Twin study in space: Gemini mid-mission update on pathbreaking nature-nuture research

Gemini–the name has meant different things in different time periods, all in connection with space. There is the myth of Castor and Polydeuces, where Zeus placed the two twins in the sky. There was Project Gemini in which the National Aeronautics and Space Administration (NASA) first sent two astronauts together into space in preparation for Project Apollo. And, now there is really a new kind of Gemini mission, except this time the twins are not together. As in any good genetic study, they're separated to help scientists determine the relative contributions of genetic and environmental factors to a biological phenomenon.

In genetic research, twin studies are the gold standard when it comes to addressing–gene by gene, trait by trait–that old question: is behavior shaped by nature or nurture, or a combination of both; and in the latter case what is the relative contribution of each?

The one-year mission

On the international space station (ISS), astronaut Scott Kelly of NASA and Cosmonaut Mikhail Kornienko of the Russian Federal Space Agency (Roscosmos) are now into a routine work schedule. Recently, they passed the halfway point of their one-year mission that began last March, and they have a regular sleep-wake cycle. Each "morning", they wake up and go to work and each "night" they go to sleep to get ready for the next day. Unlike most people on Earth they can't leave their workplace, but they enjoy an unusual view through the window and during the workday they're pretty busy, mostly running experiments, many on themselves.

Unlike Kelly, Kornienko has no twin brother. Back on Earth, whenever possible, Mark Kelly is doing things the way his brother is doing them in orbit. Because the two are identical genetically, any differences in results of hundreds of different tests on the two brothers will be the result of the space environment. For example, if levels of a certain hormone are higher in Scott, or if the gene that makes the hormone is turned on in one brother and not the other, scientists will be able to hone in on the differences in terms of how they are affected by the space environment.

Data are being collected

The studies involve virtually every body system on multiple levels: organ-system, tissue, cell, and genetic. It's a massive project and for most of the scientific questions, we won't have answers until after the mission when all of the data are analyzed and published. To be sure, there's always the possibility that the results will not be published; there's an issue of genetic privacy and how families can be affected by genetic revelations. Either brother can decide not to allow the results to be released. But most likely, that's not going to happen. Both twins are committed to the study, one of its main motivations being that it will provide information about human space biology over a long period in the space environment that will facilitate a human Mars mission. Both brothers are public figures–Mark is the husband of Congresswoman Gabrielle Giffords, who was wounded seriously in an attempt on her life, and he therefore is active in movements to strengthen gun control– and both have a military background and a strong sense of mission. Still it's always possible that some major susceptibility to a medical condition will show up in the testing, leading to a need for either brother to protect his family.

The studies include how weightlessness, space radiation, and other aspects of the space environment affect the immune system, the cardiovascular system, gut microorganisms, bone density and the the likelihood of osteoporosis, exercise physiology, vision, and also mental health.

As for how the experiments are going so far, it's the science operations people on the ground at NASA that can answer best.

"Probably one of the biggest hurdles was coordinating, planning and executing the first session of the Fluid Shifts study," said Becky Grimaldi, payload operations manager at NASA's Marshall spaceflight center for space station Expeditions 43 and 44. "Fluid Shifts examines the various fluids moving around the body in microgravity and pressures it can put on organs such as the eyes and brain. In orbit, the experiments involve activities in the Russian segment of the station and we had not done those types of operations before. We needed to coordinate with our Russian counterparts a lot more than usual."

Implications for a future Mars mission

Press release after press release, new conference after news conference, much is made about the relevance of the one-year twin study to a future mission to send humans to Mars. It's true that the experiment results are likely to be helpful for any future human missions, which will be getting longer and longer as humans move outward. However, it's also possible that the Mars mission connection is being hyped. In the stories, quite often the long time in space for the twin study is emphasized based on the idea that the first human mission to Mars and back to Earth will last 2.5 to 3 years. But that's based on NASA design reference missions that assume standard chemical propulsion systems, like those used to deliver astronauts into low Earth orbit and, back in the 1960s and 70s (and probably again soon), to the Moon). But for going to Mars and beyond, propulsion researchers are looking to decrease travel time substantially.

To understand what the design reference missions are, consider NASA's Apollo spacecraft that took astronauts to the surface of the Moon six times from 1969-1972. With an extra module and extra supplies, the old *Saturn* V booster and a modified *Apollo* vehicle could have taken astronauts at least to flyby or maybe orbit Mars in the 1980s. That could have happened, had the US desired it badly enough and had we not diverted human space flight into the shuttle program.

