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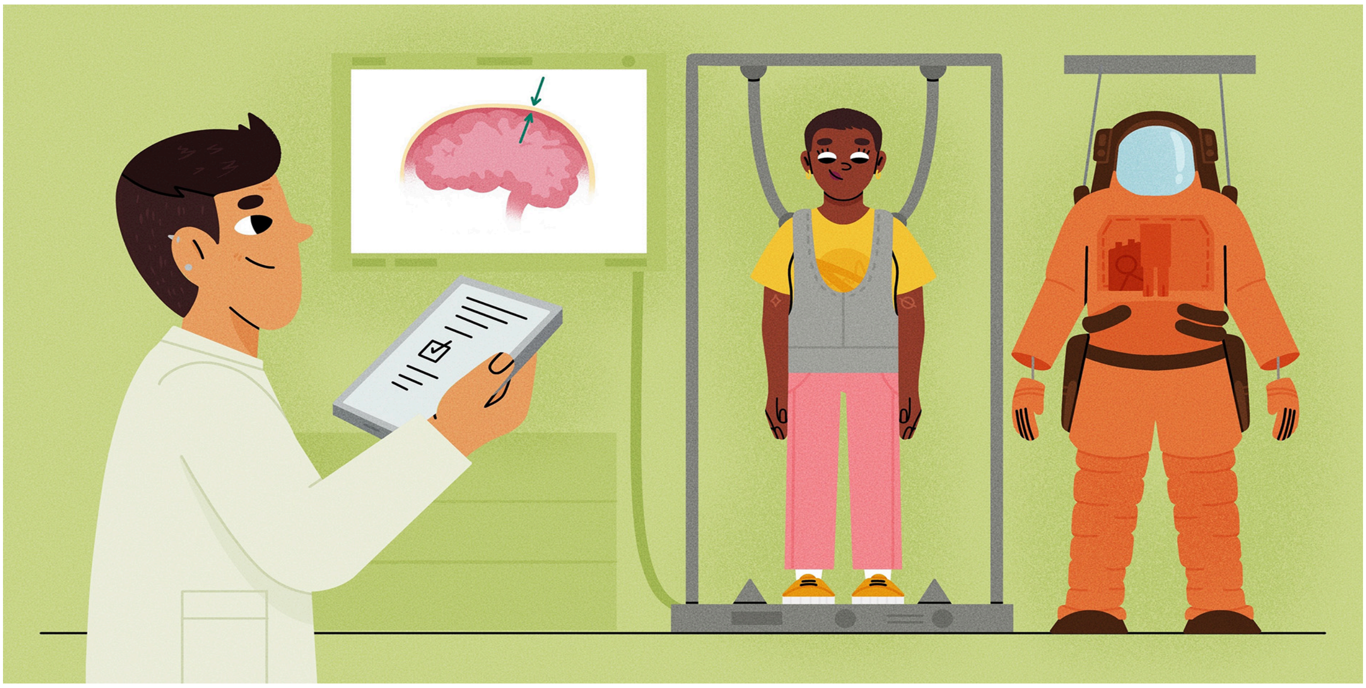

WHAT HAPPENS TO ASTRONAUTS' BRAINS WHEN THEY TRAVEL TO SPACE?

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YOUNG REVIEWERS:

AJAY
AGE: 8

CHRISTINA SEIX ACADEMY
AGES: 13–14

MRITTIKA
AGE: 15

For over 20 years, astronauts have lived and worked aboard the International Space Station. Astronauts face many challenges living in space, like not having Earth's gravity. This means that astronauts do everything—from brushing their teeth to doing science experiments—while floating. Not having Earth's gravity makes everything more difficult, and it changes astronauts' brains. Over the last decade, we tested 15 astronauts before and after their space travel. We measured their walking, balance, and coordination, and collected pictures of their brains. This article talks about our results. We found that, when astronauts returned to Earth, they had problems moving, like trouble walking and balancing. We also found that spaceflight changed how astronauts' brains look and function. We finish our article by talking about what is still left to learn. Our

big goal is to keep astronauts healthy for very long missions—to Mars and beyond!

