"Major Tom's Brain to Ground Control" with Mark Shelhamer, Sc.D.

Transcript of Cerebrum Podcast

Guest: Mark Shelhamer, Sc.D., is professor in the Department of Otolaryngology—Head & Neck Surgery at the Johns Hopkins School of Medicine, where he started as a postdoctoral fellow in 1990. He has bachelor's and master's degrees in electrical engineering from Drexel University, and a doctoral degree in biomedical engineering from MIT. At MIT he worked on sensorimotor physiology and modeling, including the study of astronaut adaptation to spaceflight. He then moved to Johns Hopkins where he continued the study of sensorimotor adaptation with an emphasis on the vestibular and oculomotor systems and nonlinear dynamics. From 2013 to 2016 he served as chief scientist for the NASA Human Research Program. His research since that time has emphasized multi-system and cross-disciplinary interactions that contribute to personal and mission resilience in spaceflight.

Host: Bill Glovin serves as editor of Cerebrum and as executive editor of the Dana Foundation. He was formerly senior editor of Rutgers Magazine, managing editor of New Jersey Success, editor of New Jersey Business magazine, and a staff writer at The Record newspaper in Hackensack, NJ. Glovin has won 20 writing awards from the Society of Professional Journalists of New Jersey and the Council for Advancement and Support of Education. He has a B.A. in Journalism from George Washington University.

Bill Glovin:	When we think about what we can learn from spaceflight, the first thing most of us think about is how do you get so far so fast? And then maybe next you wonder with the way robots and artificial intelligence is advancing, whether we even need humans in space. After all, and no matter how you slice it, spaceflight is a dangerous business, especially when you factor in the possible cost of human life. Hi, I'm *Cerebrum* editor Bill Glovin and welcome to the Cerebrum Podcast, where we explore brain science topics with leaders in the neuroscience field. Our podcast is sponsored by the Dana Foundation in New York City, and you can find all our content at Dana.org.
Mark Shelhamer	We send people into space on a regular basis. There has been constant presence of humans in the International Space Station for over 20 years. 20

years, that would have seemed like science fiction when I was young. And it's only going to get more ambitious with Elon Musk sending people into space, other space programs. So the fact that people are still able to function at a very high level, given all of these stressors, given all of these risks, given the demands of spaceflight, is really remarkable.

Bill Glovin: Today we have a little something different for you. We welcome in Mark Shelhamer, who served as chief scientist for the NASA human research program from 2013 to 2016 and is today a professor of head and neck surgery at the Johns Hopkins School of Medicine. Mark also happens to be the author of our recent *Cerebrum* magazine cover story on what spaceflight is teaching us about the brain. We called it "Major Tom's Brain To Ground Control," a shout out to the masterpiece of a song by the late David Bowie.

Anyway, welcome to our podcast, Mark. Let's start by getting into the fundamental question that I posed in that long-winded introduction. Do we even need humans in space? And if we do, what is the advantage of having them there?

Mark Shelhamer Thanks, Bill. First of all, glad to be here. Most people have the good graces to wait until the end of an interview to ask me that question, because that's the real payoff question that a lot of people are curious about.

Bill Glovin: Why bury the lead, as they say.

Mark Shelhamer I'm happy to get it out of the way early while I'm still fresh. Really, it's a great question. And it's kind of a fundamental question because I think as we go on with this, you'll discover the many challenges to sending people into space, and at some point, you could very easily throw up your hands and say, "Well, what's the point of it all? With all this complication, all this risk, all this potential danger, why send people at all? Robotic probes and rovers are doing a phenomenal job." And there's a couple answers to that.

There's the intangible aspect of it. And I think there's a report that came out of a program at MIT 10 or 15 years ago that basically at the bottom line said, *"Human exploration of space expands the human experience."* And for me, that's basically as simple as you can get it. If you can do it, if you can go out, if you can expand the range of human capabilities and the human intellectual reach by actually sending people to very extreme places and having them explore, that's, I think, worthwhile doing in itself. Now, there's a question of whether the government should support that. How dangerous should you get? All those things are involved, but I think that's largely what it comes down to for me.

Now, let me give you a second answer that's maybe a little bit more related to the scientific aspects of things. Because I get this from my scientific colleagues and my wife is an astrophysicist. She works for NASA, so we have these spirited debates sometimes at home about the need to send humans. And I ask some of my scientific colleagues occasionally, "Would you be happy sending a robot into your laboratory to do your scientific research?" Now I get it, a laboratory environment is not as dangerous as sending people to Mars and nowhere near as expensive. But still, the idea is we're sending people to Mars, to the moon, out into space, deep space exploration, because we haven't been there before. We're sending people with the very notion that they will discover things that are unexpected, unanticipated, and that's where people really shine and where robotic and automated probes are arguably less good. You want them to be able to follow up on serendipitous observations, pursue the unexpected, and for that, you need people.

Bill Glovin: One thing that wasn't in the story that I think our listeners would be interested in is, how did you become chief scientist for the NASA or human research program? And have you ever fantasized about becoming an astronaut yourself?

Mark Shelhamer I'll answer the second question first. Of course. I think almost anybody who gets anywhere near close to this endeavor, human spaceflight, thinks about what it would be like to be an astronaut. And I would say yes. I would say the more I learn about it, the more I have some trepidations because it can be grueling at times. It's a demanding environment, and we ask a lot of astronauts; but who could turn down the opportunity if it were realistically presented, whether that would be just to go into orbit for a while, or to actually go to the moon or to Mars?

Now, as to how I got the position at NASA, I'm tempted to say it was a matter of poor career-planning on my part, but in fact it was a series of happy accidents, let's say. The business of exploring what happens to people in space for me started back in the 1980s when I was a graduate student. I was working in a laboratory at MIT called, at that time, the manned vehicle laboratory. And I was interested in spaceflight and I was learning everything that I could about the Apollo program, the early NASA space program, just as a hobby and looking for a place to go to graduate school. And I found, much to my surprise, that there was a laboratory where I could do graduate level research, getting my Ph.D., that was doing it on the changes in sensory motor function that occur when you send people into space. And I just had no idea that I could combine some of my professional interests in how brains adapt biomedical signal processing, those kinds of things, with my hobby interest, human spaceflight, and what NASA had been doing.

And this was the start of the shuttle program in the early 1980s. So I did that for a number of years. Came to Johns Hopkins as a postdoctoral fellow in 1990, didn't do anything space-related for several years, trying to catch up on some of the more fundamental neurobiology work that I wasn't doing in graduate school. And then started getting back into spaceflight research, and then the opportunity came up to take a temporary position. At that point, the manager of the program wanted to bring some new blood into the program for a limited time. So the idea was that I would go in for two years, it since expanded it to three, serve as the chief scientist and bring some new ideas and then go back to my academic position. It was a bit of an agonizing choice to put away my own research for two years, what turned out to be three years, and take a position that was really involved with oversight of research. But I was fascinated by the prospects of seeing the big picture, seeing how all the different pieces are connected in the human research program's research portfolio.

So that's how I ended up there and glad I did it. Glad to be back at Johns Hopkins where I can pursue my research, but now I'm pursuing my own research with, really, a very different eye now that I have seen the vast range of things that are involved in keeping humans healthy and fit in long duration spaceflight, looking at this a much broader multidisciplinary perspective.

Bill Glovin: Becoming an astronaut may be one of the most selective jobs on the planet. Some people are willing to pay Elon Musk millions of dollars for the opportunity. Given that you have 20 unbelievable candidates for a particular mission, what are the key attributes the space program looks for in narrowing the number down from, let's say, 20 to three or four people?

