Thermoregulation During Spaceflight

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SPACE ADAPTATION RESEARCH PROGRAM

TITLE: THERMOREGULATION DURING SPACEFLIGHT

DATE SUBMITTED:

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ADDITIONAL INFORMATION IF NEEDED:
SUMMARY

The purpose for this flight proposal is to investigate human thermoregulatory parameters during exercise in microgravity. The hypothesis to be tested is that microgravity-adapted astronauts will exhibit accentuated increases in their core temperatures (excess hyperthermia) during exercise because of altered heat loss responses due to reduced sweating and/or accentuated vasodilation. The specific aims are (a) to compare core and skin temperature responses during moderate exercise before flight and inflight; (b) to determine whether the hypothesized inflight excessive hyperthermia is due to increased heat production, reduced sweating, impaired peripheral vasodilation, or to some combination of these factors; and (c) to determine whether heat production at an exercise load of 60% of the maximal working capacity is similar preflight and inflight. It is expected that the astronauts will exhibit excessive hyperthermia during exposure to microgravity which will be caused by decreased sweating and decreased skin blood flow.

A. PROGRAM DESCRIPTION:

1) **Hypothesis**: Microgravity-adapted astronauts will exhibit excess hyperthermia during exercise because of altered heat loss responses due to reduced sweating and/or vasodilation.

2) **Introduction**: Little information is available for determining the effects of microgravity exposure on human thermoregulation. Leach et al. (1978) have suggested that there is a decreased sweat loss during exercise in microgravity and possible reduced insensible heat loss. Presumably, an increased "sheeting" of sweat on the surface of the body reduces convective as well as evaporative heat loss during exercise in microgravity. Spaceflight is associated with a developing hypohydration. Results from numerous ground-based studies have shown that hypohydration results in reduced sensitivity and elevated core temperature threshold for the onset of both skin blood flow and sweating heat loss responses. To date, there have been no direct measurements of skin blood flow or sweating responses during exercise in astronauts in microgravity.

3) **Specific Aims**:

   a) To compare core and skin temperature responses in astronauts during moderate exercise before flight and in microgravity.

   b) To determine whether the excess inflight hyperthermia is due to altered heat production, impaired vasodilation, impaired sweating, or to some combination of these factors.

   c) To determine whether heat production at a moderate level of oxygen uptake (60% of preflight peak oxygen uptake) is similar preflight and inflight.

4) **Rationale/Justification**: Humans, with their normal core temperatures of 37°C (98.6°F), are closer to their upper lethal limit of core temperature (42°C or 107.6°F) than to their lower lethal limit of 27°C (80.6°F). Astronauts undergoing EVA would more likely have problems with excess heating than with enhanced cooling because of their physical work (exercise) performance. Any countermeasure effective for reducing heat production and/or increasing heat dissipation should
allow for higher work rates for longer periods of time. Also, understanding the relationship between heat production and evaporative heat loss will be required for accurate estimations of drinking water requirements during long-duration spaceflight.

5) **Background:** To date there have been no published accounts of heat maladies suffered by astronauts; i.e., heat exhaustion or heat stroke. The capacity of the environmental control system in the Space Shuttle is more than adequate to accommodate the crew’s heat dissipation load, even when heavy exercise is performed periodically during orbital missions. The same was true during the Apollo and Skylab missions (Waligora and Horrigan 1975, 1977).

Because of the limitation of heat removal capacity of the extravehicular (EVA) suit, the upper limit of energy utilization during EVA in the Gemini, Apollo, and Skylab flights was 225-300 kcal/hr; this corresponds to an oxygen uptake of 0.8 to 1.0 liter/min during light exercise. The average EVA time was about 6 and 4 hr for Apollo and Skylab astronauts, respectively (Waligora & Horrigan 1977). Total heat removal capacity of the Space Shuttle-Space Station EVA suit is 2,513 kcal (10,000 BTU) and maximal rate of heat dissipation is about 503 kcal/hr (2,000 BTU/hr). The average steady-state range is about 213 kcal/hr (850 BTU/hr), which is somewhat lower than the 225-300 kcal/hr range of earlier suits. Vorobyev et al. (1986) reported mean energy expenditures of 198-294 kcal/hr for two cosmonauts during 170-175 min. of EVA; their average oxygen uptake was about 0.7 liters/min. The upper limit of heat removal of our suit (503 kcal/hr) is approximately equivalent to an oxygen uptake of 1.7 liters/min., a level about half the peak oxygen uptake (peak VO₂) of 3.4 liters/min. (45 ml O₂/min/kg body wt.), the average level for the total astronaut corps. Constant work at 50% of the peak oxygen uptake, i.e., at 1.7 liters/min., can be endured for about 5 hours of EVA. Constant work at 50% of the peak level will result in an equilibrium level of body core temperature of 38.0 ± 0.1°C (100.4°F), an optimal level for efficient work performance.

Since the rate of rise and final equilibrium level of body core temperature is directly proportional to the absolute exercise load (Greenleaf 1979), it is clear when astronauts work at loads greater than 503 kcal/hr (50% peak VO₂) that all metabolic heat will not be removed, suit ambient temperature will increase, and thus body temperature will rise above 38°C. The level of non-steady state hyperthermia depends on a number of factors including exercise intensity and duration, level of physical fitness, muscle groups involved, the size of the lean body mass, and the degree of microgravity deconditioning of the astronauts. The last factor involves the level of hydration and the efficiency of cardiac function which determine if sufficient blood is available to supply sufficient nutrients to working muscles as well as providing adequate perfusion of deep and especially peripheral veins to transport body heat for dissipation.

If we assume the average, normal body core temperature to be 37.0°C (98.6°F), death can ensue when body temperature falls below 27°C (80.6°F) and when it exceeds 42°C (107.7°F); i.e., with a drop of 10°C but with an increase of only 5°C. Thus overheating is more critical than overcooling. The lower limit of core temperature for the onset of heatstroke is between 41.1°C and 42.0°C (Shibolet et al. 1976), but cases of classical heatstroke have been reported with core temperatures of 40.6°C (105.1°F) (Leithead and Lind 1964). The rate of heat exchange is also important. Unacclimatized men resting in a hot, humid environment (42°C, 90% relative humidity) are near their limit of tolerance and consciousness with rectal temperatures of 38.5°C (Convertino et al. 1980). But
during intense isotonic exercise, rectal temperatures in the heatstroke range have been recorded with no adverse symptoms or lasting effects. Robinson (1963) measured rectal temperatures of 40.0°C and 41.1°C in two champion runners after a 3-mile race, and Pugh et al. (1967) observed rectal temperatures of 41.1, 40.5, and 40.2°C in the first, third, and fourth place finishers, respectively, after a marathon race. In normal ambient conditions, heat exhaustion and physical debilitation usually occur before heatstroke occurs. Under conditions in which heat flow away from the skin is reduced, such as in workers wearing impermeable clothing or astronauts wearing a suit with inadequate heat removal capacity, skin temperature rises resulting in a reduced core to skin temperature gradient. Under such conditions heat cannot be adequately removed from the core and symptoms of heat stress may occur even at core temperatures as low as 38°C (Tanaka et al. 1978, Smith 1980). Clearly, the absolute level of core temperature cannot be used to determine the physiological state of astronauts or when heat exhaustion is likely to occur.

All of these considerations, prognostications, and measurements have been applied to and performed on normal, healthy subjects on Earth. Jauchem (1988) has reviewed the effects of various environmental stressors including acceleration and hypergravity, hypogravity and weightlessness, hyperoxia and hypoxia, radiofrequency radiation, vibration, and circadian rhythm changes, and concluded that all of them influence body temperature to some degree. There is a close relationship between body fluid-electrolyte-osmotic parameters, cardiovascular (peripheral blood flow) heat dissipation mechanisms, and exercise thermoregulation in eugravity. There appear to be adaptive changes in fluid-electrolyte and cardiovascular parameters in microgravity. Therefore it is reasonable to assume changes in exercise thermoregulatory function will occur in microgravity-adapted astronauts. The major questions are (a) whether there is a unique effect of adaptation to microgravity per se on thermoregulation; (b) if so, will this effect adversely influence astronauts' performance and well-being; and (c) if so, can appropriate countermeasures be implemented?

Thermoregulatory studies conducted on astronauts in microgravity have, in general, produced either indirect data (Leach et al. 1978) or have been performed under inadequately controlled environmental conditions (Novak et al. 1980). Conclusive results have not been obtained. Instructive results have come from controlled studies of exercise thermoregulation after prolonged bed rest (Fortney 1987, Greenleaf and Reese 1980) and water immersion (Greenleaf et al. 1985). The excessive increases in esophageal (Fortney 1987) and rectal (Greenleaf and Reese 1980) temperatures during submaximal exercise after 12-14 days of horizontal bed rest have been attributed mainly to reduced conductive heat loss via enhanced peripheral vasoconstriction responses that were not the result of reduced plasma volume and were the result of reduction in sweating and evaporative heat loss (Fortney 1987, Greenleaf and Reese 1980). The rectal temperature response to exercise in air after immersion deconditioning is also higher than the pre-immersion level (Greenleaf et al. 1985), similar to the response after bed rest. While resting rectal temperature is increased post-immersion, it has also been reported to be unchanged from ambulatory levels (Greenleaf and Reese 1980) or to be increased above control levels (Fortney 1987) after bed rest deconditioning. The reason for this discrepancy is not clear and is currently being investigated at Ames.
B. EXPERIMENTAL DESIGN AND METHOD:

1) **Overall Design:** The overall study design involves a comparison of the thermoregulatory responses of 8 male astronauts during exercise in a ground-based environmental chamber to those on 10-14 day flights. Measurements of core and skin temperatures, local sweating, forearm blood flow, and oxygen consumption will be measured at a constant exercise level (60% preflight peak VO\(_2\)) during exercise tests (ET) conducted 3 times preflight, 3 times inflight, and 2 times postflight. Since thermoregulatory responses are dependent upon relative exercise intensity, exercise capacity (VO\(_2\) peak) will be measured 3 times preflight, two days before the end of the flight, and once post-flight. The ET will be conducted in an environmental chamber at a temperature and humidity characteristic of the Shuttle middeck (77°F, 30-35% relative humidity). Because of the roughly 24-hr fluctuations in cabin ambient conditions during flight (see appendix 1 for examples of ambient cabin conditions), the ET will be scheduled for approximately the same time of the astronaut’s activity day—approximately 3 hr after waking and 2 hr after breakfast. Exercise tests will be done in duplicate preflight, 3 times inflight (flight days 2, 5, and the day before scheduled landing) and 2 times at least 30 days postflight. Thermoregulatory responses will be assessed during each 60-min. ET from measures of core and skin temperatures, local sweating responses, forearm blood flow and heat production calculated from the exercise oxygen consumption.