The first humans traveled to space over 60 years ago. And, for over 20 years, humans have been living and working in space aboard the **International Space Station**. Now, we are making plans to send humans to Mars. However, to get people safely to Mars, scientists still need to understand more about how space travel impacts the human brain and body. Our lab has spent the last 10 years studying how spaceflight affects astronauts' brains and their walking, balance, and **coordination**.

INTERNATIONAL SPACE STATION

A space laboratory orbiting about 250 miles above Earth, where astronauts from various countries live and work in space.

COORDINATION

The ability to move parts of the body together smoothly while doing one task. The eyes and hands have trouble working together after spaceflight, but this gets better pretty quickly!

WHAT IS DIFFERENT IN SPACE?

Astronauts face many challenges in space [1]. They must figure out how to live and move without Earth's gravity. Imagine taking a shower or doing a science experiment while floating! In addition, the balance system in the inner ear, which is also known as the **vestibular system**, relies on Earth's gravity to tell us which way is "up" (Figure 1). Astronauts often confuse "up" and "down" in space because the vestibular system does not work the same way without gravity!

VESTIBULAR SYSTEM

The balance system, located in the inner ear, that sends information to the brain to help us balance and keep track of which way is "up" and which way is "down".

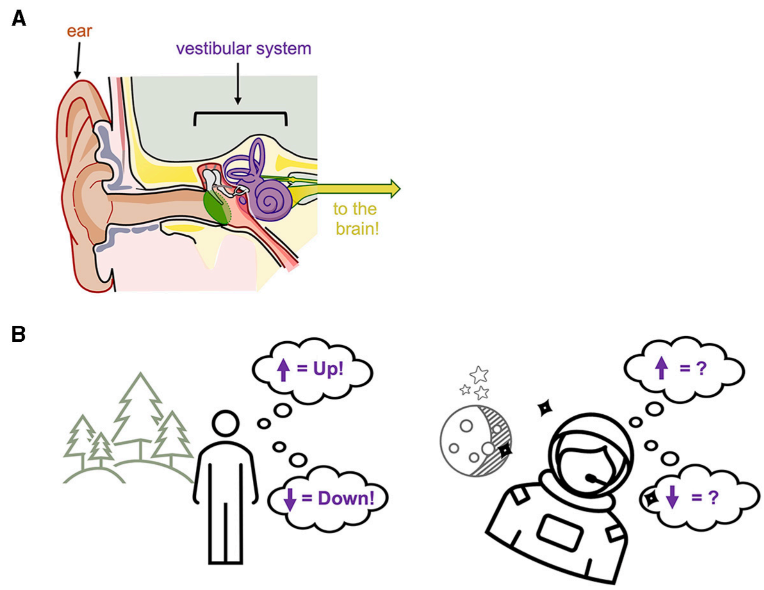

Figure 1

Figure 1

The vestibular system. **(A)** This picture shows the location of the vestibular (balance) system inside the inner ear. The vestibular system connects to the brain and helps us balance and know which way is "up" and which way is "down." **(B)** On Earth, the vestibular system works normally, and people can tell which way is "up." In space, without gravity, the vestibular system does not work as well, and the brain can get confused about up and down directions.

An astronaut's job is also stressful. For example, astronauts living in space spend months away from their families and friends. Astronauts also do not get the best sleep. We think that all of these things cause changes to the brain that would not normally happen on Earth. So, this was our big research goal—to understand what happens to the brain when people go to space.

WHAT DID WE DO?

We asked 15 astronauts to be in our study. They traveled to the International Space Station and lived there for 6 months to a year. We took pictures of each astronaut's brain two times before they went to space and four times after they returned home (Figure 2A). We took these pictures using a **magnetic resonance imaging (MRI)** scanner (Figure 2B). The MRI scanner recorded two things: the size and shape of the astronauts' brains, and which parts of their brains were working during various activities.

MAGNETIC RESONANCE IMAGING (MRI)

A machine that uses a powerful magnet and cellphone-like waves to take pictures of specific body parts. We use MRI to take pictures of the brain.

