ear," said Paloski. "But we've learned from the Russians that after long-duration missions the proprioceptive changes may be more important – they take longer to appear and persist far longer afterwards."

Control of Locomotion

The ability to walk can be significantly altered after space flight. Sensory inputs including those provided by visual, vestibular, and proprioceptive sensors are required to maintain locomotor ability on Earth. Adaptation to weightlessness apparently results in changing the way the brain interprets information from these receptors. The outcome of this change is disturbances in gait when astronauts try to walk after they return to Earth.

Normal gait depends on acquiring pre-programmed patterns of muscle activation, and requires continuous monitoring of external sensory input. Detailed studies of locomotion after space flight indicate that weightlessness changes the relationship between sensory input and motor output.

One consequence of this adaptation is that orientation and movement control systems of astronauts returning from long periods in space are no longer optimized for Earth's gravity. Disturbances in postural equilibrium and gait upon return from flight have been among the most consistently reported responses associated with space flight.

Dr. Jacob Bloomberg, a senior scientist in the Neuroscience Laboratory, is investigating how space flight affects the ability of astronauts to walk after flight. "Astronauts experience significant postural and locomotive difficulties when they return after short- and long-duration space flight. This is an important operational issue because astronauts, after long-duration space flights or trips to Mars, need to be able to walk after flight. Our research involves understanding some of the underlying neurophysiological changes that are associated with these disturbances and developing countermeasures to mitigate against them."

> *From the moment of conception, we are 1 g organisms. We're conceived, born, reared, and work in a one gravity field. If you take away that gravitational component, then there are certain specific parts of the nervous system that are going to respond.*
>
> – Dr. Millard Reschke

Eye-Head Coordination

Eye movements serve two purposes: to hold gaze steady or to shift it to an object of interest. Compensatory eye movements maintain a steady image on the retina during head movements. Otherwise our vision would be blurry. The elimination of gravity alters the physiological systems – principally, vestibular and sensory motor – underlying compensatory head and eye movements.

"The changes that we see primarily pertain to the way that the eye responds when the head is moved," said Reschke. "For example, a good way to demonstrate the phenomena of compensatory eye movements is to ask the reader to shake his or her head back and forth while gazing at the printed text at about one cycle per second. Under this condition, the text will remain clear and readable because the eye, driven by the vestibular system, is moved equally and opposite that of the head – just watch someone else's eyes when they do this. If, on the other hand, you shake the paper you are reading back and forth and hold your head still, the print will be blurry because the eye and the vestibular system are not working together. We believe that in space the compensatory relationship between head and eye movements is disrupted, and that changes occur in the brain that allow adaptation to the new environment. It is during the adaptation process, whether upon the initial exposure to microgravity or the transition to a new inertial environment [Earth or Mars], that problems will be manifest in the vestibular and visual systems.

"The real importance of the adaptive process is that compensatory eye movements, including those that move our eyes when we look at something as well as those that allow us to track a moving target, are mediated by the balance organs of the inner ear where they stabilize one's vision while walking, keep an image focused on the retina when we redirect our eyes to a new target of interest, or even use our eyes to maintain our balance."

NASA Photo STS060-21-027

Astronaut Ronald M. Sega (left) and Russian Cosmonaut Sergei K. Krikalev work on a joint U.S./Russian metabolic experiment (DSO 202) on the Space Shuttle *Discovery*'s middeck. Note the electrodes on Krikalev's face.

To study compensatory eye movements, an experiment slated to be flown aboard the ISS in 2002 or 2003 will examine gaze control, and the role of prolonged space flight on the visual and vestibular systems. Pre- and post-flight studies of long duration Mir crews suggest that the changes in the brain controlling compensatory eye movements are very long lasting. The ISS study will permit researchers to look at the adaptive process.

Vestibulo-Autonomic Function

Dr. Todd Schlegel, a research physician in the Neuroscience Laboratory, and his team are looking at relationships between changes in the inner ear and brain, and changes in the function of the cardiovascular system during and after exposure to altered gravitational environments.

"We're looking at these relationships because when astronauts return from space, they can sometimes experience, simultaneously, problems such as motion sickness, postural imbalance and orthostatic intolerance, or fainting after standing up," Schlegel said.

