



Using Dynamic Foot Pressure as a Countermeasure to Muscle Atrophy

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Abstract

At issue is whether or not dynamic foot stimulation (DFS) applied to the plantar surface of the rat foot would counteract skeletal muscle atrophy normally observed in hindlimb unloaded (HU) rats. Mature adult male Wistar rats (six months old) were randomly assigned into ambulatory control (AMB), hindlimb unloaded alone (HU), or hindlimb unloaded with the application of the DFS (HU+DFS) group. Pressure was applied to one of the rat's hind feet using a specially fabricated boot containing a microprocessor-controlled inflatable air bladder. The anti-atrophic effects of DFS were quantified morphometrically by measuring the myofiber cross-sectional area (CSA) of the soleus muscle after staining the dissected/frozen sections by the metachromatic dye-ATPase method. After ten days of unloading, CSA decreased by 42% in type I, 32% in type IIA, 43% in type IIB, and 30% in type IIC fibers of the rat soleus muscle. Application of DFS during unloading significantly counteracted (85%) atrophy in type I fibers, yet it did not protect the type II fibers. DFS had no systemic effect on skeletal muscle mass preservation; the effect was confined only to the soleus muscle within the leg that underwent DFS stimulus. Results illustrate that application of dynamic pressure to the plantar surface rat foot is an effective countermeasure to soleus muscle atrophy caused by hindlimb unloading.

THE EFFECTS OF SKM ATROPHY HAVE SERIOUS IMPLICATIONS for various and diverse populations. It is important that astronauts maintain optimal physical performance in order to deal with the demanding tasks and unexpected situations they encounter in the space environment. Bed-ridden patients, on the other hand, require effective rehabilitation techniques in order to counteract the inactivity-induced atrophy and facilitate the recovery process. The elderly seek physical activity alternatives capable of retarding the detrimental effects of the aging process on the neuromus-

MUSCLE TONE—Dr. Charles L. Layne, Professor and Chair of the Department of Health and Human Performance, holds a Dynamic Foot Stimulator, an instrument designed in his laboratory to excite and massage muscles in the foot. Dr. Lane and his team of researchers seek methods for stimulating muscles. Their work has applications in space flight where astronauts in weightlessness suffer muscle atrophy. Space research has applications on Earth. Devices developed at UH and NASA-JSC prove useful in medical therapy. By exerting subtle pulsating pressure, they can strengthen muscles of diabetics and maintain muscle tone in victims of spinal cord injury who cannot any longer exercise their limbs.



MYTONOMETER—Researchers from a variety of disciplines are responsible for the development of the Mytonometer, a mechanism that provides treatment personnel a non-invasive means for assessing muscle tone. Conceptualized by Dr. Layne, the device was subject to design developments in electrical engineering, mechanical design, and shop fabrication. Research assistants, electrical engineers, and shop technicians provided advice and supplied needed manpower. To produce a device of this quality required local and federal funding.

cular system. Thus, it is of paramount importance to design and validate a simple and efficient countermeasure to inactivity-induced neuromuscular decrements.

Background and Significance

Mechanical unloading of skeletal muscle (SKM) during space flight or ground-based analogues, such as human bedrest and rodent hindlimb unloading (HU) models, induces SKM atrophy particularly affecting the anti-gravity musculature of the lower limbs in humans.^{1,2} Atrophy is characterized by a decrease in muscle volume, mass and strength, alterations in histochemical and electrophoretic characteristics, and a decrease in neuromuscular function.^{3,4,5,6,7}

Previous research conducted during space flight in humans⁸ and on the ground both in humans⁹ and in rats¹⁰ has demonstrated that increasing plantar sensory input by applying pressure to the soles of the feet results in an increase in neuromuscular activation of the lower limb muscles beyond the levels observed in the absence of foot pressure, showing that sensory input enhances motor output. In the latter study,¹⁰ investigators using hindlimb unloaded rats showed a significant attenuation of soleus muscle atrophy after pres-

sure application to the soles of the rat feet. In the terrestrial environment, maintenance of normal muscle function of the lower limbs depends partially on the interaction between gravitational forces when the feet are in contact with the ground and activation of specific sensory receptors that transmit this stimulus to the central nervous system.¹¹ Under unloading conditions, this interaction is no longer present resulting in a disruption of the neural pathways between the sensory receptors and central nervous system.