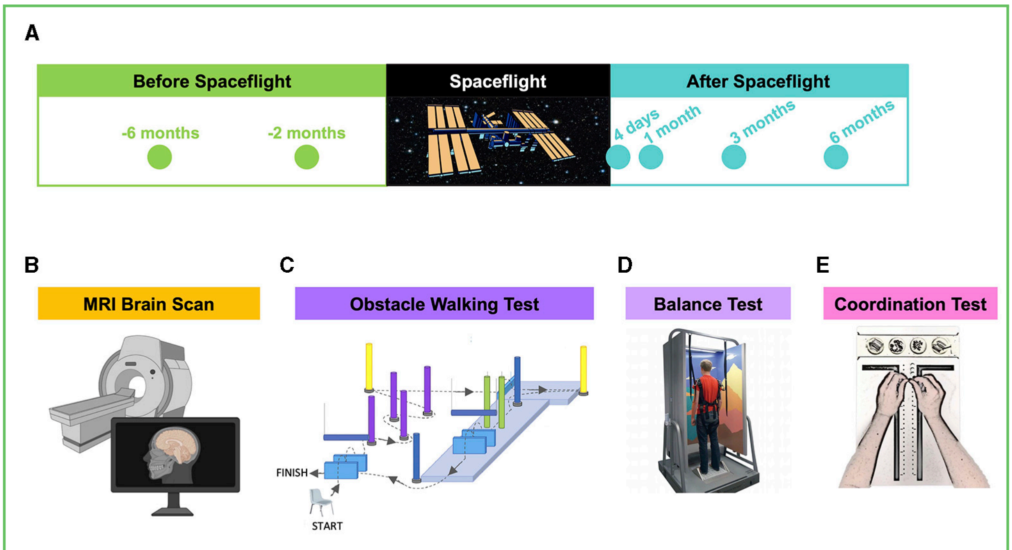

Figure 2

Figure 2

Timeline and tests. **(A)** We tested each astronaut six times: two times before and four times after they went to space. **(B)** Before and after spaceflight, astronauts had MRI scans of their brains; **(C)** then they walked through a timed obstacle course; **(D)** balanced on a tilting platform; and **(E)** put pegs into tiny holes. During the balance test, the platform tilted the astronauts' feet while they had their eyes closed. This made it feel like they were tilting.

We also tested astronauts' walking, balance, and coordination by having them perform activities like a timed obstacle course (Figure 2C), standing and balancing on a platform that tilts (Figure 2D), and putting pegs into rows of tiny holes (Figure 2E). We wanted to compare how well the astronauts did on these tests before vs. after spaceflight.

DOES SPACEFLIGHT CHANGE HOW ASTRONAUTS MOVE?

What did our research find? First, when astronauts got back to Earth, they were worse at walking, balancing, and using their hands to insert small pegs into holes than they were before they went to space [2]. We think this is because astronauts got used to moving around in a totally different environment in space—one without gravity. Because the vestibular system did not work properly without gravity, the brain "turned down the volume" of information from this system while in space. The astronauts also did not need to use their leg muscles very much to move in space—they could just float around the space station for months! These changes made it hard for them to walk normally when they got back to Earth. The astronauts' brains had to turn the vestibular signals back up and relearn how to move in gravity.

DOES SPACEFLIGHT CHANGE HOW THE BRAIN LOOKS?

Our next goal was to study how the brain looks after astronauts go to space (Figure 3A). We found multiple changes. First, the brain shifts up inside of the skull during spaceflight [3]. This shift squishes the top of the brain against the inside of the skull. We think that this squishing might play a role in some of the walking, balance, and coordination problems that astronauts have when they get back to Earth because brain areas involved in movement are the ones getting squished.

