From Perception to Movement

Executive Summary

Humans use sensory information continuously to perceive their surroundings, understand the position and movement of their body, and adapt to a changing environment. While sight, hearing, smell, taste, and touch are familiar to most of us, less familiar senses also play an important role in how we move.

Walking is a remarkable example of sensory information working together. Vision provides information about the environment, proprioception about the position and movement of the body, and the vestibular system about movement and orientation. The nervous system continuously integrates this information to guide and adapt movement. Understanding this interaction also introduces the concept of sensory augmentation, in which additional sensory information, such as vibrotactile feedback, can become part of this ongoing exchange.

1. From Perception to Action

How we perceive, interpret, and respond to the world around us.

Every interaction with our environment begins with perception. We see the color of a traffic light, hear an approaching bicycle, smell freshly baked bread, taste a sip of coffee, and feel the warmth of the sun on our skin. At the same time, we unconsciously sense the position of our joints, the movement of our limbs, the pressure beneath our feet, and the orientation of our head.

Although we often think of sight, hearing, smell, taste, and touch as our primary senses, the nervous system also relies on less familiar sensory systems. Proprioception provides information about the position and movement of our body, and the vestibular system contributes information about head movement, orientation, and balance [1,2].

Specialized sensory receptors detect information from the body and environment and transmit signals to the nervous system, where information from the different senses is integrated. The brain can then coordinate an appropriate response. Every movement generates new sensory information, creating a continuous interaction between perception and action. This process underlies everything from reaching for a cup of coffee to maintaining balance while walking across uneven ground.

2. The Senses Behind Movement

How the nervous system knows where we are, how we are moving, and what surrounds us.

All sensory systems contribute to our experience of and interaction with the world, but some are particularly important for movement and balance. Three sources of sensory information play a central role in walking: proprioception, the vestibular system, and vision. [2–4].

Proprioception: Sensing the Body

Proprioception provides information about the position and movement of our body. Sensory receptors in our muscles, tendons, and joints continuously provide information about how our limbs are positioned and moving. Much of this happens without conscious awareness, allowing us to know where our legs and feet are without having to look at them [1].

The Vestibular System: Sensing Balance and Motion

The vestibular system is located within the inner ear. It detects head movement and acceleration, providing information about orientation relative to gravity. The vestibular system continuously contributes to balance, spatial orientation, and postural control while we are standing or moving [2].

Vision: Seeing What Comes Next

Vision enables us to gather information about our environment before we interact with it physically. While walking, vision helps us identify obstacles, changes in terrain, distances, and potential places to step. For example, seeing a curb or uneven surface allows us to begin adapting our movement before our foot reaches it [4].

These sensory systems work together to provide complementary information about the body, its movement, and the surrounding environment.

3. Making Sense of the Senses

How the nervous system combines sensory information to guide movement.

The nervous system continuously processes sensory information to develop an evolving perception of the body and its surroundings. This process, known as sensory integration, allows information from vision, proprioception, and the vestibular system to contribute collectively to movement and balance [3].

Importantly, the nervous system does not rely equally on each sense. Rather, it adjusts how strongly it weighs different sources of information depending on the situation and their reliability. This process is called sensory reweighting. For instance, when you close your eyes, your nervous system must rely more heavily on proprioceptive and vestibular information to maintain balance [3].

4. How the Senses Shape Every Step

Walking is automatic, but the sensory processes behind it are remarkably complex.

Walking follows a repeating pattern known as the gait cycle. This cycle consists of two phases: the stance phase, when the foot is in contact with the ground, and the swing phase, when the foot moves forward in preparation for the next step.

Throughout this cycle, sensory information is constantly changing. Proprioception provides information about limb position and movement. The vestibular system contributes information about movement and orientation, while vision provides information about the path ahead. These signals work together to allow movement to be continuously adapted from one step to the next [2–4].

Imagine walking from dry pavement onto wet grass. Your vision may detect the change in surface before you take your first step. As the foot touches the grass, sensory information from the foot provides additional information about contact with the new surface. If the body moves unexpectedly, vestibular and proprioceptive information provide further details about changes in position and movement. Therefore, what appears to be a simple step is actually the result of multiple sensory systems working together continuously [1–4].

5. When Sensory Information Changes

The nervous system can adapt when sensory information becomes reduced or unreliable.

Injury, disease, or age-related changes can affect the amount or quality of sensory information available to the nervous system. In such cases, the nervous system can adapt by placing greater reliance on the remaining available sensory information [3].

Proprioceptive information from the lower limbs allows us to sense their position and movement without having to watch every step. However, if this information becomes less reliable, vision can take on a greater role. Looking at our feet provides an additional visual reference for foot placement and the surface ahead. This shift toward another available source of information is an example of sensory reweighting [3,4].

However, one sensory system cannot completely replace another because each system provides different information about the body and environment. This raises an interesting question: Could additional sensory information complement what is already available to the nervous system?

6. Adding to the Sensory Conversation

How additional sensory information can become part of the sensorimotor loop.

Sensory augmentation is the process of providing additional information through another sensory channel. One approach to providing such information is vibrotactile feedback.

Precisely controlled vibrations applied to the body can provide sensory information to the nervous system. Research has shown that vibration can influence proprioceptive and haptic perception, including the perception of surfaces while walking [5,6].

Rather than replacing the body's natural sensory systems, vibrotactile feedback can be understood as an additional channel through which movement-related information can be sent to the nervous system. From this perspective, sensory augmentation is based on a fundamental principle of human movement: our ability to move through the world depends on the continuous exchange of information between our bodies, nervous systems, and environments.

This principle also has practical relevance. Vibrotactile feedback can be incorporated into wearable technologies to provide additional sensory information during movement. For example, vibrations delivered through footwear can provide sensory cues during walking, adding another source of information to the ongoing sensorimotor loop.

Ongoing research continues to explore how vibrotactile feedback interacts with movement and how it may be applied when sensory or motor function is affected by neurological conditions, injury, or aging.

References

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