2) **Core Temperature:** Core temperature will be measured using two separate techniques—rectal temperature for the steady state response, and ear canal-tympanic membrane temperature for the initial transient temperature response. The rectum is the site most often used to assess core temperature during long-duration steady-state exercise. The limitations of the rectal measurement site are that it takes 50-60 min. to reach equilibrium and it may be influenced by local muscle heat production during leg exercise. Ear-canal temperature measurement is an indirect method to estimate brain temperature. It is fast-responding and an accepted method to measure transient core temperature responses which are essential for the identification of an altered sweating or skin blood flow reflex response. Esophageal temperature will be measured with soft, disposable thermocouples (Mallinckrodt Anesthesia Products). Thermometer pills (Human Technologies, Inc.) will be evaluated preflight using volunteers to determine whether they might be used in place of the rectal temperature site for measurement of steady-state core temperature.

3) **Forearm blood flow and sweating responses:** Both vasodilation and sweating heat loss responses are effected via reflex nervous responses. To determine the effector reflex responses, forearm blood flow and sweat rate are plotted as a function of the rise in core temperature during the first 10-20 min. of exercise. The slopes of these relationships are an indication of the sensitivity of the responses, while the core temperature at which sweating or vasodilation begins is the threshold of the responses (Nadel et al. 1977). Changes in sensitivity are thought to reflect changes in the function of the peripheral, afferent nervous system, while changes in threshold are interpreted as a central neural change in the thermoregulatory system (Fortney and Vroman 1985, Nadel et al. 1977). We predict there will be both central and peripheral modifications in heat loss responses upon exposure to microgravity; threshold changes in the central nervous system changes will be caused primarily by changes in body hydration, and changes in the peripheral nervous system by the postulated sheeting of sweat on the surface of the skin.
4) **Oxygen Consumption:** Heat production can be calculated by the method of indirect calorimetry (Newburgh 1949) from measurements of oxygen consumption and respiratory exchange ratio (VCO₂/VO₂). Oxygen consumption will be measured twice during each ET test—after 50 and 60 min. of exercise. The subject will breathe through a large-bore two-way breathing valve with the expired air directed through an ultrasonic flowmeter for measurements of ventilation. The expired gases will then go into a mixing chamber from which aliquots of the gas will be sampled and analyzed for percent oxygen and carbon dioxide. Samples of the cabin air will be taken immediately before each oxygen consumption determination for measurement of the inspired percentages of oxygen and carbon dioxide. All determinations will be performed in duplicate. If a gas analyzer is not available by the time of the flight, aliquots of the cabin air and expired air will be stored in small gas cylinders to be analyzed after the flight.

**C. CREW TRAINING:**

Approximately two months before flight, one 1-hr and one 2-hr training sessions will be required to familiarize the crew with the ET and peak VO₂ tests (Table 1). All ET and peak oxygen tests will be conducted on an electrically-braked cycle ergometer with the crewmen in the supine position to minimize orthostatic effects on the cardiovascular system. Then, as close as possible to launch, two peak VO₂ tests and two ET tests will be performed. Each ET will include 60 min. of a constant-load exercise, plus 30 min. for calibrating the equipment and instrumenting the crew. The load on the cycle ergometer will correspond with that required to produce an oxygen uptake of 60% of each crewperson’s preflight peak oxygen uptake. The ET will be conducted at least 2 hr after a meal (breakfast) with the crew abstaining from all drugs—including alcohol, nicotine, and caffeine—for 24 hr prior to each test.

1) **Preflight:** One 1-hr and one 2-hr exercise training sessions two months preflight. Then two preflight ET and two preflight peak oxygen tests will be done as close as possible to launch, allowing at least 2 days between the ET tests for complete recovery from the exercise.

2) **Inflight:** Three ET tests (total time required = 90 min./test) on flight days 2, 5, and one day before reentry. One peak oxygen test two days before reentry.

3) **Postflight:** One peak oxygen test approximately 28 days postflight. If this value is not back to preflight levels, it will be repeated 15 days later and the postflight ET tests also postponed. Two ET tests will be performed on postflight days 30 and 32, unless a longer delay is required for return of the peak VO₂.