Although the characteristics and the spatial localization of sensory receptors (cutaneous mechanoreceptors) in the rat foot have been adequately described,¹² sufficient information regarding their potential role and underlying mechanism in preventing SKM atrophy is not yet available. In the study of De-Doncker et al.,¹⁰ a rat HU model was used to examine the potential implications of cutaneous mechanoreceptors in the development of muscle atrophy. The study, although well designed, did not implement a pressure device that was attached to the foot but rather pressure was applied by a simple experimental setup consisting of a balloon inflated by a sphygmomanometer. Therefore, the present study was designed to investigate whether or not the use of a novel stimulation paradigm/technology known as dynamic foot stimulation (DFS) would counteract soleus muscle atrophy normally observed in the hindlimb suspended rats. Utilizing this technology, pressure was applied to the rat foot using a specially fabricated boot containing a microprocessor-controlled inflatable air bladder. It was hypothesized that mechanical stimulation of the plantar surface of the rat foot during HU would attenuate unloading-induced SKM atrophy.

Experimental Design and Methods

Experimental plan. Use of animals was approved by both the Committee for Animal Use for Research and Education (CAURE) at NASA/Johnson Space Center and the Institutional Animal Care and Use Committee at University of Houston, prior to the initiation of the study. All procedures were in accordance with the guidelines established by the Public Health Service Policy on humane care and use of laboratory animals. Rats were anesthetized and prepared for hindlimb unloading. A custom-built boot was attached to the foot of one leg of the rats assigned to the UH+DFS group. Cyclic pressure of a chosen magnitude and duration was applied to the plantar surface of the foot throughout the 10 days of HU. After termination of the 10-day HU period, rats were deeply anesthetized and the soleus muscles harvested for frozen cross-sectioning followed by morphometric analysis. Animals were then euthanized by intravenous (i.v.) injection of Euthasol.

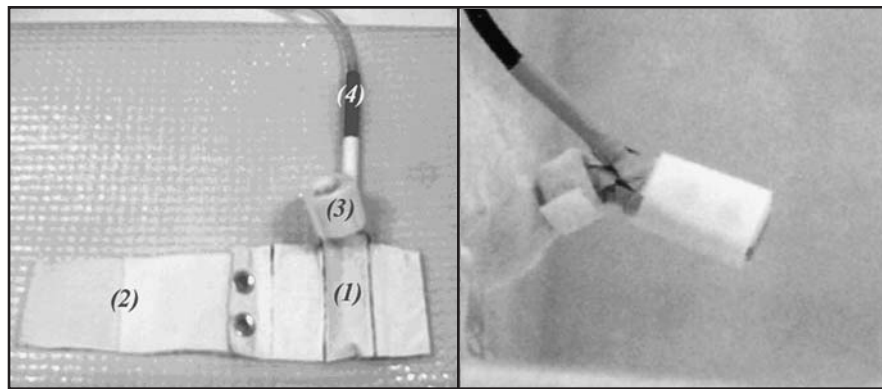


Figure 1. The inflatable boot is fabricated with a very thin and extremely light, yet durable, plastic with an attached inflatable/deflatable latex air bladder (1). Velcro restraint straps secure the boot to the sole (2) of the foot of the treatment leg and around the ankle joint (3) during HU. The air bladder is connected to an extremely quiet air pump by a single air line (4). The bladder is inflated by pumping air down the line and then passively deflates. The boot fits comfortably on the foot without restricting the natural movement of the ankle joint, which maintains its full range of motion. The limb with the boot is in a relaxed position with a slightly open angle at the ankle joint, as is also the case with the contralateral limb.

Hindlimb unloading procedure. Unloading of the hindlimbs was achieved using a modified model of a previously described tail-suspended rat procedure.¹³ This model allows the animals to move freely and to access all areas in the cage using their forelimbs as their means of movement, while removing all load from the hindlimbs. Rats were suspended at a 25° angle from the cage floor by adjusting the bar height. The hindlimb suspension condition was continued for 10 days.

Dynamic foot pressure application. A custom-built inflatable boot (Fig. 1) was used to stimulate the sensory receptors in the soles of the rat's foot. Under isoflurane (5%) gas anaesthesia the boot, outfitted with an inflatable/deflatable latex air bladder, was attached to the foot of one leg in unloaded animals. Pressure was applied to the foot by inflation/deflation of the latex bladder using an air pump (WPI, Sarasota, FL) attached to a hose leading to the bladder. The pressure stimulation protocol consisted of a 5 sec inflation/5 sec deflation of the air bladder for a total of 20 min followed by a 10-min rest interval. This cycle was repeated eight times over a four-hour period during each day of the 10-day HU period. The pressure in the bladder during the inflation was 104 mm Hg. Pump cycling time and duration were controlled by a microprocessor. The boot was maintained on the foot only during the application of the pressure and was removed every day after termination of the stimulation protocol.

