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Innovations Influencing Physical Medicine and Rehabilitation

Adaptation, Artificial Intelligence, and Physical Medicine and Rehabilitation

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Abstract

Adaptation, cooperation, and trust are at the center of rehabilitation. Artificial intelligence and robots enhance adaptation with guidance for movement, cues for sensation, control of environment, and improved situational awareness. That said, how do we decide to trust complex technologies that might seek personal information or control dangerous equipment?

Introduction

Life adapts. Adaptations happen at every scale of size and time throughout the world. We respond within seconds to an emergency, becoming stronger, faster, more awake, and more alert. On a longer time scale, we learn skills such as how to ride a bike or how to hit a tennis ball. Our minds and bodies respond to new input with stronger muscles, greater coordination, and smoother moves. On evolutionary time scales, species adapt to changing climates and different environments. Adaptations make life remarkably resilient; there are creatures that live in alkaline lakes, in acid ponds, and in undersea vents where there is no sunlight and temperatures reach hundreds of degrees.

Humans have taken an extra step; we not only adapt mentally and metabolically, but we also actively change our environment to make our lives more comfortable. We can now effect change on a planetary scale and, although that could have negative repercussions for Earth, it opens the possibility of someday walking on Mars in shorts and short sleeves.

As physiatrists, we help people who have undergone irreversible changes adapt their bodies and minds to recover lost function. We strengthen some muscles to take over from others that have become weak. We use techniques to relearn sensation and proprioception through alternate paths. We provide methods for new types of communication when normal speech and hearing no longer work properly. We restore mobility. We find new ways for people to use their remaining abilities so they can still drive a car, take a bath, or cook a meal. However, the natural responses to trauma or disease or a new environment involve different adaptations. Some of those are positive and some are negative. Our job is to enhance the positive ones, suppress the negative ones, and sometimes create new ones.

We have all experienced adaptation, but I feel fortunate to have experienced some unique forms. Space flight causes neurologic and neuro-vestibular changes (Figure 1). Proprioception is altered in a way that is not well understood. As my arms were unloaded from gravity, I had to use visual cues to know where they were. Just before going to sleep, I let my arms float in front of me, closed my eyes, and waited 30 seconds. Then I tried to touch my right index finger to my left. Not only did I miss by more than 8 inches, I also had a strong and strange perception that my right arm was passing through my left arm! My ability to do this task did not improve over the 9 days in flight. Some anecdotes are reminiscent of neglect syndromes. For example, one astronaut told me that shortly after entering orbit he was reading a display when someone's hand floated in front of him. Only when he pushed it away did he realize it was his own hand.

Our crew did a series of experiments during the flight to measure our vestibulo-ocular reflexes (Figure 2). The results showed that reflexes change during space flight, which impedes performance on tasks such as following

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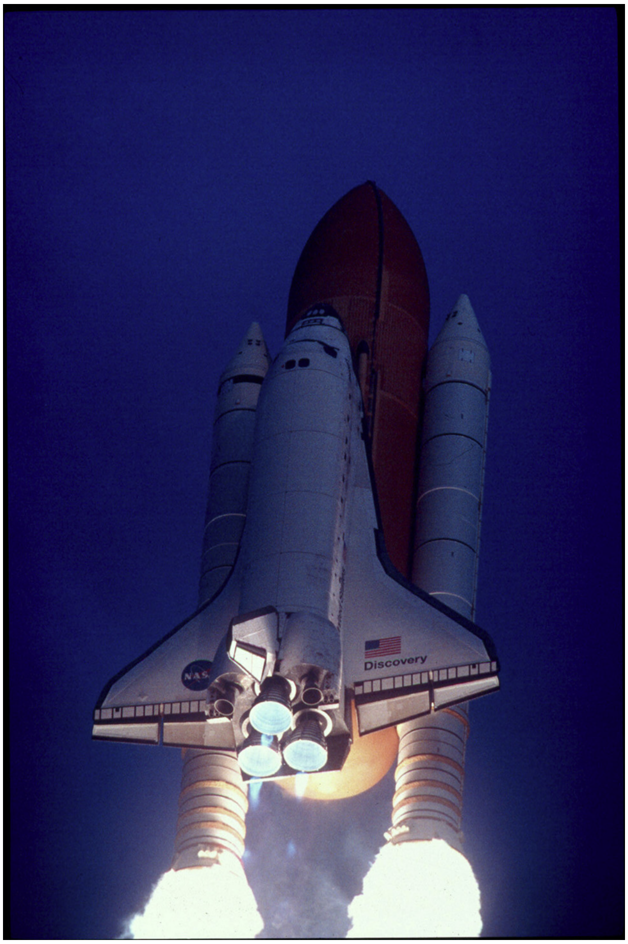

Figure 1. Discovery heads to orbit. I had the honor of flying twice on the Space Shuttle Discovery and once on the Endeavour between 1996 and 2001, including 4 space walks and 2 trips to the International Space Station. Image credit: NASA.

checklists. On Earth, it is easy to read a line in a checklist, look up to throw a switch, and look back down right at the same place on the checklist. In flight, if we float just a little bit, when we look back down our eyes arrive at the wrong spot on the page. This makes it easy to skip a step in the checklist. As the flight progresses, we adapt and become more accurate at the task.

Figure 2. I am wearing sensors testing my vestibulo-ocular reflex responses. Image credit: NASA.

Here is the clinical note written about me immediately after my first flight, after just 9 days in space: "Patient has reduced postural stability and orientation, perceived exaggerated pitch and roll head movements during walking, significant oscillopsia during locomotion, a wide gait, increased knee bend, and greater strike force." Mechanisms of these characteristics can include decreased viscoelastic properties of joints; altered pattern of joint kinematics during locomotion; decreases in muscle strength, tone, and force and velocity profiles; hyperactivity in H-reflex and stretch reflex characteristics; altered lower limb muscle activation patterns; and decreased otolith-spinal reflex. Note that most of these changes correspond to *adaptive* responses from being without gravity. They are a problem only if you want to return to Earth.

These changes resolved but it took a week before I was safe to drive and a few more days before I was safe to fly again. During the first few days, especially when just awakening, I would catch myself trying to float an object (in a notable example, our 8-year-old sleeping son, which produced a remarkable amount of squawking) from one place to another, to no avail. After my second flight, 3 years later, I recovered within a day. After my third flight, 2 years later, I was fine in just a few hours. The improved recovery times surprised me, because I did not consciously change anything about my post-flight activities. This is a typical pattern for veteran astronauts, but the mechanism is a mystery.

While in space, I was happily unaware of the consequences of my new responses but not all adaptations are positive. For example, spasticity after spinal cord injury allows a cat to walk but is often a significant problem for human patients. The loss of bone mass with bedrest or spaceflight is a harmful adaptation. Astronauts in freefall lose from 1% to 1.5% of their bone mass every month they are in orbit [1]. Some of that bone mass returns with rehabilitation on Earth, but there is not a complete recovery. Even for those who regain the mass, the architecture of the bone remains permanently altered. Furthermore, the process of bone resorption produces increases in blood and urine calcium levels, with their own attendant problems such as increased risk of kidney stones. Therefore, the normally beneficial adaptive process of bone remodeling based on stress patterns becomes a maladaptive process under these circumstances. Of course, for those who plan to live their entire lives in space, bones are not needed—possibly the science fiction movies showing aliens with bloated bodies attached to long tentacles are an accurate reflection of a species adapted for life in space.

Helping people to adapt was what first brought me to rehabilitation medicine. I will never forget the first patient I encountered who got me thinking about rehabilitation. She was an elderly woman who had