4) **Flight Equipment:** An electrically-braked supine cycle ergometer will be used for all exercise tests, and the ET may be done in place of a usual daily exercise bout. Measurements to be taken during the 30 min. resting (instrumentation) pre-exercise period and during exercise are: rectal temperature (or stomach temperature with a thermometer pill), ear-canal temperature, 6 skin temperatures, heart rate from the electrocardiogram, and rate of sweating from chest hygrometer capsules, forearm blood flow measured during baseline and twice/minute during the first 20 min. of exercise. Oxygen consumption will be measured once, two days before reentry. Backup or actual flight ET and peak oxygen equipment should be used for all pre- and post-flight testing.
D. MEASUREMENT DEVICES AND EQUIPMENT:

1) **Body Temperature Measurements**: Rectal, skin, and ear-canal thermocouples and/or thermistors interfaced with a continuous recording system; e.g., Yellow Springs instruments thermistors connected to a Science/Electronics Physiological Squirrel Monitoring System. If proven accurate, Cortemp thermometer pills may be substituted for the rectal temperature site (Human Technologies, Inc., St. Petersburg, FL). The ear-canal-tympanic membrane thermocouples have cotton ends for comfort (Mallinckrodt Anesthesia Products, St. Louis, MO).

2) **Oxygen Consumption Measurements**: Ventilation will be measured with an ultrasonic flowmeter (OHO Electronic, Switzerland). Gas samples will be analyzed either postflight (MGA medical gas analyzer), or inflight, with a middeck gas analyzer for oxygen and carbon dioxide (to be developed in the Space Biomedical Research Institute). In either case, before aliquots are taken, they will be sampled from a gas mixing chamber (Meer Instruments, La Jolla, CA).

3) **Local Sweat Responses**: Dew point hygrometry system to be developed by Boeing.

4) **Forearm Blood Flow**: Measured using the System for Venous Occlusion Plethysmography developed for SLS-1 (Engineering Development Laboratories, Newport, VA).

5) **Exercise Device**: An electronically-braked cycle ergometer which will provide accurate graded exercise levels with little upper body movement which is necessary to insure the forearm blood flow measurements are free of movement artifact.

6) **Cabin temperature, humidity and air flow**: Standard thermistor, humidity sensor, and hot-wire anemometer (Appendix 1).

7) **Heart Rates**: Standard inflight electrocardiograph used during other inflight exercise protocols.

E. EXPECTED RESULTS:

We expect that the astronauts will exhibit excessive increases in their core temperatures during exposure to microgravity. The higher core temperatures may be due to decreased sensitivity of both skin blood flow and sweating responses to the increased core temperature.

F. SUPPORTING FACILITIES:

1) **Preflight**: Johnson Space Center’s environmental physiology heat chamber.

2) **Inflight**: Shuttle middeck.

3) **Postflight**: Johnson Space Center’s environmental physiology heat chamber.
G. REFERENCES:


H. BIOGRAPHICAL SKETCHES:

See appendix 2 at end of proposal.

I. BUDGET:

(Please note the equipment needed for this study is most likely redundant with equipment needed for other DSO or EDO projects). Therefore, some of these costs may be shared, and once developed, this equipment will be available for other studies.

1) No additional salaries are required.

2) Equipment (duplicate flight and ground-based equipment):

   Development of Dew Point Hygrometry Sweat System 50K
   Evaluation of Thermometer Pills 1K
   Mixing Chamber 10K
   Development of gas analyzer 50K
   Ultrasonic flowmeter 15K
Yellow Springs Thermistors and Data Storage System 10K
Development of Cycle Ergometer 30K
Purchase of System for Venous Occlusion Plethysmography 30K
Cabin temperature, humidity and air flow sensors. 2K

3) Other direct costs:
Subject costs for ground-based studies and validations 10K

4) Travel costs:
Travel and housing for Dr. Greenleaf from Ames to JSC 12K
(12 trips/$1000)

5) Other costs:
Data analyses and publication costs 10K

6) Overhead costs: none

TOTAL COSTS: 230K

J. CURRENT AND PENDING SUPPORT:

1) John Greenleaf:
   a) FY 1990 RTOP funds. “Fluid and Electrolyte Shifts during Deconditioning: Rehydration and Exercise Thermoregulation”; 90K.
   b) FY 1991 RTOP funds; 90K (year three).

2) Suzanne Fortney:
   a) FY 1990: Directors discretionary funds. “Plasma Volume and Orthostatic Intolerance”; $60K.
   b) FY 1990 RTOP funds. “Mechanism of Orthostatic Intolerance During Bedrest of Varying Duration”; $50K.
   c) FY 1991 Directors discretionary funds (last year); $60K.

K. PROVISIONS FOR USE OF HUMAN TEST SUBJECTS:

The investigations proposed will be reviewed by the Johnson Space Center Human Research Policy and Procedures Committee, and the Ames Research Center Human Research Experiments Review Board. If approved, the study will conform with the principles of the Helsinki Code of the World Medical Association.

Table 1. Crew Time Requirements

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<td>(L + 38)</td>
<td>(L + 30, L + 32)</td>
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*Preflight training sessions should occur within 60 days of the flight. Preflight VO₂ peak or ET tests should occur as close as possible to the launch, with the ET tests done on separate days, separated by at least 2 days.
APPENDIX 1: CABIN TEMPERATURE (°F) VARIABILITY DURING SHUTTLE FLIGHTS.

