Research on Muscle Fibers Sheds Light on Why Muscles Weaken in Space and on Earth

Exercise is important to maintaining muscle strength and tone here on Earth, but it's even more important in space. Without the resistance provided by gravity, muscles quickly lose both size and strength. If long-term human exploratory missions in space are to become a reality, it is essential to find ways to prevent this muscle atrophy. The work of Robert Fitts and his colleagues is aimed at understanding the cellular processes that cause muscles to weaken and at developing exercise regimens so astronauts can maintain their muscle strength during space missions.

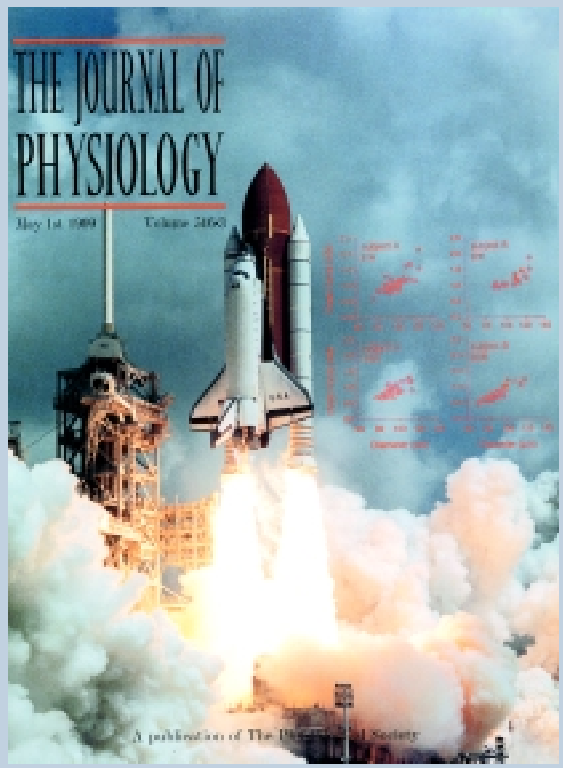
When astronauts return to Earth after a space flight—even one of just a few days' duration—they find that the leg muscles that enable them to stand and walk have weakened. When they walk, the weakened muscles feel sore as a result of damage caused by the unaccustomed weight bearing.

"The loss of muscle and bone that occurs in weightlessness is one of the main limitations on NASA's ability to send astronauts into space for extended missions," says Robert H. Fitts, Wehr Distinguished Professor of Biology at Marquette University in Milwaukee. "Our research is primarily aimed at helping NASA overcome this limitation. The particular research questions that our work is addressing are: What particular parts of the muscle are being lost? How is that affecting function? And how can we prevent it?"

To try to answer some of these questions, Fitts and his colleagues conducted an experiment aboard the Life and Microgravity Sciences space shuttle mission in 1996. Another NASA-supported investigator, Danny A. Riley, of the Medical College of Wisconsin in Milwaukee, collaborated on these studies.

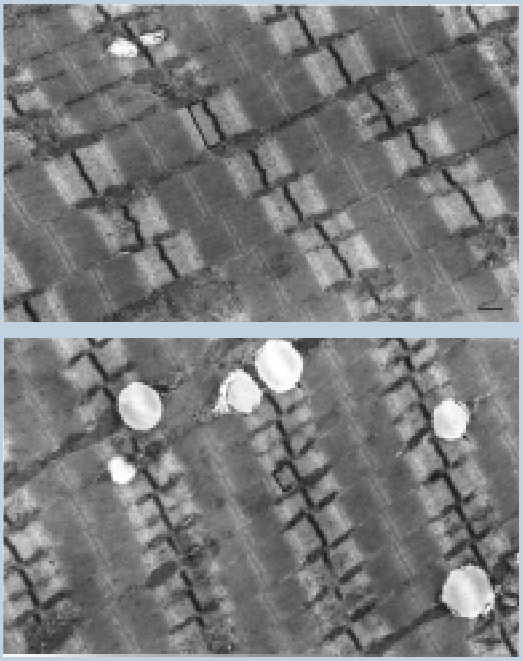
About six weeks before the mission launch, samples of a muscle in the calf that is important for standing and walking—the soleus—were obtained by needle biopsy from four of the mission astronauts. Immediately after the shuttle returned to Earth on completion of its 17-day mission, additional samples of the same muscle were obtained from the same astronauts.