Tissue Collection and Processing. Rats were deeply anaesthetized with an intraperitoneal injection of an anaesthesia mixture (ketamine 40-80 mg/kg body wt and xylazine 5-10 mg/kg body wt at a ratio of 1:1). The hair of the lower limbs was shaved up to the knee joint and a small incision cut into the backside of the ankle uncovering the Achilles tendon. Skin was gently reflected by blunt-tip forceps and the calf muscles were exposed. The soleus muscle was next carefully

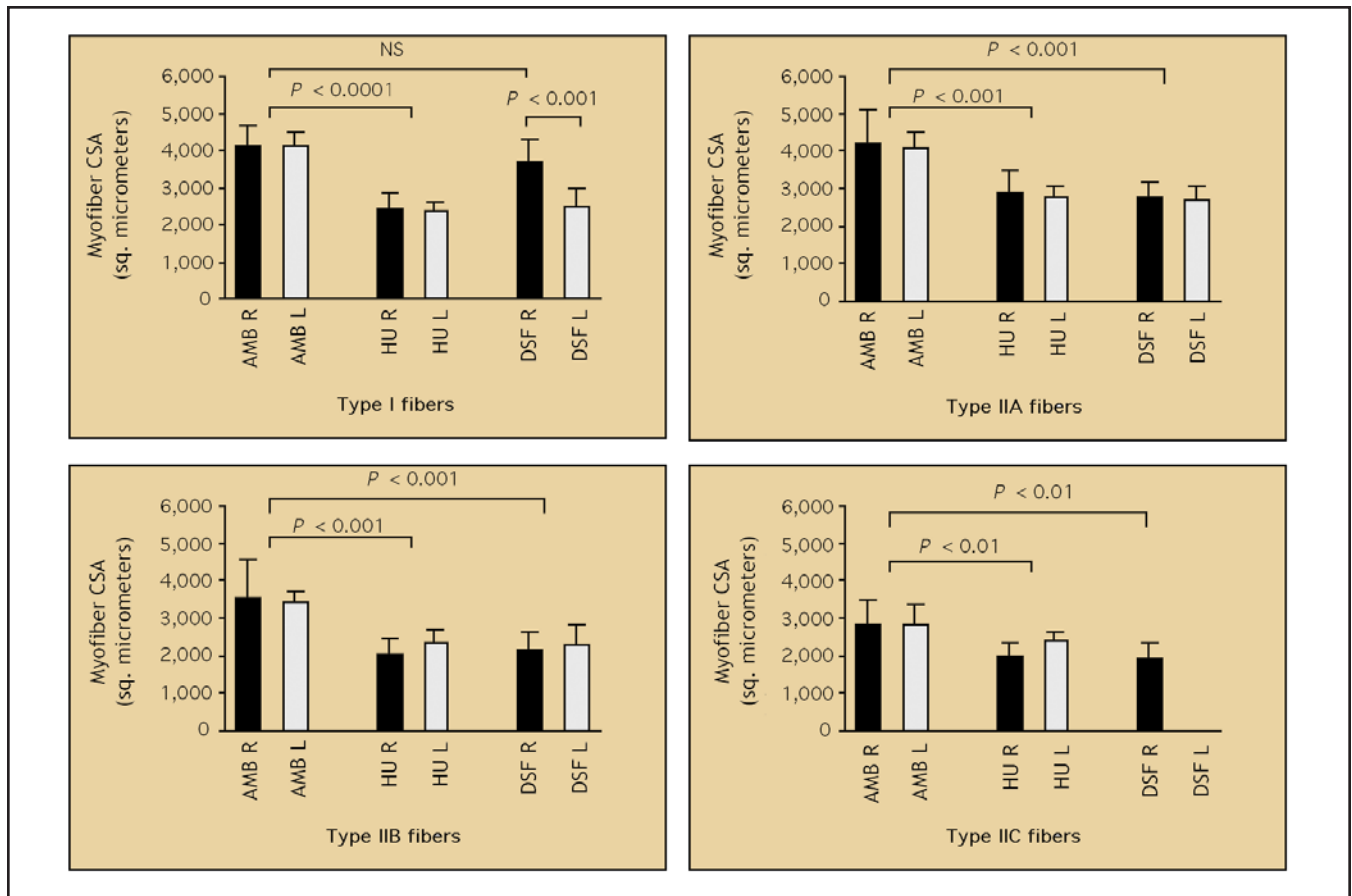


Figure 2. Fiber cross-sectional area (CSA) in the soleus muscle among treatment groups. Values are expressed in square micrometers (μm^2) and represent means \pm SD; n = 10 rats per group. AMB = ambulatory control, HU = hindlimb unloaded, DFS = hindlimb unloaded + dynamic foot stimulation; R = right leg, L = left leg. In the DFS group only, an inflatable boot is attached to the right leg. For type I fibers, CSA in the HU group was significantly smaller than that in the control group ($P < 0.0001$). No significant difference in CSA was found when the right leg (“boot” leg) in the DFS group was compared with either leg in the control group ($P > 0.05$). In DFS group, CSA in the “no boot” left leg was significantly smaller compared to that in the “boot” right leg ($P < 0.001$).

separated and excised. The excised muscles were attached to wooden rods by pins inserted through the tendon attachments so that the muscle was elongated without being stretched. The muscle was then divided using a sharp razor blade into smaller pieces, which were processed for subsequent analysis. In preparation for histochemical analysis, muscle samples from the midbelly of the soleus were covered in TissueTek OCT mounting medium (Sakura Finetek, Torrance, CA), quick frozen in liquid nitrogen-cooled isopentane, and stored at -80°C . Frozen cross sections ($5\ \mu\text{m}$) were cut using a Zeiss Microm HM 500 OM cryostat and picked up onto Superfrost Plus glass slides (Erie Scientific, Portsmouth, NH).

Histochemical and Morphometrical analysis. PI's performed fiber typing of frozen sections utilizing the metachromatic dye-ATPase myofibrillar stain method originally described by Ogilvie and Feedback¹⁴ as modified by Konishi et al.¹⁵ This staining method distinguishes the four major fiber types (type I, IIA, IIB and IIC) in a single section based on the different colors produced as follows: type I (turquoise), type IIA (light pink), type IIB (violet), and type IIC (blue).