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11
John E. Greenleaf, Ph.D.  Research Scientist  Sept. 18, 1932

### EDUCATION

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<tr>
<td>University of Illinois, Urbana</td>
<td>B.S.</td>
<td>1955</td>
<td>Physical Education</td>
</tr>
<tr>
<td>New Mexico Highlands Univ., Las Vegas</td>
<td>M.A.</td>
<td>1956</td>
<td>Physical Education</td>
</tr>
<tr>
<td>University of Illinois, Urbana</td>
<td>M.S.</td>
<td>1962</td>
<td>Physiology</td>
</tr>
<tr>
<td>University of Illinois, Urbana</td>
<td>Ph.D.</td>
<td>1963</td>
<td>Environ. Physiology</td>
</tr>
<tr>
<td>Karolinska Institute, Stockholm</td>
<td>Postdoc</td>
<td>1966-1967</td>
<td>Human Physiology</td>
</tr>
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</table>

### RESEARCH AND/OR PROFESSIONAL EXPERIENCE

- Research Scientist, NASA Ames Research Center 1963-1966
- Swedish Medical Research Council Senior Post-Doctoral Fellow 1966-1967
- Research Scientist, Space Physiology Branch, NASA Ames Research Center 1967-present

### HONORS:


### PUBLICATIONS:


# BIOGRAPHICAL SKETCH

<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
<th>Birthdate</th>
</tr>
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<tbody>
<tr>
<td>Suzanne M. Fortney</td>
<td>Research Physiologist</td>
<td>August 6, 1950</td>
</tr>
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</table>

## Education

<table>
<thead>
<tr>
<th>Inslit. and Location</th>
<th>Degree</th>
<th>Yr. Conferred</th>
<th>Field of Study</th>
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<tbody>
<tr>
<td>Univ. of Missouri, St. Louis</td>
<td>BA</td>
<td>1972</td>
<td>Biology</td>
</tr>
<tr>
<td>St. Louis University</td>
<td>Ph.D.</td>
<td>1979</td>
<td>Physiology</td>
</tr>
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</table>

## Research Experience

<table>
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<tr>
<th>Year</th>
<th>Position</th>
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<tbody>
<tr>
<td>1988-Present</td>
<td>Research Physiologist, NASA Johnson Space Center</td>
</tr>
<tr>
<td>1981-1987</td>
<td>Assistant Professor, Johns Hopkins Univ. (Dept. Environ. Physiology)</td>
</tr>
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</table>

## Publications (Selected)


To: John E. Greenleaf, Ph.D. (ARC/NASA) and Suzanne M. Fortney, Ph.D. (SD5/NASA)  
From: Steven F. Siconolfi, Ph.D (SD5/NASA)  
Subject: DSO "Thermoregulation during Spaceflight"

I understand, that as a co-investigator, my primary role in this project will be to assist in the collection and analysis of all exercise data.
### Biographical Sketch

<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
<th>Birthdate</th>
<th>Field of Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steven S. Siconolli, Ph.D.</td>
<td>Research Physiologist</td>
<td>4 October 1952</td>
<td>Exercise Physiology</td>
</tr>
</tbody>
</table>

#### Previous Experience

<table>
<thead>
<tr>
<th>Year</th>
<th>Position and Institution</th>
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<tbody>
<tr>
<td>1980-present</td>
<td>Adjunct Professor of Exercise Physiology, Health and Human Performance</td>
</tr>
<tr>
<td></td>
<td>University of Houston Clear Lake, Houston, TX 77038</td>
</tr>
<tr>
<td>1985-88</td>
<td>Associate Professor of Exercise Physiology, Exercise Physiology Section</td>
</tr>
<tr>
<td></td>
<td>Movement Sciences Laboratory, Springfield College, Springfield, MA 01109</td>
</tr>
<tr>
<td>1987-88</td>
<td>Exercise Physiology Consultant, National YMCA Certification Programs in Fitness</td>
</tr>
<tr>
<td>1984-85</td>
<td>Visiting Assistant Professor of Exercise Physiology, Purdue University, West Lafayette, IN</td>
</tr>
<tr>
<td>1983-84</td>
<td>Adjunct, Assistant Professor of Physical Education, Human Performance Lab, University of Rhode Island, Kingston, RI</td>
</tr>
<tr>
<td>1980-84</td>
<td>Exercise Physiologist and Director, Human Performance Lab, Department of Cardiology, The Memorial Hospital, Pawtucket, RI 02860</td>
</tr>
<tr>
<td>1979-80</td>
<td>Teaching Fellow at Kent State University</td>
</tr>
<tr>
<td>1977-80</td>
<td>Basic Coordinator of the Fitness KSU Program (an adult physical fitness program)</td>
</tr>
<tr>
<td>1977-80</td>
<td>Instructor at YMCA Physical Fitness Specialist Workshop at Kent State University</td>
</tr>
<tr>
<td>1975-77</td>
<td>Physical and Fitness Director, Hamilton YMCA, Hamilton, OH</td>
</tr>
<tr>
<td>1974-75</td>
<td>Laboratory Instructor for Physiology of Exercise at Springfield College</td>
</tr>
<tr>
<td>1974-75</td>
<td>Research Fellow at Springfield College</td>
</tr>
</tbody>
</table>

#### Selected Publications


BIOGRAphICAL SKETCH

Harold J. Guy

Date of Birth: [redacted]. Citizenship: United States

Address: 4021 Alicia Dr., San Diego, CA 92107

Degrees and Qualifications:

M.B.Ch.B. (graduate degree in Medicine), Otago University, 1963
B. Med. Sc. (degree in Medical Science, Pharmacology) Otago University, 1963
M.R.A.C.P. (Member, Royal Australasian College of Physicians), 1972
F.R.A.C.P. (Fellow, Royal Australasian College of Physicians), 1976
Licensed Physician #A42714 - State of California, Expires 11/30/91

Appointments:

1966 - Resident in Internal Medicine & Cardiology, University of Otago, New Zealand
1967 - Pilot Training, Royal New Zealand Air Force (RNZAF)
1968-70 - Flight Surgeon, RNZAF Medical Officer, NZ Services Med Team, Viet Nam
1971-72 - Medical Officer, RNZAF Airborne Rescue Team
1971-72 - Resident in Internal Medicine, Christchurch Hospital, NZ
1972-74 - Postdoctoral Fellow, RNZAF Overseas Study Grant: Pulmonary Physiology at University of California, San Diego
1974-81 - Lecturer, Senior Lecturer in Medicine, University of Otago, NZ; Director, Pulmonary Laboratory; Attending Pulmonary Physician; Physician, Intensive Care Unit; Physician, Hyperbaric Facility, Christchurch Hospital
1981-82 - Sabbatical leave at University of California, San Diego
1982 - Specialist, Section of Physiology, Department of Medicine, UCSD, Co-Investigator, NASA Experiment 196, Pulmonary Function in Microgravity, ESA D2 experiment, Pulmonary Function in Microgravity, Pulmonary Gas Exchange, Ventilation & Blood Flow in Microgravity
1985 - Clinical Assistant Professor, Department of Medicine, UCSD
1985-87 - Attending physician, UCSD Medical Center
1987 - Present - Attending Physician, VA Medical Center

Relevant Publications:


Harold J. Guy, M.D.


Work in Progress:


Honors, Awards and Memberships:

Honors and Awards:

Honorary RNZAF Physician to the Governor General of New Zealand, 1981

Member of:

Undersea Medical Society
American Society for Gravitational & Space Biology
Aerospace Medical Association
Aerospace Medical Association, Space Medicine Branch
Aerospace Human Factors Association
International Society for Aerosols in Medicine
Discipline Implementation Team (DIT) of the Exercise Countermeasures Project for the Extended Duration Orbiter (EDO)
New Zealand Medical Association
New Zealand Thoracic Society
New Zealand Physiological Society

20
Harold J. Guy, M.D.

New Zealand Medical Physics & Biomedical Engineering Society

Correspondent in Gravitational Physiology; International Union of Physiological Sciences
TO: ARC/NASA/John E. Greenleaf, Ph.D.
SD5/NASA/Suzanne M. Fortney, Ph.D.

FROM: SD5/KRUG/Alan D. Moore, Ph.D.

DATE: January 25, 1991

SUBJECT: Collaboration in the proposed SDO entitled
"Thermoregulation During Spaceflight"

My primary role as a scientific collaborator in the proposed study shall be to participate in the collection, quality assurance, and interpretation of the exercise data. Attached is a "mini-vita" that should meet your documentation requirements.

ADM/hmg

Attachment
BIOGRAPHICAL SKETCH

Name: Alan D. Moore, Jr.
Title: Senior Research Scientist
Birthday: June 25, 1958

Education

<table>
<thead>
<tr>
<th>Institution/Location</th>
<th>Degree</th>
<th>Year Conferred</th>
<th>Field of Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campbell Univ., Buies Creek, NC</td>
<td>BS</td>
<td>1980</td>
<td>Biology</td>
</tr>
<tr>
<td>Virginia Tech, Blacksburg, Virginia</td>
<td>MS</td>
<td>1983</td>
<td>Exercise Physiology</td>
</tr>
<tr>
<td>Virginia Tech, Blacksburg, Virginia</td>
<td>Ph.D.</td>
<td>1987</td>
<td>Applied Research</td>
</tr>
</tbody>
</table>

Experience

1989-Present: Senior Research Scientist, KRUG Life Sciences, NASA Johnson Space Center
1987-1989: Assistant Professor, University of Houston, Dept. of Health and Human Performance
1980-1987: Graduate Research Assistant and Fellow, Virginia Tech, Dept. of HPER

Current Professional Certifications

1990: American Heart Association-Advanced Cardiac Life Support (ACLS)
1988: American College of Sports Medicine (ACSM)
1983: Preventive and Rehabilitative Exercise Program Director
1981: ACSM Preventive and Rehabilitative Exercise Test Technologist

Publications and Presentations (Selected)

SECTION II

PROTECTION OF HUMAN SUBJECTS.

I. Justification. Explain briefly why human subjects are required.

II. Requirements and Selection Criteria. Describe in detail all subject selection procedures. Include source of subject population, recruitment methods, and schedules for subject briefing sessions. List all selection and exclusion criteria such as age, sex, smoking history, physical condition, and special requirements such as current Air Force class III physical examination results, and history of drug allergies. Any other special health-related testing requirements must be clearly indicated.