Mark Shelhamer Need to be careful to say that I was never involved in the astronaut selection process, either bringing astronauts in has as astronaut candidates, hiring them to be astronauts, or selecting them for missions. That's a—I won't say—a secretive process, but it's a process that has some proprietary aspects to it. But I can tell you the aspects that we try to maintain in people on the research side, the big thing for me, of course, you want to select people who are extremely healthy, extremely fit, but you want to select people who have put themselves into demanding situations, you might say risky situations, people who know how to make risk calculations, pilots, skydivers, people who climb mountains, those types of things. Not dare devils, not people who are necessarily adrenaline junkies, but people who know how to take calculated risks and can put themselves in those positions, preferably as part of a team, because the team aspect, the interpersonal relationship aspect of spaceflight is huge. And it's going to get bigger as we have more demanding missions, where it's just not possible to come home if you're not getting along with your crew mates.

So in general, good health, fitness, good healthy lifestyles, but resilience, I think would be the key word. Have these people overcome obstacles in their own lives and personally and professionally? But also do they show the ability to compensate when they can't perform tasks in a demanding setting? Do they know what it is to have work arounds? Do they not get flustered when there is no ideal solution to a problem and they just have to make do with the best that they have available? So, all of these related, of course, to very high cognitive function, but also very high fitness across the board. So resilience would be my keyword here.

Bill Glovin: So what kind of mental and physical testing is required?

Mark Shelhamer

I don't know, frankly. In detail, I really don't know. There are legendary stories. I understand that a lot of this is proprietary, to some extent. There are legendary stories from other space programs. For example, the Canadian space program is extremely selective even compared to the American program because they select very few astronauts and very rarely do they have a selection process. But my understanding is that they will put their Canadian astronaut candidates, at least when they've already jumped through a number of hoops, in situations in which they are asked to solve problems for which there is no solution. It is literally impossible to find an answer to the situation that the Canadian Space Agency interviewers put the candidates in. And this is unusual for high performing individuals in any space program.

You do not get to be an astronaut by not performing at a very high level for a long period of time throughout your career. These are people who are used to achieving great things. So to put them into positions where they're frustrated, because they might not be able to achieve a desired solution, I could very well imagine that that would be the kind of thing you would look for.

And then I'm just guessing here, because like I said, I'm not privy to the real details of the selection process, but I would imagine standard cognitive tests, short-term memory, some spatial awareness, reaction time. I know we use those on the research side, I imagine they're probably part of the selection process as well.

Bill Glovin:

Since you brought up the Canadian program, that makes me wonder, how much collaboration goes on between, let's say, or does it at all, between countries, between the Elon Musk adventure in terms of getting results about cognitive and mental health, for example, something your article focuses on? Does that exist?

Mark Shelhamer

It does exist. It exists very, very much so. Just as an example, the International Space Station, which is now the centerpiece of human spaceflight programs, while we prepare to go to the moon and Mars, the International Space Station is called the International Space Station for very good reason. It is run by an international consortium. The Americans through NASA and the Russians through their space program, are the primary players. They put up the most resources, but there's significant contributions from Canadian Space Agency, Japanese Space Agency, European Space Agency, including a number of others that I'm sure I'm leaving out. And that also extends to the research that's done.

Each program, of course, runs their own research program, runs their own astronaut and cosmonauts selection process, but they train together before they will fly together. They have to, because their lives depend on each other. And they work together very closely on the International Space Station, including working together on science experiments. And those science experiments are brought forward by a number of countries. There is, right now, a compliment of experiments that NASA has put together. It's called CIPHER. I think that stands for Compliment of Integrated Protocols for Human Exploration Research. And this is a very ambitious effort on NASA's part to proactively integrate a number of individual studies across sensory motor system, bone health, nutrition, a lot of different areas, and look at them as an integrated package. And NASA has about a dozen or so of those studies. And there's about five or six that are from international partners. So I would say, yes, very much so, there is international coordination and collaboration.

Bill Glovin: Mark, your article focuses a lot on stress, and it certainly doesn't take a brain surgeon to realize that stress is a big part of the spaceflight experience for astronauts. Is stress factor the most studied area of the astronaut experience?