Historically, post-flight motion sickness and imbalance has been attributed to inner ear changes, but orthostatic intolerance has been attributed to headward fluid shifting and cardiovascular deconditioning. The work by Schlegel and his team looks at whether the inner ear changes lead to or exacerbate changes in blood pressure and heart rate upon return to Earth. The team is studying test subjects during and after parabolic flight and centrifugation.

Neuroplasticity

"The biggest problem we see is when people make transitions from one gravitational state to another," said Reschke. "It often takes weeks or months for responses to adapt."

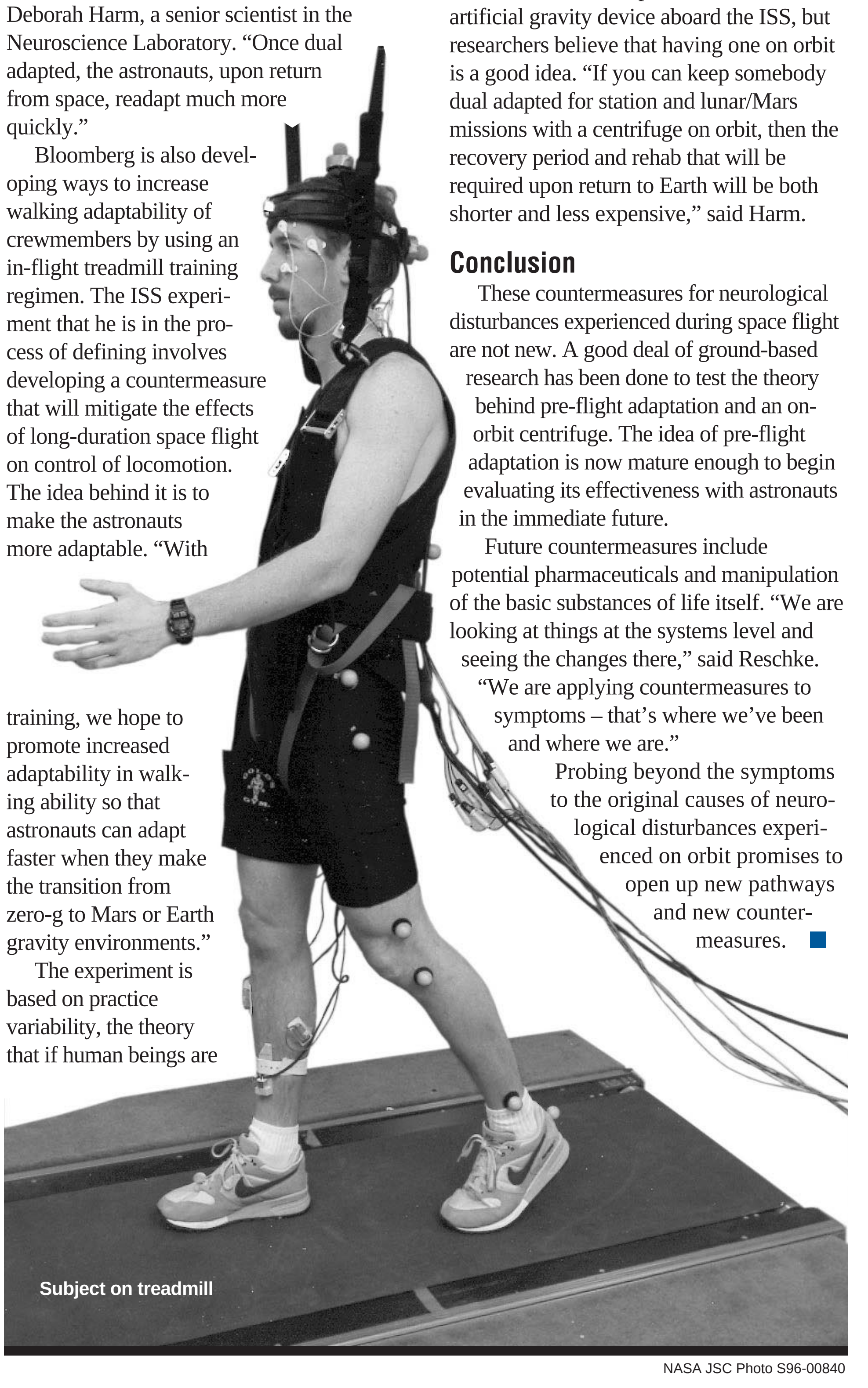
Fortunately, the human brain is "plastic" and knows how to deal with changing circumstances. So individuals adapt very well in transitioning from one gravitational state to another.

