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Beyond sight: environmental interaction with the hands or feet?

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Abstract

How humans perceive the texture of a surface can inform and guide how their interaction takes place. From grasping a glass to walking on icy steps, the information we gather from the surfaces we interact with is instrumental to the success of our movements. However, the hands and feet differ in their ability to explore and identify textures. Higher concentrations of mechanoreceptors in the fingertips provide tactile information to help modulate force and grip whereas the receptors of the feet help to inform surface texture and aid in balance. Cleland et al. (*J Neurophysiol* 132: 643–652, 2024), explores the relationship between texture perception, mode of exploration, and region of body used to explore said texture (hands vs. feet). This research is especially important in the context of understanding how texture perception affects stability, how hands and feet differ in their management and execution of tasks, and how this is adjusted in special populations of visually impaired individuals.

environment; perception; stability; texture; visual

In sighted individuals, our sense of sight and touch are individually or concurrently used to discriminate and interact with our environment. Visual perception allows individuals to infer the shape, distance, and texture of an object or surface before interaction with the hands and feet. As individuals with total visual impairment cannot rely on visual feedback of their environment, they often develop a heightened sensitivity of other senses, including touch, to navigate the objects and surfaces around them (1). To compensate for this lack of visual input, the hands and feet are the end-effectors that serve as a primary source of sensory information and aid in object manipulation and locomotion. Tactile feedback from the hands serves as one of the primary sources that humans use to interact with the external environment. The human body contains ~230,000 cutaneous afferents distributed across its surface, with 15% located in the hands. These afferents are activated by external stimuli, send signals to the spinal cord, and ultimately to the somatosensory cortex (2). It is these signals that allow us to form a perception of an object or surface characteristics. Of the different mechanoreceptors that allow us to discriminate touch, they are commonly delineated based on their stimulus modality (pressure, vibration, skin stretch), their firing properties (fast or slow adapting), and the size of their receptive field (type I or type II) (3). Unlike the forepaws and hindpaws of quadrupeds, the hands and feet in human bipeds display key functional differences in their receptor activity and arrangement. Previous research has shown that across both fast and slow-adapting cutaneous afferents, the size of receptive fields in the foot sole are much larger and distributed differently than in the hand (4, 5). Smaller receptive fields in the hands make it suited for detailed tactile discrimination and object manipulation, whereas the primary task of the foot is to aid in locomotion and posture, when high tactile acuity is not necessary. Cutaneous receptors in the foot sole have higher average firing thresholds than those found in the hands, as some of the increase in firing threshold can be attributed to the thickness and hardness of the skin in the foot sole (5, 6). Greater forces are required to indent or cause enough skin deflection to activate the mechanoreceptors underneath. Cutaneous afferents in the foot sole not only help form our perception of surface texture, they also inform us of pressure across the foot, weight distribution, and shifts in our center of mass (7). For these reasons, afferent feedback from the foot sole aids in posture, balance, and locomotion. Functionally, the decreased sensitivity of the foot makes it optimal for loading conditions, whereas if it were like the hands, there would be spurious activity of the mechanoreceptors likely saturating any signals that may aid in balance or weight distribution. Higher firing thresholds and larger receptive fields in the foot underscore the idea that the primary role of the foot is to support the weight of the body during loaded condition in which higher forces are experienced and acute tactile feedback is not essential. However, despite these differences, the sole of the foot is used similarly to our hands to explore surface environments and textures.