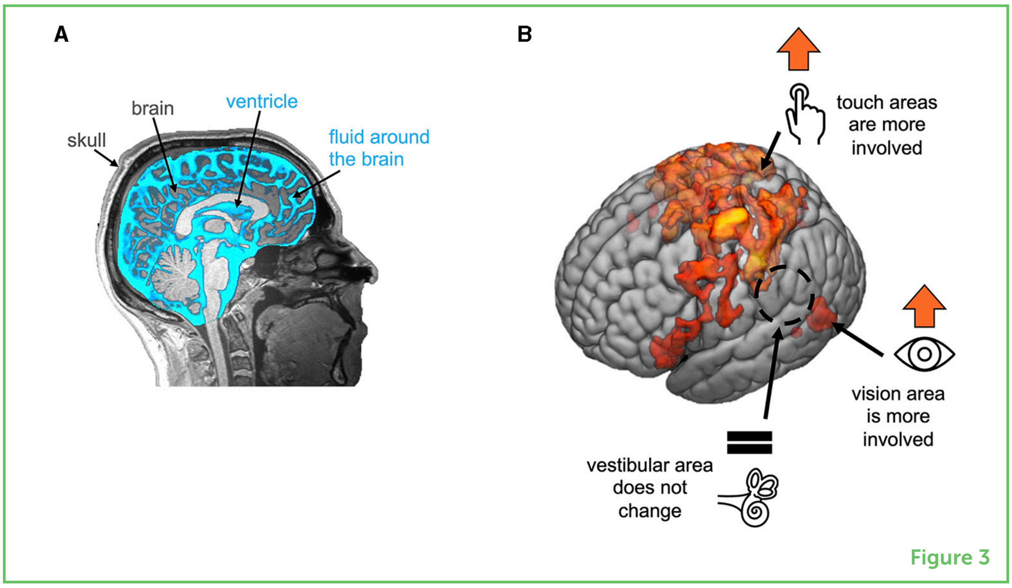

Figure 3

(A) Example brain MRI scan. We outlined the fluid and ventricles (water pockets) in blue (to protect astronaut privacy, this is a scan from a regular adult). **(B)** Changes in brain function with spaceflight. After spaceflight, brain areas involved in touch and vision also help the vestibular system process information. Since the vestibular system does not work as well after spaceflight, the brain needs help from touch and vision areas to understand incoming information!

VENTRICLES

Pockets inside of the brain that are filled mostly with water.

Second, we looked at how water in and around the brain is shifted after spaceflight. Inside the skull, the brain is surrounded by water. There are also pockets of water inside of the brain, which are called **ventricles**. We found that the ventricles got larger after spaceflight [3, 4]. In space, there is no gravity to “pull” water toward the feet. We think the lack of gravity causes extra water to stay inside the skull and makes it difficult for the extra water to drain out. The ventricles get bigger to help store this extra water. Right now, we are not sure if it is a bad thing that extra water stays in the brain during spaceflight, and we also do not yet know how long it takes for the ventricles to return to their normal size (if at all) when astronauts come home to Earth. So, this is definitely something that we want to study more.

Lastly, we found that astronauts who spent more time in space (like a full year) had bigger brain changes than astronauts who took shorter trips [3]. This is important because we want to plan longer space missions—but we need to make sure that people’s brains will stay healthy. For instance, a Mars mission could take almost 3 years, which is longer than any human has ever spent in space!

DOES SPACEFLIGHT CHANGE HOW THE BRAIN WORKS?

Our last goal was to study whether spaceflight changes how the brain works. As we mentioned, when living in space, astronauts lose their sense of "up" and "down." Since astronauts can float, this means they do not have to stand on the floor to brush their teeth, for example. They could brush their teeth while bouncing off the ceiling if they feel like it—they would not even feel like they were upside down!

We wanted to know if going to space changes the way the vestibular system works. To do this, astronauts laid in the MRI scanner, and we recorded their brain activity to see if their vestibular systems worked differently after spaceflight [5]. When astronauts returned to Earth, we found that more sensory parts of the brain got involved to help the vestibular system process information (Figure 3B). So, after spaceflight, brain areas responsible for understanding vision and touch still got involved to help the vestibular system work! We think this happens because the brain spends months in space getting used to not having Earth's gravity. Then, when astronauts get home, they need more "brain power" to function in Earth's gravity again.

Why is this important? These brain changes related to how well astronauts could balance after they returned home. Specifically, the astronauts who showed more brain changes could balance *better* post-flight. We think it is really important to understand why some astronauts adapt better than others to living in space and returning home. This could help us figure out which astronauts might need extra training before going to space or which might need the most help getting back to normal after returning home.

HOW CAN WE STUDY THIS ON EARTH?

Not very many people go to space, so this limits who can participate in our research studies. It took us many years to study just 15 astronauts!

So, scientists have come up with other ways to study spaceflight here on Earth. For instance, we have tested what happens to the bodies and brains of healthy people when they lay in bed—without standing up at all—for 2 months! These bed rest experiments let us study some effects of spaceflight, like how astronauts in space do not need to use their legs and feet to support their own body weight while standing and walking.

