Don't forget to pack the gravity

Exercise alone won't be enough to keep astronauts healthy on a round trip to Mars

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FLOATING around in microgravity inside a spacecraft might look like fun, but it can do nasty things to your body. With the current enthusiasm for crewed space flight and particularly NASA's plan to send astronauts to Mars, there is a need to find ways to counteract the damaging effects of a lack of gravity.

Without Earth's gravity, astronauts lose their hand-eye coordination and as the days go by they suffer a steady loss of red blood cells and deterioration of bones and muscle, including the heart.

Back on Earth it can take weeks for an astronaut to re-adapt to terrestrial gravity, and they risk broken bones and torn muscles for much longer. "The body tries to adapt itself to a free-fall environment, and this creates enormous problems on return to gravity," says Kevin Fong of the Centre for Aviation, Space and Extreme Environment Medicine at University College London.

This could be a huge problem if NASA decides to go ahead with its planned trip to Mars. Existing proposals for a "bank robbery" mission, in which a spacecraft would fly there and back as quickly as possible, would take six months each way. After such a spell in microgravity, astronauts could find themselves landing on the Martian surface in dire physical shape. The techniques so far developed to try to limit this deterioration, including subjecting astronauts to rigorous exercise in orbit strapped to a treadmill or cycling machine with elastic bungees, have all proved ineffective.

The answer, space scientists increasingly believe, is to create artificial gravity in orbit. "We'll be taking our own air, food, heat and light to Mars. Why not just take gravity along with us as well?" says Fong.

Gravity can be simulated using a rotating body, which produces a centripetal force. The idea was first proposed in 1911, when space-travel pioneers envisioned a large spinning doughnut-shaped section of a spacecraft that would provide a gravity-equipped habitat for astronauts. Among alternative designs was a large centrifuge created by two rotating crew habitats on each end of a long boom – rather like a spinning baton – jutting out horizontally from the centre of the spacecraft. Work, exercise or recreational time spent in such centrifuges would greatly reduce the physical deterioration of astronauts on a trip to Mars.

The problem is that spinning spacecraft modules are not practical at present. Since the force generated by such a module depends on its radius and how fast it rotates, it would have to be well over 100 metres across, or roughly the size of the London Eye, to create the same gravity as Earth while spinning at a reasonably gentle few rotations per minute. Artificial gravity systems would also generate a number of other disorientating sensations and illusions (see "Light head, heavy feet").

Far more feasible in engineering terms would be to create a small centrifuge that spins at high speed within the main body of the spacecraft. That's what Bill Paloski, a neuroscientist at NASA's Johnson Space Center in Houston, Texas, is investigating. He is carrying out a study in which volunteers spend three weeks lying in a bed with their head lower than their feet, to recreate some of the damaging effects of weightlessness. Half of the people are taken to a centrifuge and spun for an hour a day to create an artificial gravity of 2.5 *g* at their feet, decreasing to about 0.7 *g* at their head.

"We're seeing what benefits artificial gravity brings to the body as a whole, looking at everything from muscle and bone strength to heart function, levels of stress hormones and aerobic fitness," says Paloski. The early results are encouraging, he says, and he hopes to be able to publish them next year.

Small centrifuges have a major drawback, however. A centrifuge around 6 metres across – small enough to be reasonably accommodated inside a space station or spacecraft – would have to spin at up to 30 rotations per minute to generate Earth gravity at an astronaut's feet. This is enough to cause severe motion sickness. To prevent astronauts being crippled by these effects, teams are concentrating on developing spinning gyms rather than living or working quarters where astronauts would be free to walk around.

Vincent Caiozzo, an orthopaedics specialist at the University of California, Irvine and his team have built a short-arm centrifuge called the Space Cycle. One astronaut sits on a suspended bicycle-like device, opposite which hangs a cage containing another astronaut, and both are attached to a central pole to form a centrifuge. By pedalling the cycle, the astronaut makes the centrifuge spin, swinging the bike and platform outwards. The device not only provides a strenuous cardiovascular workout for the pedal-pusher, but also generates artificial gravity for both. The astronaut in the cage can then exercise and keep their muscles toned. "Squats are particularly good, as they target the large muscles worst hit by weightlessness, in the legs and lower back," says Caiozzo.

The team has also been experimenting with the possibility of boosting the dosage of artificial gravity, spinning faster in order to provide the same physical protection from shorter gym sessions. "We've had some subjects doing squats straining against three times terrestrial gravity," says Caiozzo. Paloski is also interested in the prospect of using hypergravity, but warns that there is a lot of work still to be done on how this might work best.

For a start, hypergravity means spinning the centrifuge at a nausea-inducing 40 rotations per minute. However, Paloski has shown that by keeping their heads still, people can largely avoid motion sickness, even while performing gentle squats.

Also designing an artificial gravity gym is Larry Young at the Massachusetts Institute of Technology. His gym will have a cycle on one arm and a cage containing a treadmill on the other. He believes astronauts can adapt to artificial gravity. "Virtually anyone can adapt to head movements at very high centrifuge rotations within just a few sessions," he says.

The trick, Young says, is to train the brain by making repeated movements in artificial gravity and progressively increasing the rotation rate. "The brain learns sensory-motor programmes appropriate for each gravity environment and simply loads up the one required at the time," he says. "It is much like the experience with new spectacles as your brain learns how to make head movements without causing motion sickness."

So not only should astronauts be able to move around on the centrifuge without crippling nausea, just as importantly they can also hop off again with no after-effects. This should mean that ultimately living and working quarters might not be out of the question.

So will astronauts be able to cope with a trip to Mars? More work needs to be done on the effects of long-term exposure to centrifuging, Paloski says. To start to address this, Young's team is set to launch the Mars Gravity Biosatellite into near-Earth orbit in 2010. In it, mice will be spun for over a month inside a small centrifuge to recreate the partial gravity of Mars, which is around a third that of Earth.

If the research proves successful, astronauts could take a spin in the gym once a day, and return from Mars as fresh as they went out. "Ultimately, we might prescribe gravity like a drug, with astronauts taking a couple of doses a day," says Paloski. ●

LIGHT HEAD, HEAVY FEET

Astronauts in artificial gravity would experience a number of disorientating sensations. Not least of these would be the disturbing sight of the universe wheeling around them at high speed whenever they catch a window out of the corner of their eye.

The force generated in a spinning capsule would also have a steep gradient, so while it might be the same gravity as Earth at the astronaut's feet, it would be noticeably lower at their head. This means that if someone were to sit down in a chair, they would feel themselves growing steadily heavier.

Since the strength of artificial gravity depends on the speed of rotation, an astronaut's weight would also change depending on whether they were walking in or against the direction of spin. Run too quickly, and they could float off the ground.

Adding to these strange sensations would be the Coriolis effect, which causes objects moving in a rotating system to be deflected sideways. So everyday tasks like reaching for a keypad would suddenly become difficult.

Worse still, when someone moves their head, the mismatch in balance information registered by the inner ears would mean that whenever they looked up at an instrument panel, they would experience the brief illusion of their entire body tumbling headlong.

V. J. CAIOZZO, UNIVERSITY OF CALIFORNIA, IRVINE

A spell in the space gym, the next best thing to a spinning space module

"We'll be taking our own air and food to Mars, why not just take gravity along as well?"