coupling strength was weaker in those older adults (Fig. 2, bottom left). 250 Hz vibration was not effective at driving Tibialis Anterior muscle activity in any participant. Most importantly, postural sway amplitude was significantly correlated with increases in plantar detection thresholds at 30 and 250 Hz in both age groups (Fig. 2, bottom right). Given this, we argue that measurement of plantar vibrotactile thresholds is a useful method for assessing the risk of balance impairment.

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