Pre-Post-Flight Neuromuscular Control with Variable Resistance / Assistance Exercise Machines

The physical activity of astronauts is one of the top concerns of modern space flight. It is well documented that extended exposure to a microgravity environment has a detrimental effect on muscle mass. This results in reduced motor coordination that can result in movement safety (for example, falling), extended delays in returning to regular activities, and other undesirable health effects. There is a pressing need to provide crew members with effective means for maintaining physical activity before, during, and after flight. Part of the problem is traced to the current state-of-the-art of exercise machines.

The project seeks to design, develop, and test fully-functional expert-based, variable resistance/assistance (EVRA) exercise machines in support of the goals and objectives of NASA-JSC's Exercise Physiology Laboratory (EPL):

1. To conduct support for pre-flight, in-flight, and post-flight medical physical fitness testing operations.
2. To assist in the development of Astronaut physical conditioning programs.
3. To evaluate and validate exercise countermeasure equipment, procedures, protocols, and conditioning programs related to the maintenance of crew health and performance during Space Shuttle and International Space Station missions.
4. To understand the effects of microgravity upon human performance during and after exposure to microgravity and space flight.

EVRA machines remove many shortcomings found in currently available constant-resistance and other variable-resistance exercise machines. EVRA machines can be used for pre- and post-flight routines; they may also be used in-flight, thus impacting current and planned human operations in space. EVRA machines utilize the latest technologies in microprocessor-based control of electrical motors to generate especially designed torque/force profiles.

It is important to initiate the development of the EVRA machines by building and testing a system that manipulates the knee joint because the lower limb muscles are often associated with the maintenance of upright posture and locomotion control, problems that crewmembers suffer returning from space flight.

A unique feature of EVRA is its ability to evaluate a user's current kinetic, kinematic and neurophysiological signals and compare these signals against a preprogrammed "standard." If a user deviates beyond a specified range, the EVRA will be engaged to assist with a movement or employed to increase the resistance to a given movement. This comparison "standard" is presently being developed by obtaining kinetic (e.g., joint torque, velocity, acceleration) and neurophysiological signals (muscle activation electrical signals), developing population averages, and associated variability, and then programming these into the EVRA controller. During any human motion there is a point at which the combination of muscle and bone angles results in the loss of biomechanical advantage (i.e., a "sticking point") and can be identified as a significant variation in either a kinematic and/or neuromuscular activation profile.

EVRA will be able to detect significant changes in kinematic and neurophysiological movement profiles, compare this data with an existing database, and then provide the appropriate level of mechanical assistance to the moving limb to maintain a coordinated movement profile. A unique feature of EVRAs is that they can be individualized in the sense that a particular person's "normal" data profile can be selected when that person is going to exercise on the device. Much like speech recognition software, the EVRA can be "trained" to recognize the selected current user and provide assistance and/or resistance based upon that individual's profile. EVRA will need to provide the greatest assistance at previously identified "sticking points." Conversely, if a user exceeds a "normal" movement profile by a specified magnitude, the EVRA will be able to detect such a deviation and provide greater resistance until the movement profile returns to "normal."

Major Tasks

Researchers have four major tasks ahead of them:

1. Identify "normal" mean torque, velocity and acceleration profiles, and related intra- and intersubject variability associated with joint motions such as seated knee flexion and extension. This means identifying "normal" mean neuromuscular activation profiles (i.e., EMG) and associated intra- and intersubject variability of selected lower limb muscles used to produce seated knee flexion and extension.
2. Improve on the design of the kinematic structure of a one degree-of-freedom (knee flexion/extension). Extend methodology to multi degree-of-freedom machines.
3. Investigate the design and implementation of digital controllers that employ the profiles developed in Objectives 1 and 2. A mathematical model of the EVRA machine is presently being developed to simulate its dynamic behavior using the Matlab/Simulink software package. Controllers are tested in simulation first and later transferred to the EVRA machine.
4. Integrate the various components of the EVRA machine

and perform tests. Electric motors are to be controlled by software, based on the control algorithm developed in Objective 3. Proposed software developments are divided into three parts: (a) A database to store relevant parameters for a healthy person with no physical limitations, (b) Background processing which includes data collection and analysis and generation of control signals to control the EVRA, and (c) A Graphical-User-Interface (GUI) which provides the Man-Machine-Interface (MMI).

Exercise Physiology Laboratory at NASA-JSC
Areas of research interest include cardio-respiratory functional capacity, musculoskeletal strength development and maintenance, orthostatic intolerance, biomechanics of movement, bone metabolism, and thermoregulation. The JSC Laboratory also evaluates in-flight exercise responses and activity patterns as a way of evaluating and validating exercise countermeasure concepts. Basic research investigations are conducted through the NRA, NSBRI, and CEVP peer-review processes.

Current, projects include: biomechanical analysis of treadmill locomotion in weightlessness using the KC-135, evaluation of eccentric and concentric muscle strength using the Agaton system, evaluation of the Muscle Lab measurement device, and preliminary investigations of the use of near-infrared spectroscopy in the evaluation of muscle and skin blood flow during dynamic exercise of the arms and legs. Hardware used in the Exercise Physiology Laboratory (EPL) is both traditional and innovative. Equipment is upgraded on the basis of ongoing research:

Metabolic Gas Analysis Systems
Heart Rate and Blood Pressure Systems
Treadmills
Cycle Ergometers
Rowing Machines
Resistance Exercise Dynamometers
Electromyography Recording System
Hardware for Thermoregulatory Studies
Hardware to assess Orthostatic Responses
Computers and cameras to conduct motion analysis studies
Underwater Weighing Tank Launch and Entry Suit
Advanced Crew Escape Suit
IBM and Macintosh computers

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Development of Micro-Column Arrays (MCA) for Thermal Management Applications

THERMAL MANAGEMENT OF spacecraft and space station environments is an important issue in both the manned and unmanned exploration of space. Transporting heat away from spacecraft components and bringing heat to other systems often rely on large, liquid-based heat exchange systems. Such active systems add extra weight to the spacecraft and comprise additional mechanical components which can malfunction, thus affecting maximum payload and mission lifetime. A possible alternative is a passive cooling system in which thin coatings or foils would collect or remove heat by radiative absorption or emission.

A technology for the successful fabrication of Micro Column Arrays (MCAs) on thin metal foils has recently been developed in conjunction with Integrated Micro Sensors, Inc. (IMS) of Houston, TX. MCAs consist of densely packed micro cones separated by cone-shaped micro cavities. They exhibit low reflectance (< 0.171) and high absorptance (> 0.978) over a wide spectral range in a very close approximation of blackbody behavior. The goal of this project is to explore the use of MCA structures on metal foils for heat acquisition and/or heat rejection through their near-blackbody nature.

In-depth simulation of their heat transport properties will be undertaken using a newly developed Transmission Line Matrix (TLM) methodology. In this approach, a novel TLM link line is introduced to account for the enthalpy heat transport in a fluid or gas. Incorporation of an electrical diode in the new enthalpy link has proven to be an excellent way of accounting for the heat convection without altering the classical TLM algorithm arrangement. Full extension of this model to radiative heat dissipation and collection will be undertaken.

Technical Approach
MCAs are produced by pulsed laser ablation combined with mechanical translation of the substrate material to create cone-shaped micro tips interdigitated with cone-shaped micro cavities[1,2] (Fig. 1). The tips are on the order of 10-20 μm in base diameter and 20-30 μm tall. MCA surfaces feature large (more than 10X) specific areas, low-threshold electron field emission, and unique optical properties.[3] To date,