One cross-section taken from the midbelly of the soleus muscle was analyzed for each rat. Six photo frames, covering almost the entire section, were taken from each section with a digital camera (DCS 420 Kodak) attached to a light microscope (Zeiss, Germany). The perimeter of the myofibers in each photo frame was then acquired by drawing around the fibers using Adobe Photoshop software. The cross-sectional area (CSA) of the four different fiber types in all six-photo frames was separately calculated using Object-Image 2.09 software (NIH, Bethesda, MD). Results obtained from the six photo frames were then combined separately for each fiber type and the final number of different fiber types in the section determined. Myofiber CSA and fiber type distribution of the soleus muscles were evaluated after analyzing a total of at least 600 myofibers for each muscle.

Statistical Analysis

Data were analyzed using the SPSS program. To evaluate the differences among groups, one-way analysis of variance (ANOVA) was applied and, when the univariate F test was significant, Scheffe's post hoc test was used to further identify

Table 1. Fiber Type Distribution in the Rat Soleus Muscle for Both Legs Among Experimental Groups

Fiber type	AMB		HU		HU + DFS	
	R Leg	L Leg	R Leg	L Leg	R Leg	L Leg
I	91.8 ± 4.5	90.5 ± 6.1	87.9 ± 14.6	89.2 ± 10.2	93.5 ± 4.9	93.3 ± 5.5
IIA	3.7 ± 2.8	6.6 ± 5.4	5.5 ± 7.8	5.8 ± 5.4	5.0 ± 3.9	3.8 ± 4.1
IIB	1.5 ± 2.0	2.0 ± 1.7	2.5 ± 3.7	1.6 ± 1.9	1.4 ± 1.6	2.0 ± 1.9
IIC	3.0 ± 2.9	0.9 ± 1.2	4.2 ± 11.7	3.4 ± 9.9	0.2 ± 0.4	0.0 ± 0.0

fy differences between group pairs. To evaluate the differences between the “boot leg” and the contra-lateral “no boot leg” in the HU-DFS group, a paired Student’s *t*-test was applied. Statistical significance level was set at $P < 0.05$.

Results

Results showed that there was a significant difference ($P < 0.0001$) in CSA of soleus type I myofiber between the HU and AMBU control groups (Fig. 2). After ten days of unloading, the CSA in the HU group decreased by 42% compared to the AMBU control ($4,128 \pm 537$ vs. $2,396 \pm 479 \mu\text{m}^2$). However, no significant differences were measured between HU + DFS ($3,717 \pm 609 \mu\text{m}^2$) and AMBU ($4,128 \pm 537 \mu\text{m}^2$) groups ($P > 0.05$). DFS appeared to reduce by 85% the atrophy normally observed in the soleus type I fibers induced by ten days of hindlimb unloading.