Other researchers study what happens when people fly on special airplanes that "fall" through the air for about 20 seconds at a time. This lets people on the airplane float for 20-second periods. But the problem is that 20 seconds is a really short time for researchers to study what happens without Earth's normal gravity! So, these tests are different from tests on people who spend months in space.

Other scientists have studied what happens to people who spend the winter in Antarctica. These people cannot leave their research stations because of the unbearable temperatures outside. These studies help us understand how being very isolated and confined inside might affect people's mental health and how their brains work.

Each of these situations can provide us with *some* information about how the human body might respond to spaceflight. However, nothing is as informative as actually going to space. Therefore, over the next years, scientists will need to continue studying more and more astronauts. This will give us an even better understanding of what happens to astronauts' brains and bodies when they spend time in space.

WHAT IS THE TAKEAWAY MESSAGE?

Overall, traveling to space seems to be generally safe for humans. When astronauts return from space, they should expect to have some temporary problems moving around, like trouble walking and balancing. With an MRI scanner, we can see that certain brain changes happen when astronauts go to space. The brain shifts up, the ventricles (water pockets) get bigger, and more "brain power" is needed to process certain information. Some of these changes take a few months or more to get back to normal after astronauts return to Earth.

Together, all our results will be really important for planning future space missions. Studying what happens to the brain in space will help us understand how humans can safely live in space. This information can also help us to develop better training and better treatments to keep astronauts healthy as we send people on longer and longer missions.

WHAT IS NEXT?

There is still a lot of work to be done before we fully understand what happens to people's brains when they go to space. But do not worry—there are a lot of people on the job! Many scientists around the world are studying how to make space travel safer.

For example, our team's next research will follow astronauts for 5 years after they get home, to see just how long it takes for certain brain changes to recover. Overall, we hope that this work will help us better understand how to keep astronauts safe when they explore new frontiers—like Mars, or beyond!

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

AJAY, AGE: 8

8-year old Ajay studies in the third grade and likes to write screenplays, put together storyboard for comics, make paper crafts and lego models. He likes playing with friends and watches Arthur episodes. Ajay's favorite time during vacation trips is in the pool. Both Ajay and Mrittika are voracious readers.

CHRISTINA SEIX ACADEMY, AGES: 13–14

Christina Seix Academy's class of 2023 is a group of 17 brilliant, curious and motivated adolescents who value intelligent dialogue and a good scientific challenge! Being a part of the peer review process with Frontiers for Young Minds set a wonderful expectation of academic accomplishment as they begin their final year of the independent schools educational experience in the middle school.

MRITTIKA, AGE: 15

15-year old Mrittika loves hanging out with friends and family. Her interests include: playing the viola, dancing, singing, reading, and calligraphy. Math, Social Studies, and Music are her favorite subjects. Mrittika's favorite accomplishments are becoming a senior editior on her yearbook editing team and being a publicist for her school's Drama Department. She received an award for being the best foreign language student of the year in middle school and is a finalist in a nationwide computer science competition. Mrittika aspires to be a more open-minded and knowledgable person.

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Dr. Kathleen Hupfeld is a postdoctoral fellow at the Johns Hopkins University School of Medicine. Her research looks at how the brain changes as people get older and after they return from outer space. She uses brain imaging, brain stimulation, and various types of behavioral tests in her research. She hopes to 1 day be a professor with her own neuroscience lab. In her spare time, she loves to read, kayak, SCUBA dive, and hang out with her rescue cat, Yeti.

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Dr. Heather McGregor is a postdoctoral fellow at the University of Florida in the department of Applied Physiology and Kinesiology. Her research focuses on how sensation affects movement and how learning changes sensation abilities. Outside of the lab, she enjoys traveling, comedy, and watching movies.

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Dr. Rachael Seidler is a professor of Applied Physiology and Kinesiology at the University of Florida. Her research focuses on how the brain changes with spaceflight or with aging, and how that impacts peoples' abilities to move. She measures various aspects of brain structure, function, and chemistry as well as how people think and move. She has published over 150 research articles. In her spare time, she likes to play tennis and spend time with her teenage daughters. *rachaelseidler@ufl.edu