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The study by Cleland et al. (8) sought to examine how textures are perceived by the hands and feet. Although they are functionally similar in the sense that they are extensions of our body that interact with the environment around us, they are also different in that the main goal of the feet is to support balance and gait. The investigators created a protocol (8) that allowed them to determine if texture perception with the hands and feet are influenced by their individual anatomical properties (e.g., mechanoreceptor innervation, firing rate, receptive fields), or by the modes with which the body parts interact with their environment (e.g., reaching and touching vs. standing and walking). In this study, 20 participants (7 males, 13 females) with no history of sensory deficits were exposed to 16 texture samples during three conditions: foot-stepping, foot-exploration (seated), and hand-exploration. Visual and auditory feedback were removed by use of noise canceling headphones and subjects were blind folded in all conditions, which eliminated the use of prediction or other feedback to alter perception. After exposure to a texture sample for 2–3 s, participants immediately rated the texture along one of three dimensions (hardness, roughness, or stickiness) and a stability dimension was included for the standing condition only. Texture types, although varied, were common to everyday natural interactions and included cork and gel materials often used in the insoles of shoes. Ratings using free magnitude scaling (a method to assign a numerical value to a presented stimulus) were used to determine the perception of the sample's magnitude of hardness, roughness, stickiness, or stability. Of the total ratings recorded, the results showed that roughness levels were magnified when walking, making textures seem rougher than when perceiving them with the hand or under low forces during exploration with the foot. This result is unsurprising given that the rougher an object is, we approach it more cautiously during hand and foot exploration, and we do not have that same option when supporting bodyweight during walking. Previous work from Gates et al. (9) has demonstrated that humans alter their gait during cautious walking by using flatter foot placement, a lower center of mass, and increased ground contact times. The same pattern was evident for hardness perception, with higher ratings during stepping. In contrast, the distribution of responses for stickiness perception was equal across all conditions. Perceptual rankings of the hand and foot exploration conditions were more highly correlated to each other than the standing condition was with either exploration condition. Consequently, perceptual ranking is likely driven by mode of interaction, specifically as it pertains to the loaded standing condition. Lastly, of interest is the positive relationship between perceived hardness and stability. The authors found that this relationship accounts for 36% of the variance in stability rating results. Although some textures may take a back seat to stability in the role of foot cutaneous afferents, perhaps other textural properties such as malleability and temperature can affect texture perception. These findings support the notion that there are functional differences between the cutaneous afferents of the hands and feet and knowing how the foot commonly interacts with the environment in loaded conditions can impact and inform a person's perception of their environment.

How the hands and feet are used to explore the environment and gather sensory information has an interesting parallel to the mammalian world. In the walking rat, during spontaneous gait, there is an initial "soft contact" phase by the forepaws where contact time is up to four times longer than the hindpaws. It is postulated that the forepaws are used to provide tactile information of the terrain during this prolonged initial soft contact phase, while the hindpaws transmit most of the early vertical ground reaction forces (10). This is unique as the walking rat is considered a quadrupedal mammal but unlike other four-legged mammal species, they may use the forepaw for exploration during gait. Species such as the rat may bridge the gap between quadrupeds, where all four paws are primarily contributing to locomotion, and bipeds, where the feet primarily contribute to locomotion and stability but do have some object exploration abilities (under load), and the hands that only perform object exploration.

The interpretation of how rough, hard, or stable a surface is, plays quite a vital role for those who predominantly use hands and feet to explore and navigate their environment without vision. For example, a change in floor surface texture from hard to gritty can indicate a change of path in a large space to aid navigation. For people with visual impairments, this is especially relevant as this participatory relationship to the "visually biased" public space has been postulated as one of the most challenging interactions between humans and spaces (11). Exploring devices that exploit tactile-foot stimulation for improving directional navigation is an exciting and necessary venture (12). Unlike assistive devices (canes), shoe-based systems do not interfere with natural tactile feedback of the hands during exploration or auditory signals used for successful navigation. Ultimately, this should allow visually impaired individuals to have more autonomy and independence in their environment and although shoe-based devices might have some advantages, such as their ability to be seamlessly integrated into daily living, haptic feedback from these devices (vibration and texture) could create additional feedback that impacts a person's interpretation of their environment. The study by Cleland et al. (8) in the *Journal of Neurophysiology* provides valuable information on how we use our limbs to interact with our environment. Much is known about the specific mechanoreceptors and cutaneous afferents that innervate the hands and feet of humans, but it is not yet fully understood how these regions contribute to perception of various textures and performance during specific exploratory and locomotor activities. Drawing from some work in other mammals and visually impaired humans, we can see the dual role the feet play in unloaded and loaded conditions, primarily in exploration versus balance and stability, respectively. However, since we do not rely on our hands for any weight-bearing activities, it makes sense that they are designed optimally for exploration and perception, only. Future work in this area can use this information for the design of sensory-enabled prosthetics and other assistive devices that could integrate touch feedback into their model.

DATA AVAILABILITY

AQ: 6

Data will be made available upon reasonable request.

DISCLOSURES

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AUTHOR CONTRIBUTIONS

S.V., N.A., and J.M. drafted manuscript; S.V. and J.M. edited and revised manuscript; S.V., N.A., and J.M. approved final version
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