SPACE
{Editorial Insights}

What’s Load Got to Do with It?
Challenges of Space Travel for Skeletal Muscle Function

Elisabeth R. Barton*, Ph.D.

***Correspondence:** erbarton@ufl.edu**, Applied Physiology & Kinesiology, College of Health and Human Performance, University of Florida**

Abstract: Space exploration represents one of humanity’s most ambitious endeavors, pushing the boundaries of technology, science, and human endurance. Among the many physiological challenges posed by space travel, its effects on skeletal muscle are among the most significant. The microgravity environment alters normal forces acting on muscles, leading to adaptations with profound consequences for astronauts' health and performance and similar issues for space tourists. What follows is meant to capture the breadth of topics associated with the physiological effects of space travel on skeletal muscle and the underlying mechanisms, distinctions in the profile of professional and casual space travelers, and preparations needed for short- and long-term human space exploration.

Keywords: Skeletal Muscle, Space Travel, Microgravity, Muscle Atrophy, Space Tourism.

Skeletal muscle serves as a critical component of the musculoskeletal system, enabling movement, maintaining posture, and contributing to overall metabolic health. Under Earth's gravity, skeletal muscles are constantly subjected to mechanical loading. This force, whether from standing, walking, or exercising, stimulates muscle maintenance and growth through mechanotransduction—the process by which mechanical signals are converted into biochemical responses. In space, microgravity drastically reduces the mechanical load on skeletal muscles, particularly those responsible for maintaining posture and resisting gravity, such as the muscles of the lower back, legs, and neck. This lack of mechanical loading triggers a cascade of physiological responses that lead to muscle atrophy and other changes, with significant implications for astronaut health. Overall, load is critical for maintaining functional muscle mass.

Skeletal muscle atrophy, or muscle mass loss, arises from an imbalance between the pathways that make proteins and those that break them down. The “use it or lose it” mantra that underlies the goals for maintaining healthy muscle also applies in microgravity. However, by eliminating the ability to normally use muscles, space tips the balance toward degradation. Pathways contributing to functional muscle mass and function are affected in the following ways:

Decreased protein synthesis: Reduced mechanical loading diminishes the activity of anabolic pathways, such that muscle building shuts down.

Increased protein degradation: Concurrently, loss of load stimulates catabolic pathways, causing accelerated breakdown of muscle proteins.

Altered muscle properties: Microgravity affects the balance between slow-twitch and fast-twitch muscle fibers. Slow-twitch fibers, which are more resistant to fatigue and adapted for postural control, atrophy more significantly in microgravity, leading to reduced endurance and muscle function.

Altered metabolic properties: The decrease of slow twitch muscles also reduces mitochondrial content, and thereby aerobic metabolism. This compounds impairments on endurance. Further, muscle atrophy decreases glucose uptake by muscles, simply because there less muscle tissue to use it. As such, systemic metabolic disturbances arise in microgravity.

Studies on astronauts returning from space missions consistently reveal significant reductions in muscle mass and strength, particularly in the lower limbs (Fitts et al, 2000). Leg muscles that are heavily involved in weight-bearing and locomotion on Earth exhibit reductions in cross-sectional area (CSA) by 10–30% after extended missions of six months or more. Further, muscle strength declines more slowly than muscle mass, but cumulative losses of up to 30% in strength have been reported after prolonged missions. In many ways, smaller and weaker muscles after long-term spaceflight are reminiscent of the consequences of aging, but they take place in the span of a few months rather than decades. It may serve as a wakeup call to Earthbound humans to use their muscles to ensure they don't lose them.

Microgravity effects extend to other load sensitive tissues, including bone, which is exacerbated by the lack of muscles exerting forces on the bones via muscle-bone crosstalk (Demontis et al 2017). Weightbearing leg bones are particularly susceptible, and exhibit rapid bone loss. The demineralization of bones arises from an imbalance between calcium absorption and resorption, similar to the protein stability imbalance in muscle. A decrease (> 50%) in calcium absorption and an increase (>50%) of its excretion were observed in three crew members, who spent 115 days onboard the Mir space station (Smith et al., 1999). Disturbances in circulating calcium alters muscle contraction properties, as well as additional neuronal activity, expanding the impact of loss of load from the load-sensitive muscle and bone to cognitive function.

The negative impact of space travel on the human body is well known. Astronauts spend years preparing for space missions, and they undergo rigorous physical training before their missions, designed to optimize strength, endurance, and overall fitness. This preparation ensures they have a high baseline of skeletal muscle mass and metabolic health, reducing the immediate impact of microgravity on muscle atrophy. In contrast, space tourists generally do not receive extensive physical training before their flights. While some companies offer pre-flight preparation, it is often limited to a few weeks of general fitness and safety instructions. This means space tourists typically embark on their journeys with a wider range of baseline fitness levels, which may make them more susceptible to immediate effects like muscle fatigue and soreness, even during short flights. The bottom line is the fitness starting point matters for the impact microgravity will have on the body.

While fitness level is an important criterion for enduring the challenges of space travel, the during of exposure to microgravity is just as important. Short-term missions (up to 2 weeks) for astronauts have less impact on their muscle and bone physiology, particularly with the countermeasures that are becoming standard practice. Extended missions of 6 months or more are where the consequences listed above become profound for astronauts. Current times for space tourists in suborbital flights, such as Blue Origin's New Shepard or Virgin Galactic's SpaceShipTwo, are mere minutes in microgravity. The limited time in microgravity is insufficient to cause significant skeletal muscle atrophy. However, brief periods of weightlessness may still challenge untrained muscles, potentially leading to temporary discomfort or fatigue due to unfamiliar loading patterns. As space tourism begins to offer long weekend or weeklong excursions for casual travelers, preventing their return to Earth to be accompanied by severe weakness will become part of the tourism economy.

How does one use muscle in microgravity? Astronauts rely heavily on countermeasures to mitigate muscle atrophy given the long durations of their missions. Daily exercise regimens are extensive. Astronauts aboard the International Space Station exercise for approximately two hours daily using equipment like treadmills, stationary bicycles, and the Advanced Resistive Exercise Device (ARED). These activities target both cardiovascular fitness and muscle strength. Muscle mass maintenance needs calories, and so diets rich in protein and other nutrients are also part of the routine. Professional astronauts are highly motivated to comply with exercise and dietary protocols, knowing the critical role these countermeasures play in mission success and personal health. Space tourists, especially those on short-duration flights, typically do not engage in structured countermeasure programs. For suborbital flights, no in-flight exercise is required. On orbital flights lasting a few days, the absence of daily exercise may result in minor deconditioning but not significant atrophy. However, because these individuals are often motivated by the novelty and thrill of the experience, they may lack the discipline or understanding required for rigorous physical maintenance, especially on longer flights.

As space tourism evolves to include longer-duration orbital and even lunar missions, the distinction between astronauts and space tourists will blur. Future advancements in space tourism may involve more comprehensive health protocols for longer journeys, and a need to implement structured health guidelines. By addressing these challenges, the space tourism industry can ensure the safety and well-being of its participants while expanding access to the transformative experience of space travel.

References

Demontis, G. C., Germani, M. M., Caiani, E. G., et al. (2017). Human pathophysiological adaptations to the space environment. *Frontiers in Physiology, 8,* 547. https://doi.org/10.3389/fphys.2017.00547

Fitts, R. H., Riley, D. R., & Widrick, J. J. (2000). Microgravity and skeletal muscle. *Journal of Applied Physiology, 89*(2), 823–839. https://doi.org/10.1152/jappl.2000.89.2.823

Smith, S. M., Wastney, M. E., Morukov, B. V., Larina, I. M., Nyquist, L. E., Abrams, S. A., Taran, E. N., Shih, C. Y., Nillen, J. L., Davis-Street, J. E., et al. (1999). Calcium metabolism before, during, and after a 3-month spaceflight: Kinetic and biochemical changes. *American Journal of Physiology, 277*(1), R1–R10. https://doi.org/10.1152/ajpregu.1999.277.1.R1

Elisabeth Barton is Professor of Applied Physiology & Kinesiology at University of Florida, and Associate Dean for Faculty & Staff Affairs for the College of Health & Human Performance. She is a molecular physiologist with a primary focus on skeletal muscle regeneration and neuromuscular disease. Her work has broad applications including accelerating the resolution of muscle damage after acute injuries, altering the balance between damage and repair in chronic injury associated with neuromuscular disease, and enhancing the repair axis in aging muscle. She is a founding member of the UF InSpaBio Hub, which serves as a launching pad for creative and collaborative projects to address the challenges of space travel. Previous NASA funding sparked her interest in the load-sensing proteins in muscle critical for the maintenance of muscle mass on Earth. These may be key to developing strategies that counter the loss of mass and function in microgravity. In the meantime, Dr. Barton is happily keeping her muscles loaded while tending to her vegetable garden, orchard, giant dogs, and a herd of goats.

CONTACT INFO
202G Florida Gym | 1864 Stadium Road
Gainesville, FL 32611 UNITED STATES
1-352-294-1714 | erbarton@ufl.edu