When the DFS treatment leg (right) and non-DFS treatment leg (left) within the same animal after ten days of HU were compared with respect to myofiber CSA (Fig. 2), a significant difference ($P < 0.001$) was found. The soleus type I fiber CSA in the “no boot” leg ($2,499 \pm 447 \mu\text{m}^2$) was significantly smaller than the “boot” leg ($3,717 \pm 609 \mu\text{m}^2$).

Unlike type I fibers, CSA of type IIA, IIB and IIC fibers in the rats wearing the boot and undergoing DFS (HU + DFS) were not different ($P > 0.05$) from those of suspended rats (HU). No differences in soleus muscle CSA were observed among groups in any fiber type when the left legs were compared. Type IIC fiber was not detected in the left leg of the HU + DFS group.

With respect to the soleus muscle myofiber type composition, no significant differences ($P > 0.05$) were found among any of the experimental groups in either leg. Fiber type distribution data of each experimental group are reported in Table 1.

Values are expressed in percentage (%) and represent means \pm SD; $n = 10$ rats per group. AMB = ambulatory control, HU = hindlimb unloaded, HU + DFS = hindlimb unloaded + dynamic foot stimulation; R = right leg, L = left leg. In the HU + DFS group, an inflatable boot is attached to the ankle of the right leg. No significant differences in the fiber type distribution were found among groups ($P > 0.05$).

Discussion

The main objective of this study was to test a new technology as a countermeasure tool to mechanical unloading-induced muscle atrophy. Our data clearly demonstrated that the countermeasure technology used in the present study,

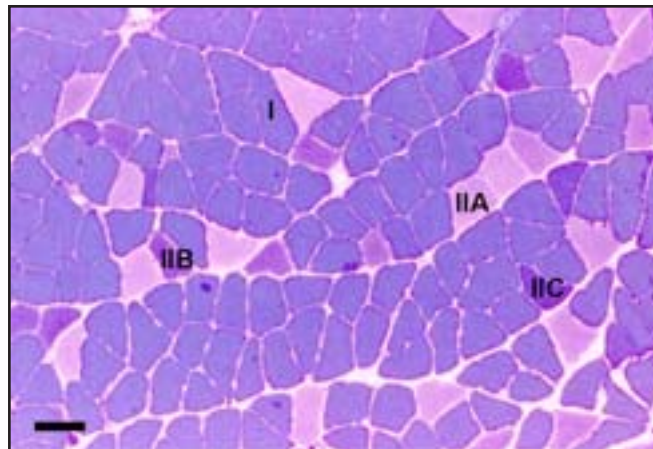


Figure 3. Cross-sections of rat soleus muscle fibers (metachromatic dye-ATPase preincubated at pH 4.35 and stained with toluidine blue). Bar equal to 50 μm . On the basis of color, fiber types were classified as type I (turquoise), IIA (violet), IIB (light pink), and IIC (dark blue).

namely the application of DFS during unloading conditions, efficiently reduced the atrophy in the soleus muscle type I myofibers. The decrease in CSA normally induced during unloading was counteracted by 85% in type I fibers. However, DFS did not protect type II fibers from atrophy. The degree of atrophy in the HU + DFS group, compared to ambulatory controls, was about 35% in type IIA, 39% in type IIB, and 32% in type IIC fibers. A similar degree of atrophy in soleus muscle type II fibers was observed in the HU group.

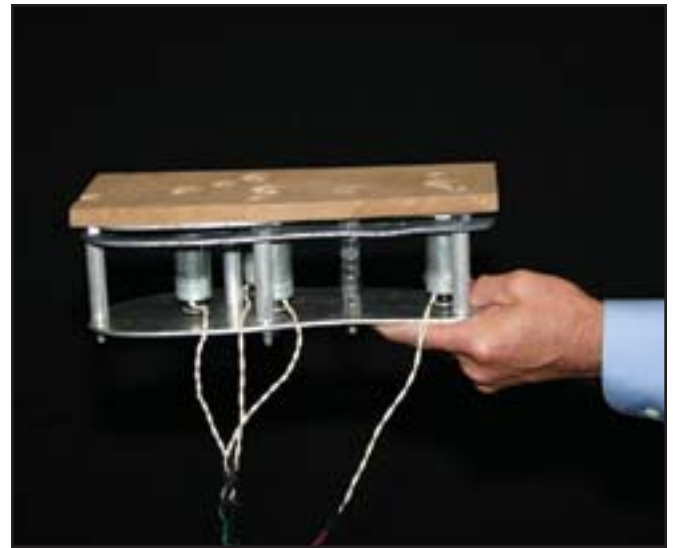
The basic concept of foot stimulation has been previously tested yielding promising results. De-Doncker et al.¹⁰ showed that foot pressure to the soles of the rat feet partially prevented soleus muscle atrophy normally induced by 14 days of unloading. In that study, researchers delivered pressure of 40 mm Hg to the plantar surface of both hind feet using a latex balloon manually inflated by a sphygmomanometer. The feet were stimulated for 5 sec followed by 10-sec rest, 10 min/day throughout the 14-day unloading period. Regardless of the differences in the experimental design between De-Doncker’s et al. protocol and ours, both designs support the effectiveness of foot stimulation in preventing mechanical unloading-induced SKM atrophy. Unlike our findings though, De-Doncker’s et al. data suggested a partial prevention of SKM atrophy not only in the type I but also in the type II fibers. In their study, fiber types were classified following

an older and less descriptive histochemical method¹⁶ than the one we used.¹⁴ They found that the soleus muscle CSA was counteracted by 31% in type I fibers, 40% in type IC fibers, 49% in type IIC fibers, and by 43% in type IIA fibers. However, foot pressure did not prevent the transformation of type I to type II fiber types in the soleus muscle. The higher CSA preservation (85% vs. 31%) in the type I fibers found in our study might be explained by the longer duration of our protocol and/or the higher stimulation pressure applied to the rat foot compared to De-Doncker's stimulation protocol (5.6% of the 10-day unloading vs. 0.23% of the 14-day unloading and 104 mm Hg vs. 40 mm Hg). The younger rats used by De-Decker et al. (3-month old vs. 6-month old) might also have been a factor in this difference for the fiber type I to type II transformation found in their study.

The concept underlying the present study was the well-established motor control principle that sensory input (i.e., pressure application) can modify motor output (i.e., neuromuscular activation). Previous research has demonstrated that rat soleus muscle electromyographic (EMG) activity was significantly decreased during the first days of unloading; it was gradually restored after 7-10 days of unloading.^{17,18} De-Doncker et al., using implanted bipolar electrodes, showed that EMG activity in the rat soleus muscle was decreased by 87.5 percent during the 14 days of hindlimb unloading. Interestingly, a significant increase in soleus EMG activity was always observed when pressure was applied to the plantar surface of the feet in the suspended rats. The stimulation of the animal's sole increased the EMG activity by 110 percent. As a possible explanation for the increased EMG activity, the authors put forward the stimulation of the cutaneous mechanoreceptors (i.e., Merkel discs, Meissner corpuscles, Ruffini endings, Pacinian corpuscles) located in the plantar surface skin area of the rat's feet. In our study, we did not use EMG recording; nevertheless, because of the similarity of our stimulation protocol with that of De-Doncker's et al., we postulate that increased soleus EMG activity might have also occurred in the leg receiving DFS.

Although no direct relationship had been established between the application of DFS facilitated interactions between nerve and muscle, researchers maintained neurological interactions between the sensory and motor systems. This application suggests that the level of activity generated through the sensory and motor interaction is enough to prevent muscle atrophy. Whether or not this holds true has yet to be proved. Nevertheless, the application of DFS counteracted soleus muscle atrophy normally induced by mechanical unloading. Thus, DFS promises to serve as an experimental model for studying the underlying mechanisms of skeletal muscle atrophy.

In conclusion, the results of the present study illustrate that external mechanical stimulus applied to rat feet is capable of counteracting unloading-induced soleus muscle atrophy. One postulate holds that this effect is achieved via stimulation of proprioceptive pathways that in turn interact with motoneurons to generate muscle contraction mimicking the neuromuscular activity patterns normally induced by load bearing in a terrestrial environment. This underlying concept promis-



STIMULATION—The Dynamic Foot Stimulator utilizes plastic balls embedded in a motorized shoe to energize muscles in the foot. Subtle pressure is all that is needed to sustain muscle tone and prevent muscle atrophy for diabetics and patients suffering spinal cord injury.

es to serve as the basis for the development of a novel supplement to pre-existing exercise in-flight countermeasures for astronauts, as well as an effective rehabilitation tool for clinical populations such as bed-ridden or elderly patients.

