

Section 9

Project Summary and Conclusions

EXTENDED DURATION ORBITER MEDICAL PROJECT

Project Summary and Conclusions

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A top level summary of activities conducted throughout the course of the EDOMP in response to initial concerns at the outset of the program is shown in Table 9-1. Significant findings from the investigations are summarized, together with resulting countermeasures

that were implemented and flight rules that were developed in response to these findings. Subsequent paragraphs provide more information; details will be found in the referenced sections.

Table 9-1. Initial EDOMP concerns that led to significant findings and resulted in countermeasures and flight rules for space shuttle missions

<i>Initial Concerns at Onset of EDOMP</i>	<i>Significant Findings</i>	<i>Countermeasures</i>	<i>Flight Rules</i>
Preservation of capability for egress	Multiple factors noted below contributed to overall capability	All noted below except instrumentation monitoring	Mandatory g-suit and exercise as noted below
Anticipated degradation of landing proficiency	Time required to foveate images increased by up to 100% at landing	Commanders altered their instrument monitoring on final approach	
Orthostatic intolerance	<ul style="list-style-type: none"> • Baroreceptor function: less hypotensive buffering capacity • Significant changes in sympathetic tone <ul style="list-style-type: none"> – Non-fainters demonstrated higher catecholamine levels • Heart rate, diastolic blood pressure and premature ventricular contractions significantly reduced in flight • Plasma volume restoration did not prevent syncopal episodes • Florinef evaluated as countermeasure (CM); unacceptable due to side effects 	<ul style="list-style-type: none"> • Alternative isotonic fluid loads developed 	

Table 9-1. Continued

<i>Initial Concerns at Onset of EDOMP</i>	<i>Significant Findings</i>	<i>Countermeasures</i>	<i>Flight Rules</i>
Orthostatic intolerance (continued)	<ul style="list-style-type: none"> • Re-entry Antigravity Suit (REAGS) developed: better protection at lower pressures relative to CSU-13 • Addition of Liquid Cooling Garment (LCG) reduced incidence of orthostatic intolerance to pre-<i>Challenger</i> level • LCG decreased postflight incidence of nausea by 50% • Lower Body Negative Pressure evaluated as CM 	<ul style="list-style-type: none"> • Development and verification of REAGS • Addition of LCG to ACES ensemble • Mission implementation impact greatly outweighed physiological benefit 	<ul style="list-style-type: none"> • Mandatory preinflation of g-suit
Neuromuscular/neuro-vestibular alterations	<ul style="list-style-type: none"> • Exposure to simulated flight spatial environments facilitated “dual adaptation” and decreased incidence and severity of space motion sickness • Decreased ability to jump 30 cm postflight 	<ul style="list-style-type: none"> • Preflight Adaptation Trainer dual adaptation training 	
Maintaining aerobic capacity	<ul style="list-style-type: none"> • Cycle ergometer and rower shown to be adequate for maintaining aerobic capacity within 6-12% preflight • Exercise decrements minimized by 3× per week, 20 m sessions @ 60-80% preflight maximum levels 	<ul style="list-style-type: none"> • Cycle ergometer and rower developed and qualified for use as flight exercisers 	<ul style="list-style-type: none"> • Mandatory exercise on flights greater than 10 days
Muscle strength loss	<ul style="list-style-type: none"> • Ground-based and in-flight energy requirements determined to be equivalent • Significant strength losses in trunk musculature 		
Other	<ul style="list-style-type: none"> • Significant changes in pH, calcium, and citrate increased risk of renal stone formation • Bacterial levels increased moderately; fungal levels decreased 	<ul style="list-style-type: none"> • Daily fluid intake recommended to be greater than 2.5 liters 	

Table 9-1. Concluded

<i>Initial Concerns at Onset of EDOMP</i>	<i>Significant Findings</i>	<i>Countermeasures</i>	<i>Flight Rules</i>
Other (continued)	<ul style="list-style-type: none"> • Volatile organic compounds generally below allowable limits 		<ul style="list-style-type: none"> • Combustion Products Analyzer developed and flown on all Shuttle missions

CARDIOVASCULAR DECONDITIONING

Early mechanism studies determined vagally mediated, carotid baroreceptor-cardiac reflex responses for astronauts before and after short Shuttle missions. The investigators determined operational points that were a measure of baroreflex buffering capacity for blood pressures above and below resting levels. Low operational points indicate less hypotensive buffering capacity; conversely, high operational points imply less buffering capacity for the hypertensive stimuli. Astronauts who were unable to maintain their systolic pressures on landing day exhibited relatively slower heart rates, greater gain of vagally mediated baroreflex responses preflight, and greater weight loss and reductions of baroreflex operational points postflight than astronauts who maintained stable systolic pressures. Attempts were made to divide subjects into “more resistant” and “less resistant” groups relative to their orthostatic stability. A limitation of the baroreflex technique was that it documented changes of vagal baroreflex mechanisms but did not define sympathetic mechanisms. