Signal replicas make a flexible sensor

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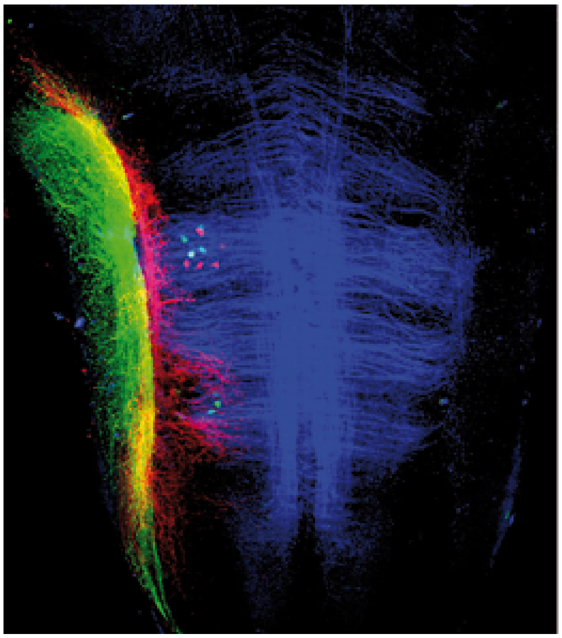

Fluorescence image showing two nerves (stained in red and green), which are responsible for transmitting information from the hair cells to the brain and from neurons (small green dots) that alter hair cell sensitivity, respectively.

Ludwig Maximilian University of Munich researchers have shown how signals from the spinal cord adjust the sensitivity of hair cells in the inner ear to accommodate shifts in head position associated with active locomotion—thus ensuring that balance is maintained.

When a jogger sets out on his evening run, the active movements of his arms and legs are accompanied by involuntary changes in the position of the head relative to the rest of the body. Yet the jogger does not experience feelings of dizziness like those induced in the passive riders of a rollercoaster, who have no control over the abrupt dips and swoops to which they are exposed. The reason for the difference lies in the vestibular organ (VO) located in the inner ear, which controls balance and posture. The VO senses ongoing self-motion and ensures that, while running, the jogger unconsciously compensates for the accompanying changes in the orientation of the head. The capacity to adapt and respond appropriately to both slight and substantial displacements of the head in turn implies that the sensory hair cells in the inner ear can react to widely varying stimulus intensities.

In collaboration with Dr. John Simmers at the Centre national de la recherche scientifiqu (CNRS) at the University of Bordeaux, neurobiologists Dr. Boris Chagnaud, Roberto Banchi and Professor Hans Straka at LMU's Department of Biology II, have now shown, for the first time, how this feat is achieved. Their findings reveal that cells in the spinal cord which generate the rhythmic patterns of neural and muscle activity required for locomotion also adaptively alter the sensitivity of the hair cells in the VO, enabling them to respond appropriately to the broad range of incoming signal amplitudes. The results are reported in the online journal *Nature Communications*.

As Boris Chagnaud points out, "we are not really aware of what movement actually involves because our balance organs react immediately to alterations in posture and head position. The hair cells, which detect the resulting changes in fluid flow in the semicircular canals in the inner ear, enable us to keep our balance without any conscious effort."

Using tadpoles as an experimental model system, the researchers investigated how the hair cells manage to sense both low- and high-amplitude movements and produce the signals that control the appropriate compensatory response. The tadpole's balance organs operate on the same principle as the bilateral VOs in humans, and the nerve circuits responsible for communication between the hair cells and the motor neurons in the spinal cord are organized in essentially identical ways.

The role of replicate signals

When a tadpole initiates a voluntary movement, e.g., begins to swim by moving its tail from side to side, nerve cells in the spinal cord send copies of the motor commands to so-called efferent neurons in the brainstem that project to the hair cells in the inner ear. "The effect of this signal is to reduce the sensitivity of the hair cells," says Chagnaud. By dampening the intrinsic sensitivity of the hair cells, the input from the spinal cord effectively adapts the VO's dynamic range. This process enables the balance organ to maintain responsiveness to high-amplitude "afferent" stimuli from the periphery, and thus to modulate the head movements that accompany propulsive swimming.

Hence the whole adaptation process is controlled by neurons in the spinal cord, which transmit signals to the VO via nerve cells located in the brainstem just before the muscles carry out the next locomotory behavior. These signals thus notify the VO in advance about the temporal form of the impending movement. "This feedforward principle is crucial, because it prepares the hair cells to react appropriately to the next movement," Chagnaud explains. "The direct impact of input from the spinal cord on the sensitivity of sensory nerve cells in the balance organ demonstrates the importance of interactions between sensory and motor systems, and it underlines the significance of the interplay between different components of the central nervous system - in this case, the spinal cord and the brainstem. Here, evolution has not only come up with an elegant means of anticipating the effects of locomotion on the body but also of compensating for them in an adaptive fashion."

The LMU group now intends to study whether all the hair cells in the inner ear also respond to efferent information emanating from the spinal cord or whether the VO possess subpopulations of hair cells that are specialized for reception of impulses that signal either fast or slow movements.

More information: Spinal corollary discharge modulates motion sensing during vertebrate locomotion, *Nature Communications* 6, Article number: 7982 DOI: 10.1038/ncomms8982

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