Astronaut Study Sheds Light on Role of Balance Organs in Posture Control

NASA-supported research is providing important new information about the role of the otolith organs—part of the body's balance system—in posture control. This new knowledge may point the way not only to the development of countermeasures for postural instability in returning astronauts but also to improved treatment for individuals with disabling balance disorders.

When we stand upright on Earth, tiny otolith organs—part of the balance or vestibular system located in the inner ear—sense the position of the head relative to gravity, enabling us to orient ourselves in space.

During the microgravity conditions created by space flight, the continuous spatial reference normally provided by gravity and sensed by the otoliths is absent, causing temporary disorientation and motion sickness in many astronauts. Within a few days, however, the brain adapts to the absence of gravity and learns to estimate spatial orientation without reference to a gravitational signal.

On returning to Earth at the end of a space mission, many astronauts, as their brains readapt to the presence of gravity, experience dizziness, light-headedness, and postural instability (a difficulty in maintaining upright posture) when they stand upright. In an emergency requiring rapid exit from a spacecraft immediately after landing, postural instability could be dangerous.

Large Study of Returning Astronauts

A large study of returning astronauts offers compelling evidence that "re-adaptive transitioning" of otolith organ information provided to the brain lies behind postflight postural instability, says F. Owen Black, M.D., senior scientist at the Legacy Clinical Research and Technology Center in Portland, Oregon, and principal investigator for this research project.

Returning shuttle astronauts exhibit postural instabilities identical to acute loss of vestibular (inner ear balance) function in patients on Earth. The difference between astronauts and patients with balance disorders is that all shuttle crew members recover over a 2-4 day period following return from space. The typical patient requires weeks to months for recovery, while some never recover.

Black's NASA-supported research on returning astronauts has provided crucial validation of a unique postural control evaluation system that is now used routinely in the medical assessment of International Space Station astronauts, as well as in the clinical evaluation of patients with balance disorders.

Black's work uses computerized dynamic posturography (CDP), a system for quantitatively assessing the sensory and motor components of pos-

Computerized dynamic posturography system (CDP). This system is used in astronauts and individuals with balance disorders to assess postural control. During testing, the subjects may have their eyes closed or open; the visual background may be fixed or move with the subject's sway; the support surface (surface under the feet) may be fixed, move with the subject's sway, or may rotate or translate. Combinations of these testing conditions are used to evaluate the subjects' ability to use visual, vestibular, and sensory information to control balance.

ture control and their interaction with the brain. According to Black, CDP—which he co-developed with Lewis M. Nashner of the R.S. Dow Neurological Sciences Institute in Portland—is the only clinically accepted, objective test that isolates and quantifies the basic elements of balance.

In a series of tests that systematically challenge subjects' motor control and sensory organization reflexes, CDP measures subjects' ability to use visual, vestibular, and sensory information to control balance. Numerous independent studies have shown that CDP accurately detects and quantifies abnormalities of the balance system, says Black.

Otolith Dysfunction Causes Postflight Postural Instability

The astronaut study involved 45 crew members from 24 space shuttle missions between 1989 and 1995. Each crew member underwent CDP testing before flight and five times postflight—between 2 and 4 hours after landing and again at 24, 48, 96, and 192 hours after landing. All astronauts performed at or above the 50th percentile on preflight tests.

Immediately after space flight, all crew members demonstrated a deterioration in balance control compared to preflight. By 96 hours (4 days) postflight, however, most astronauts had recovered normal postural control. Veteran astronauts performed better than first-timers on postflight sensory organization tests, suggesting that the transition from microgravity to "normal" Earth gravity becomes easier with experience.

"The results show that the major cause of the astronauts' postural instability upon re-entering Earth's gravitational environment is that they cannot use inputs from the otolith system to control posture and movement," explains Black. "However, a very rapid, incremental improvement is directly related to previous flight experience. Once the brain has learned to adapt from one gravitational environment to another, it can do it more efficiently the next time.

"We have also shown that there is a high correlation between astronauts' pre- and postflight performance in the CDP tests. On the basis of their preflight performance, we can estimate how they will perform postflight." NASA now requires that astronauts coming back from tours of duty on the International Space Station demonstrate a return to preflight performance on CDP testing before resuming full duty.

Rehabilitation of Balance Disorders

The astronaut study has contributed knowledge about the effects of gravity on the otolith system that could not have been obtained in any other way, notes Black. Because gravity is a constant on Earth, the effect on the otoliths of removing and reintroducing gravity can be studied only in subjects who leave the Earth's gravitational environment for an extended time and then return.

"The metrics we've developed for observing astronauts can also be used to maximize rehabilitation of people with vestibular system dysfunction," says Black. Balance disorders caused by vestibular dysfunction are very common, he says, affecting 90 million Americans at some point in their lifetime.

Black and his colleagues have shown that CDP can be used to assist in the diagnosis of a disabling vestibular disorder known as perilymphatic fistula (PLF), which results from a leak between the fluid spaces of the inner ear and the air spaces of the middle ear. Black's group developed a test using CDP that takes advantage of PLF patients' abnormal sensitivity to changes in atmospheric pressure.

The investigators have also shown that people with chronic balance disorders performed significantly better on CDP tests after completing an individualized program of vestibular rehabilitation therapy. "Older patients responded to rehabilitation therapy just as well as younger people," says Black. Balance problems are common in the elderly and often lead to falls, which can result in chronic disability. Because most falls are thought to arise directly or indirectly from vestibular abnormalities, preventing falls could significantly reduce fall-related deaths and injuries.

"We think CDP has promise as a technique for detecting people who are at risk for falling. In the astronaut study, we could reliably predict their probability of falling on the basis of their CDP performance," Black adds.

References

1. Black FO. Clinical status of computerized dynamic posturography in neurotology. *Current Opinion in Otolaryngology Head and Neck Surgery* 9(5):314-8, 2001.
2. Black FO. What can posturography tell us about vestibular function? *Annals of the New York Academy of Sciences* 942:446-64, 2001.
3. Black FO; Angel CR; Pesznecker SC; Gianna C. Outcome analysis of individualized vestibular rehabilitation protocols. *American Journal of Otology* 21(4):543-51, 2000.
4. Black FO; Paloski WH. Computerized dynamic posturography: what have we learned from space? *Otolaryngology Head and Neck Surgery* 118(3 Pt 2):S45-51, 1998.
5. Black FO; Pesznecker SC. Perilymphatic fistula : the method of F. Owen Black. In: *Current therapy in otolaryngology*, 6th ed., p. 71-8. St. Louis : Mosby, c1998. (Current therapy series)