Space Life Sciences Research Highlights

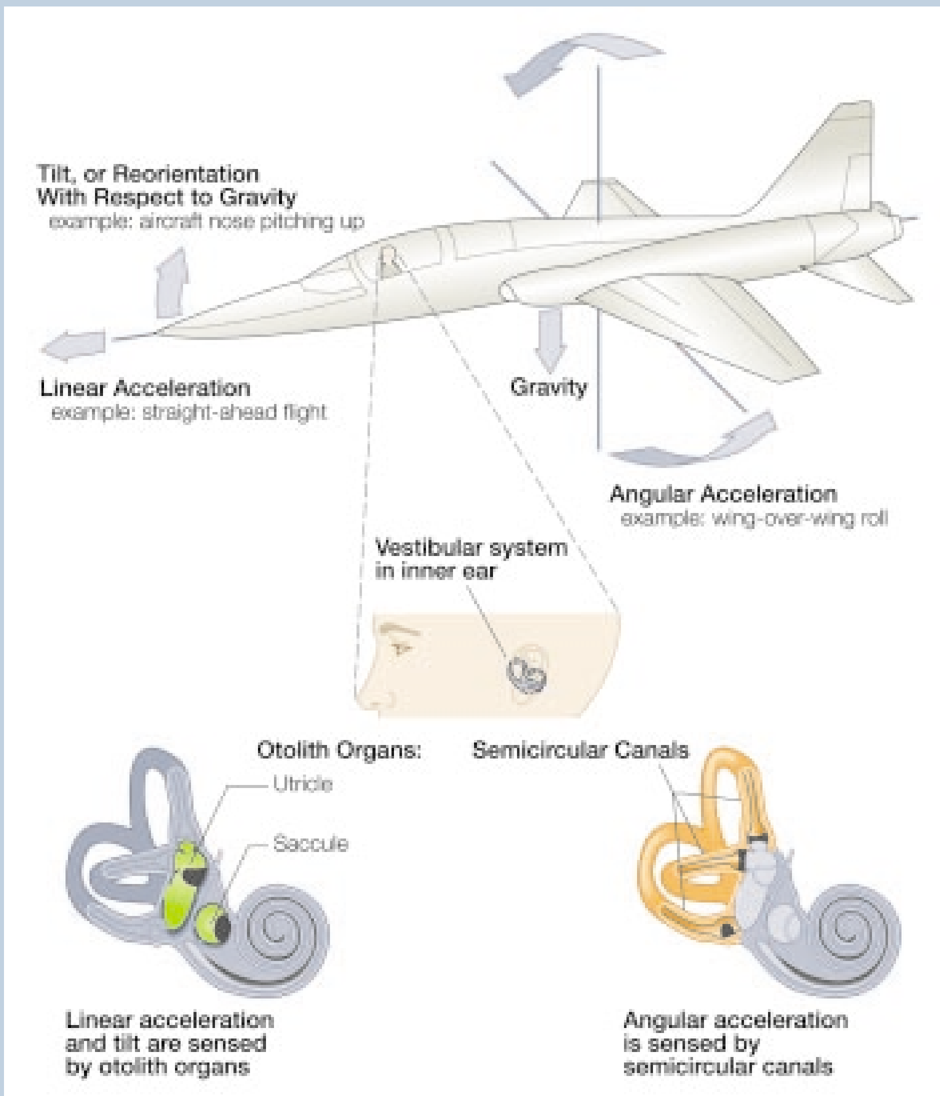
Studies Yield New Insights into How the Brain Distinguishes Gravity from Movements of the Body

The human brain can quickly adapt to major changes in the environment, even to the absence of gravity. Yet exactly how the brain senses and processes the presence or absence of gravity still remains a mystery. The work of NASA-supported investigator Dora Angelaki is providing new insights into this question by investigating how the brain distinguishes gravity from movements of the head and body. Her research suggests that the brain perceives gravity by integrating signals from the two different sets of balance organs that make up the vestibular system, an idea known as multisensory convergence.

Humans evolved in Earth's gravitational environment. We are preprogrammed to take gravity into account with everything we do. Yet exactly how the human brain—extremely complex and amazingly flexible—senses and processes information about gravity remains poorly understood.

The work of Dora Angelaki, Ph.D., associate professor of anatomy and neurobiology at Washington University in St. Louis, is shedding new light on the complex signaling pathways by which the brain differentiates gravity from the multiplicity of signals it receives from the vestibular system—the set of structures in the inner ear that regulates our ability to balance on two feet and orient ourselves in the world.