An approach to make the brain more "plastic" so that astronauts can more easily adapt to different gravitational states is to give it more challenges before flight – sensory incongruities that it has to sort out. This concept got its start 15 years ago in laboratories at JSC with the development of what is called pre-flight adaptation training. Astronauts train in two part-task trainers. They are designed to simulate the same neurosensory conditions that the crewmembers will face in flight so that they can be adapted to those conditions before they fly. Repeatedly placing crewmembers in and out of altered sensory conditions gets them dual adapted, allowing the brain to develop or have two or more sets of sensory programs for different inertial environments.

"If you repeatedly put somebody in and out of these altered sensory conditions, you can get them dual adapted," said Dr. Deborah Harm, a senior scientist in the Neuroscience Laboratory. "Once dual adapted, the astronauts, upon return from space, readapt much more quickly."

Bloomberg is also developing ways to increase walking adaptability of crewmembers by using an in-flight treadmill training regimen. The ISS experiment that he is in the process of defining involves developing a countermeasure that will mitigate the effects of long-duration space flight on control of locomotion. The idea behind it is to make the astronauts more adaptable. "With training, we hope to promote increased adaptability in walking ability so that astronauts can adapt faster when they make the transition from zero-g to Mars or Earth gravity environments."

The experiment is based on practice variability, the theory that if human beings are exposed to a lot of sensorimotor challenges repeatedly, they will become better learners; in essence, they will "learn to learn." The ultimate vision of this study is to create a virtual environment on a treadmill aboard the ISS. The next-generation treadmill would enable users to walk in more than one direction while immersed in a virtual environment. This would create a rich and varied walking environment that would enhance learning ability.



Subject on treadmill

NASA JSC Photo S96-00840

Artificial Gravity

In addition to making and keeping the astronauts more dual adaptive, artificial gravity may be used as a countermeasure to ease rapid transitions from one gravitational state to another.

There are two protocols to implement artificial gravity aboard spacecraft, one intermittent in which an astronaut would periodically get into an artificial gravity device and have gravity replacement therapy for the day and the other a longer arm device, a passive, permanent implementation of 1 g.

In the former, the person would go into a short-arm centrifuge and be spun around in a circle for a period of time. The brain would be triggered to remember 1 g adaptation and remember how to correlate all the different signals together with the otolith signal.

A different protocol would be to have the whole vehicle rotate. "We've talked about having two tethered vehicles, a kilometer apart, rotating slowly," said Paloski. "It would be a passive system, so you would always have this gravity load. As a result, you wouldn't have to worry about moving back and forth from zero-gravity to 1 g, which would result in some motion sickness upon each transition." Researchers are trying to understand the adaptive process so that they can develop a prescription for it – how often crewmembers would have to do this activity and for what periods of time.

There are no firm plans to have an artificial gravity device aboard the ISS, but researchers believe that having one on orbit is a good idea. "If you can keep somebody dual adapted for station and lunar/Mars missions with a centrifuge on orbit, then the recovery period and rehab that will be required upon return to Earth will be both shorter and less expensive," said Harm.

Conclusion

These countermeasures for neurological disturbances experienced during space flight are not new. A good deal of ground-based research has been done to test the theory behind pre-flight adaptation and an on-orbit centrifuge. The idea of pre-flight adaptation is now mature enough to begin evaluating its effectiveness with astronauts in the immediate future.

Future countermeasures include potential pharmaceuticals and manipulation of the basic substances of life itself. "We are looking at things at the systems level and seeing the changes there," said Reschke. "We are applying countermeasures to symptoms – that's where we've been and where we are."

Probing beyond the symptoms to the original causes of neurological disturbances experienced on orbit promises to open up new pathways and new countermeasures. ■