III. Confidentiality. Briefly describe the procedures employed to maintain confidentiality of subject identity and results.

IV. Risks and Hazards. Describe all anticipated hazards from the procedures (especially biological sample collections, new diagnostic procedures and treatments), materials (radioactive substances etc.), or any other experiment-related conditions, including immediate, delayed, or long-term effects. Include assessment of degree of risk (minimum, reasonable, or high) and proposed acceptable risk-benefit ratio.

V. Safety precautions. Describe details of medical intervention procedures in the event of adverse reaction. Include information on the availability of a physician and medical facilities during and after the study, any post-experiment medical check up requirements, and precautionary measures to avoid any complications (immediate and delayed) that are experiment related.

VI. Subject Information and Consent. Include all the necessary information concerning the study that will be explained to the subjects at the briefing session. Clearly state subject rights such as freedom to withdraw from the study, workmen's compensation coverage, confidentiality, and remuneration policy. Attachments must include a duly filled Consent form (JSC Form 1416 or 1416A, Revised August 1990) approved by the institutional Human Use Committee and Subject Information Handout.

A. Subject Briefing. Describe briefly the information that will be covered during the briefing session. Include a list of personnel that will attend the briefing and the procedures that will be explained or demonstrated at the briefing.

B. Subject Information Handout. Attach a handout that clearly states in simple language all the procedures employed in the study, hazards and risks involved, safety precautions during and after the study, benefits and coverage, subjects' rights and remuneration, and any post-experiment instructions.

B. Consent Form. Include appropriate form for minimum (1416) or reasonable risk (1416A) recommended by the Human Research Policy and Procedures Committee that is duly filled with information regarding the study and the investigator.
NASA HUMAN RESEARCH
REASONABLE RISK
INFORMED CONSENT FORM

1. I, the undersigned, do voluntarily give my informed consent for my participation as a test subject in the following research study, test, experiment, or other evaluation procedure:

NAME OF EXPERIMENT

TRAINING TOUR NUMBER

FLIGHT TO WHICH ASSIGNED

NAME OF DESIGNATED PRINCIPAL INVESTIGATOR

NAME OF RESPONSIBLE NASA PROJECT SCIENTIST

I understand or acknowledge that:

(a) This procedure is part of an experiment approved by NASA.

(b) I am performing these duties as part of my employment with

(c) This research study has been reviewed and approved by the JSC Human Research Policy and Procedures Committee (HRPPC) which has also determined that the protocol involves reasonable risk to the subject.

(d) "Reasonable risk" means that the risks of harm anticipated in the proposed research are greater than those ordinarily encountered in daily life or during the performance of routine tests, but that those risks are considered to be acceptable when weighed against the anticipated benefits and the importance of the knowledge to be gained from the research.

(e) The research procedures were explained to me prior to the execution of this form. I was afforded an opportunity to ask questions, and all questions asked were answered to my satisfaction.

(f) I am medically qualified to participate in the investigation.

(g) I may withdraw from the investigation at any time unless, as recommended by the Principal Investigator or his/her designee, such withdrawal would be dangerous or impossible.

(h) In the event of physical injury resulting from this study and calling for immediate action or attention, NASA will provide or cause to be provided, the necessary treatment. I also understand that NASA will pay for any claims of injury, loss of life or property damage to the extent required by the Federal Employees Compensation Act or the Federal Tort Claims Act. My agreement to participate shall not be construed as a release of NASA or any third party from any future liability which may arise from, or in connection with, the above procedures.
The confidentiality of any data obtained as a result of my participation as a research subject in this study shall be maintained, so that no data may be linked with me as an individual. However, if a "life-threatening" abnormality is detected, the investigator will notify me and the JSC Flight Medicine Clinic. Such information may be used to determine the need for care or medical follow-up, which, in certain circumstances, could affect my aeromedical flight status.

2. I, the undersigned, the Principal Investigator of the experiment designated above, certify that:

(a) I have accurately described the procedure to the test subject.

(b) The test setup involves reasonable risk to the test subject. All equipment to be used has been inspected and certified for safe and proper operation.

(c) The test subject is medically qualified to participate.

(d) The test protocol has not been changed from that originally approved by the JSC HRPPC.

Approved:

Test Subject ___________________________ Date ___________________________

Principal Investigator ___________________________ Date ___________________________

Project Scientist ___________________________ Date ___________________________

(1) A detailed description of the experiment or investigation will be attached to this consent form. The Principal Investigator is responsible for formulating this document, which should be in layman's terms such that the subject clearly understands what procedures will be required and the risks associated therewith.

(2) This form is valid for a 1-year period from the date of signature by the Principal Investigator and the test subject (which dates should be identical). A signed, dated copy of this form with attachments must be forwarded to the JSC Human Research Policy and Procedures Committee, Mail Code SA, Lyndon B. Johnson Space Center, Houston, Texas 77058.