The two balance organs that make up the vestibular system are the *semicircular canals* and the *otolith organs*. The semicircular canals sense angular movements, which occur when the head rotates or revolves—nodding yes or no, for example. The otolith organs provide signals about two other kinds of information: the position of the head relative to gravity, and movements of the head along a straight line, such as up and down head movements while running or accelerating in a car.



***Research Question:** We know that angular acceleration (rolling or rotating movements) is sensed by semicircular canals of the vestibular system. We also know that linear movements (acceleration in a straight line) and changes in body position with respect to gravity (tilt) are both sensed by the otoliths, another part of the vestibular system. But we don't know how the brain distinguishes linear movements from changes with respect to gravity, since the effect of linear movement and tilt on the otoliths is physically the same. The pilot's head experiences all these types of movement.*

Understanding Effects in Space Requires Understanding How Brain Differentiates Gravity from Movement

In space, without the presence of gravity, the gravity signal to the otolith organs is altered. During the first few days of a space mission, there is an absence of gravitationally based otolith stimuli to the brain, which creates a sensory conflict that appears to be the cause of the disorientation and motion sickness experienced by many astronauts. However, after several days in microgravity—as the eyes, vestibular organs, and brain adapt to that environment—these symptoms subside.

"The brain learns to reinterpret vestibular signals in different ways when the environment changes," explains Angelaki. "Our laboratory is specifically interested in how the brain reinterprets signals from the otolith organs in different environments."

To understand how changes occur in adapting to altered gravity environments, we need to better understand how the brain differentiates between the gravity-sensing and movement-sensing signals it receives from the otolith organs. This question is the focus of Angelaki's NASA-supported research.

Multisensory Convergence Hypothesis

"Two completely different kinds of movement—tilting the head up, which changes its orientation with respect to gravity, and movement in a straight line, such as jumping up and down or walking straight ahead—activate the otolith organs in exactly the same way," says Angelaki. "The brain readily distinguishes these movements, but how it does this is not known."

According to the multisensory convergence hypothesis, the brain—instead of relying solely on the signals it receives from the otolith organs to detect gravity—also makes use of signals from the semicircular canals. This idea conflicts with the conventional view that the two sets of organs operate entirely independently.

But testing this idea is difficult, for several reasons. To begin with, gravity regulates everything we do on Earth. "Because gravity is a constant, it's very difficult to isolate its effect," explains Angelaki. Secondly, normal movement always involves a combination of movements: movement in a straight line (linear acceleration) and changes in the position of the head relative to gravity (head tilt and angular acceleration of the head). Movement that is purely linear or angular can only be produced in controlled laboratory conditions.

Angelaki and her colleagues were the first investigators to test the multisensory convergence hypothesis experimentally. Because signals from the vestibular organs to the brain cannot be measured directly, they measured reflexive eye movements. This strategy, which is commonly used in vestibular research, takes advantage of the fact that, under normal conditions, the vestibulo-ocular reflex automatically moves the eyes in a direction opposite to that of movement of the head.

The study subjects were rhesus monkeys wearing contact lenses specially designed to enable measurement of their reflexive eye movements. This technique is widely used in both research laboratories and in the diagnosis of certain eye disorders in human clinical laboratories.

Results Support Multisensory Convergence Hypothesis

In a complex series of experiments, the researchers recorded changes in the animals' eye movements in response to several stimuli. The main experimental conditions were:

- pure linear movement (from right to left and back again) that did not change the animals' orientation with respect to gravity
- pure angular movement (rotation around an axis) while also changing the animals' orientation with respect to gravity (head tilt) but no linear movement

These two conditions exerted similar forces on the otolith organs but the second condition, by adding angular acceleration, also involved the semicircular canals. Other combinations of linear and angular movement were also tested.

From the changes in the animals' eye movements, the researchers were able to deduce whether these stimuli were activating the otolith organs, the semicircular canals, or both sets of vestibular organs. The results showed that the brain does indeed use signals from both the otolith organs and the semicircular canals to distinguish movement in a straight line from movement that changes the body's orientation with respect to gravity, thereby supporting the multisensory convergence hypothesis.

"These experiments not only help to explain how the brain senses gravity but also point out the importance of interaction by multiple sensory systems in interpreting the effect of gravity," says Angelaki.

Dr. Angelaki is a 1996 recipient of a Presidential Early Career Award funded by NASA. These awards recognize scientists and engineers in the early stages of their research careers who show exceptional potential for leadership at the frontiers of scientific knowledge in the 21st century.

References

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