As with the various robot probes that have gone to Mars, it would have been a fairly long trip. Unlike a lunar mission, an *Apollo–Saturn*-based Mars mission would have begun with more than one rocket launch with rendezvous of the astronauts and all of their supplies in low Earth orbit (LEO). Then, the ship would have set out for Mars by accelerating in LEO to a velocity just a little bit faster than the velocity used to go to the Moon. This would set the craft on its own orbit around the Sun for arrival at Mars several months later with a round trip time of 2-3 years, depending on alignment of the two planets, and that's the same way a robot mission works.

While current visions of human Mars missions depend on numerous advances made since the 1970s in life-support, computers, and a plethora of other areas, the design reference missions used to study all aspects of such a mission still assume chemical propulsion and thus the same mission timing that they've assumed since the *Apollo* era. But everything that we've learned about humans in space since the old days says that the best way to make a human mission safer is to get the astronauts to Mars and back quickly. In addition to group psychology issues, the advantages of a faster trip have to do with the effects of weightlessness, and importantly, space radiation, on the body.

One-year study will not reproduce radiation exposure of a Mars mission

The experiments going on right now will provide valuable information about human health and physiology during long-duration human space flight. That's because on the ISS astronauts are weightless, just as they will be weightless during a flight to Mars, unless the ship is designed to rotate to create some artificial gravity. Being above Earth's atmosphere, the astronauts also are exposed to a much higher level of space radiation compared with people on Earth's surface, or even those on aircraft. But the radiation exposure on ISS is significantly less than what it will be for astronauts during a Mars mission. That's because ISS still gets a lot of protection from Earth's magnetosphere, which acts as a shield against high energy charged particles, such as protons and large atomic nuclei that travel through interplanetary space.

This is not a reason to avoid sending humans to Mars, because such a mission entails many risks that any astronauts who want to go understand and are willing to take. However, due largely to space radiation, there is a realistic concern about an increased cancer risk and other health issues. Since Kelly and Kornienko get the geomagnetosphere protection, they will not get anything close to the radiation exposure of a Mars mission. Back during *Apollo*, astronauts traveled outside of the geomagnetosphere going to the Moon. During *Apollo* 16 and 17, the missions carried experiments called *Biostack* that looked at the effects of the deep space radiation on numerous species, which taught us a lot. But since the missions were relatively short (the longest was 12 days), even Apollo did not simulate a Mars mission in terms of radiation. And while the current mission on ISS stretches it out to a year, radiation of different doses produces different effects. The relatively low radiation exposure on ISS per day may not be a good model at all for exposure on a Mars mission.

New propulsion systems are in in the works

Understanding the effects of weightlessness better will be extremely helpful even for voyages not coming close to a year. When it comes to the cardiovascular system, for instance, including the body fluid shift of spaceflight that researchers are studying right now, those changes begin within the first day of weightlessness. When it comes to loss of minerals from the bones, that also happens quickly. Within a few days, the risk of kidney stones increases substantially, because astronauts are excreting calcium rapidly in the urine. Bone demineralization leads to spaceflight osteoporosis, with an estimated bone loss of 1-2 percent per month in space. Exercise and other countermeasures may slow the bone loss, but the risk of fracture upon arrive at Mars increases in proportion to the travel time.

But with all of the false starts and promises of human Mars missions going back to the 1980s, what has been chugging along the whole time is propulsion research. NASA has an active advanced propulsion program looking at nuclear engines and other technologies. Opponents of nuclear energy may find this an inconvenient truth, but nuclear engines can reduce astronauts' radiation exposure dose significantly by taking them to their destination quickly, rather than letting them soak in the radiation that Mother Nature sends through interplanetary space.

At the same time, former astronaut and plasma physicist Franklin Chang Díaz has been working a new engine strategy for decades. It's called VASIMR. During Chang Díaz's time at NASA and since his leaving NASA, VASIMR has gone from the drawing boards to a budding propulsion system. Based on Chang Diaz's calculations and results of a step by step testing program for engine prototypes, the technology will enable a human Mars mission with a travel time in each direction of just 39 days. It may sound futuristic, but considering the timelines projected for human Mars exploration –which begins in the 2030s in the best scenarios– the VASIMR engine, or something like it, will be reality prior to the first human voyages to Mars. This means that planning human missions based on chemical propulsion is not necessary, and that's advantageous not only because of the medical effects of long-duration space flight, but also for another reason. Should there be an emergency along the way, a shorter travel time (a month instead of a year) would make a rescue mission much more realistic.

We must learn all that we can about the medical issues, but also keep in mind that propulsion advances will dictate what missions are possible. Like setting course for Mars by aiming for where it will be in its orbit around the Sun when your ship arrives, we also have to research the human issues projecting for the kind of mission that we'll actually do by the time that we're ready to go and to go boldly.

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