References

- ¹V. R. Edgerton and R. R. Roy. "Neuromuscular Adaptations to Actual and Simulated Spaceflight," in *Handbook of Physiology*. Ed. The American Physiological Society. Vol. II. Baltimore, MD: Williams & Wilkins, 1996. 721-63.
- ²R. Fitts, D. R. Riley, and J. J. Widrick. "Physiology of a Microgravity Environment." Invited Review: "Microgravity and Skeletal Muscle," *J. Appl. Physiol.* 89 (2000): 823-39.
- ³K. M. Baldwin. "Effects of Altered Loading States on Muscle Plasticity: What Have We Learned from Rodents?" *Med Sci Sports Exerc* 28 (1996): S101-06.
- ⁴M. M. Bamman, M. S. Clarke, D. L. Feeback, R. J. Talmadge, B. R. Stevens, S. A. Lieberman, and M. C. Greenisen. "Impact of Resistance Exercise during Bed Rest on Skeletal Muscle Sarcopenia and Myosin Isoform Distribution," *J. Appl. Physiol.* 84 (1998): 157-63.
- ⁵C. Kourtidou-Papadeli, A. Kyparos, M. Albani, A. Frossinis, C. L. Papedelis, P. Bamidis, A. Vivas, and O. Guiba-Tziampiri. "Electrophysiological, Histochemical, and Hormonal Adaptation of Rat Muscle After Prolonged Hindlimb Suspension," *Acta Astronaut* 54 (2004): 737-47.
- ⁶M. R. Recktenwald, J. A. Hodgson, R. R. Roy, S. Riazanski, G. E. McCall, I. Kozlovskaya, D. A. Washburn, J. W. Fanton, and V. R. Edgerton. "Effects of Spaceflight on Rhesus Quadrupedal Locomotion after Return to 1G," *J. Neurophysiol.* 81 (1999): 2451-63.
- ⁷D. A. Riley, S. Ellis, G. R. Slocum, F. R. Sedlak, J. L. Bain, B. B. Krippendorf, C. T. Lehman, M. Y. Macias, J. L.

Thompson, K. Vijayan, and J. A. De Bruin. "In-Flight and Postflight Changes in Skeletal Muscles of SLS-1 and SLS-2 Spaceflown Rats," *J. Appl. Physiol.* 81 (1996): 133-44.

⁸C. S. Layne, A. P. Mulavara, C. J. Pruett, P. V. McDonald, I. B. Kozlovskaya, and J. J. Bloomberg. "The Use of In-Flight Foot Pressure as a Countermeasure to Neuromuscular Degradation," *Acta Astronaut* 42 (1998b): 231-46.

⁹C. S. Layne, G. W. Lange, C. J. Pruett, P. V. McDonald, L. A. Merkle, A. P. Mulavara, S. L. Smith, I. B. Kozlovskaya, and J. J. Bloomberg. "Adaptation of Neuromuscular Activation Patterns during Treadmill Walking after Long-Duration Space Flight," *Acta Astronaut* 43 (1998a): 107-19.

¹⁰L. De-Doncker, F. Picquet, and M. Falempin. "Effects of Cutaneous Receptor Stimulation on Muscular Atrophy Developed in Hindlimb Unloading Condition," *J. Appl. Physiol.* 89 (2000): 2344-51.

¹¹O. Bock. "Problems of Sensorimotor Coordination in Weightlessness," *Brain Res. Rev.* 28 (1998): 155-60.

¹²J. W. Leem, W. D. Willis, and J. M. Chung. "Cutaneous Sensory Receptors in the Rat Foot," *J. Neurophysiol.* 69 (1993): 1684-99.

¹³E. R. Horey-Holton and R. K. Globus. "Hindlimb Unloading Rodent Model: Technical Aspects," *J. Appl. Physiol.* 92 (2002): 1367-77.

¹⁴R. W. Ogilvie and D. L. Feeback. "A Metachromatic Dye-ATPase Method for the Simultaneous Identification of Skeletal Muscle Fiber types I, IIA, IIB and IIC," *Stain Technol.* 65 (1990): 231-41.

¹⁵M. Konishi, S. Iwamoto, H. Ohara, and M. Shimada. "Two-Dimensional Changes of Muscle Fiber Types in Growing Rat Hind Limb," *Acta Anat. Nippon* 75 (2000): 267-73.

¹⁶L. Guth and F. J. Samaha. "Qualitative Differences between Actomyosin ATPase of Slow and Fast Mammalian Muscle," *Exp. Neurol.* 25 (1969): 138-52.

¹⁷E. K. Alford, R. R. Roy, J. A. Hodgson, and V. R. Edgerton. "Electromyography of Rat Soleus, Medial Gastrocnemius, and Tibialis Anterior during Hind Limb Suspension," *Exp. Neurol.* 96 (1987): 635-49.