The researchers then analyzed and compared fibers in the pre-flight and post-flight muscle samples. "In 17 days the muscle fibers lost about 10 percent of their size," says Fitts. As a result, the muscle generates less force and power.



The Journal of Physiology, in its May 1, 1999 issue, reports the results of Robert Fitts' Life and Microgravity Sciences shuttle mission (STS-78) experiment. (Reprinted by permission of The Physiological Society).

Muscle fibers are of two main types: "slow" fibers that work against gravity to maintain erect posture and "fast" fibers that are involved in rapid, high-power movement such as jumping and sprinting. "The slow muscle fiber is the primary anti-gravity fiber," says Fitts. "When you go into space, it's the fiber that's affected the most because it isn't working against any load. The muscle cells' natural response



Sections of a slow soleus muscle fiber obtained from an astronaut before (upper) and after (lower) space flight, viewed with an electron microscope. Atrophy following flight is demonstrated by the thinner myofibrils (a functional unit of muscle) and shorter Z lines (a muscle anatomical feature) in the flight sample (see brackets for comparison.)

to the reduced load is to shrink. Our work has shown that weightlessness affects slow muscle fibers to a greater extent than fast fibers."
The researchers also observed that, when subjected to an external load, the post-flight slow muscle fibers began to behave more like fast fibers. Specifically, they contracted more rapidly, making them more adapted for rapid bouts of sprinting than for long-term standing or walking. The Fitts team's experiments suggest that this change is related to a disproportionate loss of one of two proteins in the muscle fiber cells that interact to generate muscle force.

"We think this is a positive adaptation that the muscle fiber cells are making to microgravity. As a result of this adaptation, the decline in the muscle fibers' power is less than it otherwise would have been."

Other studies of astronauts on even shorter space missions have found that slow muscle fibers actually changed to fast fibers. In a study on rats, 25% of the slow fibers in a thigh muscle changed to fast fibers during a 14-day space flight. "Our hypothesis is that with longer flights, the degree of fiber-switching from slow to fast will increase," says Fitts.

Before the shuttle experiment, Fitts and his colleagues conducted an Earth-based simulation that involved eight men who stayed flat on their backs in bed for 17 days—the same length of time as the shuttle flight. As in the shuttle experiment, samples of soleus muscle were obtained before and after the period of bed rest. These samples were subjected to the same kinds of analysis that the astronauts' muscle samples underwent later.

The result? "From the point of view of muscle fiber size, force, velocity, and power, the changes were quite similar for 17-day bed rest and 17-day space flight," says Fitts. This means that, at least for muscle studies, bed rest is a very good model for weightlessness. "It's a model that we can use to test potential countermeasures—because you can do a lot more bed rest studies than experiments on the space shuttle."

Fitts and his colleagues are planning another bed rest study to test an exercise program that they believe will offer protection against atrophy of the slow-muscle fibers. "We've seen preliminary evidence from ground studies that isometric exercise—muscle contraction at a constant length—will best protect the slow anti-gravity fibers, whereas isotonic exercise—muscle contractions with shortening and lengthening—is best for the fast fibers," says Fitts. The researchers also hope to conduct a series of experiments aboard the International Space Station to learn more about what happens to muscle when humans spend longer periods of time in space. Initially, astronauts will spend periods of three to four months aboard the space station.

"There is some evidence that the greatest amount of muscle atrophy occurs during the first month and after that it levels off," says Fitts. "Our prediction is that muscle loss does not continue indefinitely but that over time some sort of microgravity 'steady state' is reached." He and his colleagues hope to test that hypothesis by collecting data on changes in muscle fibers after 30 days, 60 days, 90 days, and longer periods in space.

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