Mark Shelhamer Probably. Of course, it depends on how you define stress and if you're willing to define stress broadly enough, you can say, yes. Just about everything we do or everything they do in the human research program or we do as spaceflight researchers, is related to stress. Now, typically people will talk about stress and they'll mean psychological stress. And of course, there are psychological stressors involved in being in space. The workload is very high.

As I point out in the article, we don't send people into space so that they can just sit around and look out the window. They do, in fact, look out the window. They find that very relaxing and very soothing in their downtime, but in general, they are extremely busy maintenance, regular operations on the spacecraft, exercise, scientific experiments, including human research program experiments. So, high workload, small space, isolation and confinement, they're away from home, away from the normal comforts of home, largely. The fact that there is very little that you would call natural. There's not a lot of plants. There's no greenery. There are some plants up there now that they've been growing recently on an experimental basis, but basically you can't smell the rain. You can't feel the wind. You're seeing the same spaces and the same people day after day, month after month. And you're being asked to perform at a very, very high level during that, with all those stressors.

So on the psychological side, there are those stressors and those are studied extensively, but you know, weightlessness is also a stressor. Now, we see astronauts jumping around in space, and I know from limited, personal experience in parabolic flight aircraft, that being in a zero G environment, being weightless, is an exhilarating experience. It would be hard to understand why you might consider that a stressor, but it is a stressor. It's a physiological stressor because of the number of things that happen to the body. When you remove gravity, you go into a zero G or weightless environment, fluids shift toward the head, get sinus congestion, that alters the sense of taste and sense of smell. That is a stressor, if you're not getting the normal satisfaction that you get out of food. So there are the physiological stressors, as well as the psychological stressors. So I would say, yes, stress is one of the key things that encompasses just about everything we look at.

Bill Glovin: So you beat me to the weightlessness question, because that was going to be my next question, but another area that your article touched on was the sleep cycle, which is tied to light and dark and more commonly known in neuroscience as circadian rhythms. There has been a definite link to proper sleep and good mental health on earth, for sure, so what is the circadian rhythm issue for astronauts? How important is it?

Mark Shelhamer Like so many aspects of spaceflight, you could hardly design a worse environment for people to get a good night sleep. And yet, as you pointed out, sleep is crucial to so many things, mental health, but also obviously performance, physical performance, psychological and physiological well-being. It's really important. Astronauts take, this is kind of an open secret, but astronauts do take medications when they're in space. And the most popular medications are for pain, headache, and backache, partly due to fluid shifting toward the head, but also because posture changes and the spine elongates a little bit when they're in space because they don't have gravity loading, so pain medication, but also sleep medication is relatively popular, not for all astronauts, but for a significant number.

And that's because, among other things, they lose the normal light, dark cycle when they're going around. It's not that there's a lot of windows on the space station to start with. But to the extent that you can even look outside, there is light, dark alteration, every 90 minutes. Every 90 minutes, they're going around the earth, so that's a lot of sunrises and sunsets during the day. And the lighting inside the space station is relatively constant because you need a certain level of lighting for safety reasons. Now, there has been some progress there. NASA a few years ago, flew some lights up that the wavelength and the intensity of the lighting can be modulating, so you can start turning them down, just like starting to see this advice online about not using the blue screen on your portable devices right before you go to bed, because blue is a bad color if you want to induce sleep.

So light, dark cycles, the lighting inside ISS, which never really gets dark except in the sleep compartments. Very high workload, astronauts are very highly self-motivated, and they have timelines that they adhere to, so it's largely go, go, go, go, go. Stop. Go to bed. Now they have a downtime built in for a pre sleep period, maybe on the order of a half hour to an hour in which they're supposed to wind down, but I imagine many of them will try to catch up on work or get a start on the next day's work and maybe not wind down as much as NASA would like them to. Some people also find it difficult to sleep because you can't put your head back on a pillow. It's hard sometimes for them to find a comfortable position. In some cases, bubbles of CO2 will start to envelop the head because, if you're sleeping in an area that doesn't have good atmospheric ventilation, good air ventilation, cabin fans. So a number of things that can contribute to poor sleep.