JSC Form 1416A (Rev August 90)
NASA HUMAN RESEARCH
MINIMAL RISK
INFORMED CONSENT FORM

1. I, the undersigned, do voluntarily give my informed consent for my participation as a test subject in the following research study, test, experiment, or other evaluation procedure:

   NAME OF EXPERIMENT ____________________________
   TRAINING TOUR NUMBER ____________________________
   FLIGHT TO WHICH ASSIGNED ____________________________
   NAME OF DESIGNATED PRINCIPAL INVESTIGATOR _________
   NAME OF RESPONSIBLE NASA PROJECT SCIENTIST _________

I understand or acknowledge that:

(a) This procedure is part of an experiment approved by NASA.

(b) I am performing these duties as part of my employment with __________.

(c) This research study has been reviewed and approved by the JSC Human Research Policy and Procedures Committee (HRPPC) which has also determined that the protocol involves minimal risk to the subject.

(d) "Minimal risk" means that the risks of harm or discomfort anticipated in the proposed research are no greater than those ordinarily encountered in daily life or during the performance of routine tests, but that those risks are considered to be acceptable when weighed against the anticipated benefits and the importance of the knowledge to be gained from the research.

(e) The research procedures were explained to me prior to the execution of this form. I was afforded an opportunity to ask questions, and all questions asked were answered to my satisfaction.

(f) I am medically qualified to participate in the investigation.

(g) I may withdraw from the investigation at any time unless, as recommended by the Principal Investigator or his/her designee, such withdrawal would be dangerous or impossible.

(h) In the event of physical injury resulting from this study and calling for immediate action or attention, NASA will provide or cause to be provided, the necessary treatment. I also understand that NASA will pay for any claims of injury, loss of life or property damage to the extent required by the Federal Employees Compensation Act or the Federal Tort Claims Act. My agreement to participate shall not be construed as a release of NASA or any third party from any future liability which may arise from, or in connection with, the above procedures.
2. I, the undersigned, the Principal Investigator of the experiment designated above, certify that:

(a) I have accurately described the procedure to the test subject.

(b) The test setup involves minimal risk to the test subject. All equipment to be used has been inspected and certified for safe and proper operation.

(c) The test subject is medically qualified to participate.

(d) The test protocol has not been changed from that originally approved by the JSC HRPPC.

APPROVED:

Test Subject _______________________________ Date __________

Principal Investigator __________________________ Date __________

Project Scientist ____________________________ Date __________

(1) A detailed description of the experiment or investigation will be attached to this consent form. The Principal Investigator is responsible for formulating this document, which should be in layman's terms such that the subject clearly understands what procedures will be required and the risks associated therewith.

(2) This form is valid for a 1-year period from the date of signature by the Principal Investigator and the test subject (which dates should be identical). A signed, dated copy of this form with attachments must be forwarded to the JSC Human Research Policy and Procedures Committee, Mail Code SA, Lyndon B. Johnson Space Center, Houston, Texas  77058.
Title of Research: Thermoregulation During Spaceflight

Principal Investigator(s): John Greenleaf, SL:239-7

File Number: H.R. 97

Based upon my examination of the Protocol for the above-entitled research, staff analysis and recommendations concerning the same including medical and legal review, as well as my independent examination of the File annexed I hereby find and determine:

1. That the research requires the use of human test subjects, and cannot feasibly be accomplished through the use of animals or by other means;

2. That the importance of the objective of the research outweighs the inherent risks to the human test subjects who may be involved, and that said subjects will not be unnecessarily exposed to risk of injury, discomfort, or inconvenience;

3. That the record contains evidence of satisfactory procedures for obtaining from each test subject his voluntary, and his informed, consent and that each test subject or his survivors would receive adequate compensation in the event of misadventure on the basis of federal, state, or private insurance compensatory plans as more particularly detailed and described in the File annexed.

Effective this date, the above entitled research is authorized and the Principal Investigator(s) herein may proceed with the same subject to the following conditions:

A. This Authorization is valid until May 31, 1992 and the research may not continue beyond this date unless additional written authorization from me is received.

B. All test subjects will receive a physical examination by a licensed physician prior to participation in the research and a physical examination upon termination of their participation in the research and in the event any medical impairment is disclosed the same shall be reported promptly and in writing to the test subject, to the ARC Chief, Institutional Operations Office, and to the Chief Counsel with an information copy to me.

Date: 5/24/91

Sule L. Compton, Director
**Thermoregulation During Spaceflight**

The purpose for this flight proposal is to investigate human thermoregulatory parameters during exercise in microgravity. The hypothesis to be tested is that microgravity-adopted astronauts will exhibit accentuated increases in their core temperatures (excess hyperthermia) during exercise because of altered heat loss responses due to reduced sweating and/or accentuated vasodilation. The specific aims are (a) to compare core and skin temperature responses during moderate exercise before flight and inflight; (b) to determine whether the hypothesized inflight excessive hyperthermia is due to increased heat production, reduced sweating, impaired peripheral vasodilation, or to some combination of these factors; and (c) to determine whether heat production at an exercise load of 60% of the maximal working capacity is similar preflight and inflight. It is expected that the astronauts will exhibit excessive hyperthermia during exposure to microgravity which will be caused by decreased sweating and decreased skin blood flow.