¹⁸Y. Ohira, T. Nomura, F. Kawano, Y. Sato, A. Ishihara, and I. Nonaka. "Effects of Nine Weeks of Unloading on Neuromuscular Activities in Adult Rats," *J. Gravit. Physiol.* 9 (2002): 49-59.

Publications

Layne, C. S., K. E. Forth, M. F. Baxter, AND J. J. Houser. "Voluntary Neuromuscular Activation is Enhanced When Paired with a Mechanical Stimulus to Human Plantar Soles," *Neuroscience Letters* 334 (2002): 75-78.

Presentations

Baxter, M. F., J. J. Houser, K. E. Forth, and C. S. Layne. "Timing of Somatosensory Stimulation to the Feet Modifies Human Neuromuscular Activation," Annual Meeting of the Society for Neuroscience, San Diego, CA, Nov. 2001.

Kyparos, A., C. S. Layne, D. A. Martinez, M. S. F. Clarke, and D. L. Feeback. "Dynamic Foot Pressure as a Countermeasure to Muscle Atrophy," Second World Space



HUMAN SUBJECT—Jorge Armando Banda, pursuing an M.Sc. in Exercise Therapy, wears the Dynamic Foot Simulator, being adjusted by Dr. Mark S. Clarke, Associate Professor of Health and Human Performance.

Congress, 34th Committee on Space Research Scientific Assembly, Houston, TX, Oct. 2002.

Kyparos, A., C. S. Layne, D. L. Feeback, D. A. Martinez, and M. S. F. Clarke. "Dynamic Foot Pressure Attenuates Myofiber Atrophy Induced by Mechanical Unloading," 14th International Academy of Astronautics (IAA) Humans in Space Symposium, Banff, Canada, May 18-22, 2003.

Kyparos A., C. S. Layne, D. L. Feeback, D. A. Martinez, and M. S. F. Clarke. "Foot Pressure May Preserve Neuromuscular Function of the Injured Athlete: Preliminary Results from a Rat Model," 7th IOC Olympic World Congress on Sport Sciences, Athens, Greece, Oct. 7-11, 2003.

Layne, C. S., K. E. Forth, A. F. Abercromby. "Using Patterned Stimuli and Varied Muscle Spindle Input To Modify Neuromuscular Reflexes," Annual Meeting of the Society for Neuroscience, New Orleans, LA, Nov. 2003.

Layne C. S., K. E. Forth, A. F. Abercromby, A. Kyparos, M. S. F. Clarke, and D. L. Feeback. "Proprioceptive and Muscle Maintenance for the Injured Athlete," 7th IOC Olympic World Congress on Sport Sciences, Athens, Greece, Oct. 7-11, 2003.

Layne, C. S., K. E. Forth, and A. F. Abercromby. "Does Varying Muscle Spindle Input Modify Neuromuscular Responses to Foot Stimulation?" 14th International

- Academy of Astronautics (IAA) Humans in Space Symposium, Banff, Canada, May 18-22, 2003.
- Layne, C. S., K. E. Forth, and A. F. Abercromby. "Spatial Factors Influence the Generation of Neuromuscular Responses to Foot Stimulation," 14th International Academy of Astronautics (IAA) Humans in Space Symposium, Banff, Canada, May 18-22, 2003.
- Layne, C. S., K. E. Forth, M. F. Baxter, and J. J. Houser. "Enhanced Neuromuscular Activity from Mechanical Foot Stimulation," Second World Space Congress, 34th Committee on Space Research Scientific Assembly, Houston, TX, Oct. 2002.
- Layne, C. S., K. E. Forth, M. F. Baxter, and J. J. Houser. "Controlled Somatosensory Input Modifies Neuromuscular Activation," Annual Meeting of the North American Society for Psychology of Sport and Physical Activity, St. Louis, MO, June 2001.
- Layne, C. S., A. P. Mulavara, P. V. McDonald, C. J. Pruett, and J. J. Bloomberg. "Maintaining Neuromuscular Contraction Using Somatosensory Input During Long Duration Spaceflight," Bioastronautics Investigators' Workshop, Galveston, TX, Jan. 2001.

Funding and proposals

- Layne, C. S., A. D. LeBlance, and Y. C. Chen. "Using Foot Somatosensory Input to Attenuate Lower Limb Muscle Atrophy During Spaceflight." National Aeronautics and Space Administration (NASA), Aug. 2001, \$399,412 (*not funded*).
- Layne, C. S. and M. Sabahhi. "Increasing Leg Muscle Activation Using Foot Sensory Input." Advanced Research Program, Texas Higher Education Coordinating Board, Aug. 2001, \$63,825 (*not funded*).