On the other hand, there are some astronauts who say they've never slept better, because being able to strap themselves in a sleeping bag, but still avoid the normal pressure points that you get from sleeping on a bed in a gravity field, they actually find that very enjoyable. So it can go either way. Nevertheless, sleep is a concern just because of the nature of the environment, high workload, lack of normal circadian rhythms. And we're finding the more we learn about circadian rhythms, the more we find that it's not just the brain and the pineal gland that is establishing a circadian rhythm for the entire body, it turns out that a whole multitude of different cell types have their own little circadian clocks in them distributed throughout the body. So you want to make sure that they're in trained with each other and they're not disrupting that. So that has to do not only with light, dark cycles, but also when do you exercise in the day, when do you eat during the day? All of those are prone to disruptions.

And other ways the environment is not sometimes not conducive to good sleep is alarms for various reasons on the space station that sometimes will go off in the middle of the night, you must get up and respond to an alarm, if you're on the space station, even if it's a false alarm.

Bill Glovin: Something like a manned spaceflight to Mars, for example, would take almost two years. Since it's never been done before, what would be the challenges to a crew over such a long period of time, at least from a mental and cognitive point of view?

Mark Shelhamer Actually, the typical thinking for a Mars mission, it could likely be three years. There are some two-year design reference missions as they're called. Typically, when we think about it, we think of three years. With current propulsion capabilities, about six to nine months to get there about the same to get back and then a year, a year and a half or so either on the surface of Mars or orbiting Mars, in the Mars vicinity. So either way, two years or three years, that is a long mission.

The current record for continuous presence in space is still held by the Russian program, and it's something on the order of 400 and some days. This was done quite a few decades ago. There have been a very small number of people who have spent on the order of a year in space, probably less than 10 at this point. NASA is going to be doing, if the plans work out, more one-year missions to the International Space Station, with the idea of filling in this gap from six months, between six month missions and three year missions to presumably to Mars. But what are the issues going to be?

Well, the big one is autonomy. Resilience is one of the keywords for spaceflight crews and autonomy is the other one. When a Mars mission gets out to a certain point, that crew is going to Mars, no matter what. They literally cannot turn around. The propulsion demands that they go to Mars, that they wait for the proper planetary alignment to minimize the distance between the earth and Mars for them to come back again, so there's no such thing as cutting the mission short. So at some point, maybe it's a month into the mission, maybe it's two months into the mission, let's say somebody comes down with an intractable illness or a traumatic injury that cannot be properly treated. Well, you may lose a crew member out of your four- or six-person crew. And guess what? The rest of the crew is going to go to Mars and perform their mission.

So there's a certain mind-set that comes along with that, that has to be taken into account. That's part of the training. That's part of the autonomy and the psychological resilience of the crew, but really autonomy in the sense that the crew is largely going to be on its own on a Mars mission. Resupply missions from earth? I don't think so, not at that distance. When the crew gets to Mars, they will have available to them whatever has been pre-positioned, so presumably a habitat and a certain amount of food, drugs, supplies, and whatever they take with them, which will be limited because of the size of the spacecraft and the propulsion capabilities. So if something breaks, if there's an emergency, if there's a medical emergency, the crew is going to have to figure out things for themselves. You can't perform surgery. You have limited supplies of antibiotics, pain medications, every type of medication and limited syringes, hypodermics, intravenous capability, all of those things. So the calculations become very tricky.

Let me give you another aspect of that, because of the distance between the earth and Mars, one way communication time, one way radio communication time can be on the order of 20 minutes. So this is on the order of 40 minutes round trip communication delay, so you have a medical emergency and you call home for help. 40 minutes later, you get an answer. And that's assuming that the earth and Mars are not on opposite sides of the sun. In which case you're not communicating with each other at all. You have to give the crew the tools, both tangible and intangible to perform autonomously. And for that period of time, with that small a crew, in such extreme circumstances, we don't have that experience, yet, with humans.

There's human experience with various pieces of it, military special forces, for example, small groups in very extreme environments. Submarine crews, long periods of time, isolated, confined, but there's a relatively large number of them and they can do a medical evacuation. So none of them captures the precise combination of the extreme environment, small group of people, and almost complete autonomy from earth.

Bill Glovin: Your article touches on increased levels of carbon dioxide and radiation and their effect on the brain and also there's issues concerning vision function and white matter in the brain in space. Any of those things you want to touch on in terms of importance to the whole matter of spaceflight and the brain?

Mark Shelhamer Well, this information is freely available. NASA is very transparent. In terms of what being done and what the findings are on the research side, this information is freely available. Go to the NASA human research program website. There are links to publications. There are links to what are called evidence reports that NASA assembles, putting together the state of the evidence for any of these various areas.

The thing that I find the most fascinating about this, is the fact that there are all these issues, and you named some of them, there's elevated CO2, there's altered sleep patterns in some cases, there have been changes found on imaging, obviously after the flight, because there's no MRI imaging capability in space, but there are changes seen from before flight to after flight in some aspects of brain structure and function. It's still a small number of people. And there are some lacks of standardization in the imaging protocols. People are working on that. So it's difficult to know what to make of some of these studies, but some of them are troubling because anything that has to do with something that might impact brain function, cognitive function, mental capacity, in space, where crews have to be autonomous in a very demanding situation, that's potentially troubling.

Now, so far, this has not been a problem. Astronauts are very capable. They are able to work around a huge number of problems. Here's what I find interesting. You can list all of these things. You can list all of these problems and you can look at some of the imaging studies and say, "Oh wow. It looks like there are some actual changes in neural structure and all right, they seem benign so far and people recover from them, but wow, this looks really bad. And the combination of these things, wow, this looks really dangerous." On the other hand, we send people into space on a regular basis. There has been constant presence of humans in the International Space Station for over 20 years, 20 years. That would have seemed like science fiction when I was young. And it's only going to get more ambitious with Elon Musk sending people into space, other space programs.

So the fact that people are still able to function at a very high level, given all of these stressors, given all of these risks, given the demands of spaceflight, is really remarkable. And I think that's the key takeaway, the fact that people, professional astronauts at least, we will see how well this holds out when we start sending paying passengers into space, but professional astronauts at least, having gone through a very highly selective process and extreme amount of training are very highly motivated.

Even if there is a decrease in cognitive function, and there is some indication from some tests that there are decreases in cognitive function in space. There's something that astronauts sometimes call space fog or the space stupids. It's just the sense that things that I used to be able to do on earth seamlessly without thinking about them, now, all of a sudden, they're a little bit more challenging for me to do. All right, given all the stressors that are going on up there, that's hardly surprising, but is there something specific about spaceflight that induces that? We don't know.

Nevertheless, it doesn't deter astronauts from doing their jobs. So, the really fascinating thing is that people exhibit a high amount of resilience, even if there is a decrease in mental capacity or cognitive function of some sort. If there's an increase in reaction time, if there's a decrease in short-term memory, any one of those things and all these things are tested regularly in space, if any of those things occur, astronauts still have the mental capacity to rearrange how they do their jobs. Maybe they ask for additional help. Maybe they say, "That's a low priority task. I'm going to wait until I'm better rested to take that on." Maybe they just reconfigure their workspace to take into account their deficits. So the fact that they're still able to do that means they're still working at a very, very high level cognitively, even if there are individual tests that indicate that there may be some deficits in specific functions. So that I think is the key takeaway, just the amazing resilience of people to reorganize and reconfigure the way that they do things.

Bill Glovin: And then one of the fundamental questions that your article tries to answer, which maybe you could briefly talk about here, is has spaceflight taught us any meaningful lessons about cognitive function or mental health that we've been able to apply to folks on earth?

Mark Shelhamer Yeah, hard to point to something specific. People have asked this, of course, about a lot of the experiments. Have we learned anything about bone loss, about cardiovascular function, about sensory motor function, And in those areas, there are some—call them success stories—there are some examples that you can point out in which human spaceflight research, research done on humans in space and the human experience in space, has given great scientific insights to terrestrial health and medicine.

In the area of cognitive function, I don't know. It would be hard for me to point to some specific things. So I think it'd be too early to say yes to that question, except, the fact that we're recognizing the extraordinary adaptive capability of people in extreme environments when they're properly prepared. I think one thing that might come out of this is a better understanding of human resilience. Are there people who are just inherently resilient or is there something about the way that people are trained? Is it something about the way that they organize their environment and their workspace and their living conditions and their interpersonal relationships?

These are all things that could potentially come out of spaceflight that would have a huge impact on understanding of cognitive and mental function, but as yet, maybe not. Except to tell us that if we're going to be trying to assess cognitive and mental functions in people on earth, you need to be clever about it. Because if people know, and especially astronauts are very high performing individuals, very competitive. If you give them a test to perform, they will, chances are, perform very, very highly on that test because they will concentrate on that test to the exclusion of all other things and perform very well.

And same with high performing individuals in a number of areas, athletes, military personnel, they want to perform at a high level, but what happens in the real world when they can no longer avoid all the distractions and have to perform at a high level, performing a number of things, all at the same time, that's something we don't yet know how to assess. So figuring out how to assess that cognitive capability of resilience and self-organization, flexibility in high performing individuals, I think lessons learned from that could be very valuable for earth based testing.

Bill Glovin: What are some of the highlight takeaways from your three-year term as a chief scientist? Does anything particularly stand out to you that you worked on or contributed to?

Mark Shelhamer Yeah, there are a few things. One is what I described earlier, and that's the huge array of things that are involved. Nominally, I'm a sensory motor researcher. This is what I've been doing for close to 40 years. Neuro vestibular function, balance function, eye movements, posture, locomotion, spatial orientation, space motion sickness, those are the kinds of things that basically paid my mortgage for a long time and got me through graduate school. And those are really important, obviously. They are parts of central nervous system function and that's the brain. And we've been talking about the brain here and it's in the article as well, very central to the human experience in space, but it was a real revelation to me to see just how critical are the other areas.

I always knew that they were important, obviously, cardiovascular health and bone integrity, and things like that. But especially the, what NASA calls, behavioral health and performance issues, that's their euphemism for psychological and psychiatric concerns, the things related to the human response to stressors of various kinds. The realization of how central that is, because if you were to look at this as a network, the stress response would be a central hub in that network. The stress response impacts not only cognitive function, but obviously cardiovascular function, we know that from terrestrial medicine, the microbiome, the immune system, and those in turn, the gut microbiome has an impact on cognitive function. So the interconnection between all of these things and the fact that, hey, guess what the neuro vestibular system is maybe not the most important thing when you send people into space. Well, okay. I kind of expected that that might be so, but really seeing it laid out because it was my job to oversee the entire portfolio and give equal weight to all of those things. So that's one of them.

The other is, the extent to which some things that are just good, old fashioned common sense here on earth are also relevant to space. Exercise, and nutrition, those are really key and sleep. And certainly, NASA puts a huge amount of effort into astronaut exercise and nutrition. The food supply in space now is really quite good and varied. And that's because it not only has to maintain their nutritional requirements, it's also a psychological countermeasure. Getting together for a meal with your crew mates, that's a very strong bonding experience in many cases. And exercising, obviously, hits a number of areas, including psychological wellbeing. That's just a, your mother could have told you that.

Bill Glovin: I think that's a great place to end. And I'd like to thank Mark Shelhamer, author of our *Cerebrum* magazine cover story, “Major Tom's Brain to Ground Control.” You can find his article at Dana.org. Again, we are brought to you by the Dana Foundation in New York City. I can't thank you enough, Mark. Your article is fantastic. This has been endlessly fascinating.

Mark Shelhamer Thanks, Bill.

Bill Glovin: I'm your host Bill Glovin. Thanks for listening. And please stay healthy out there.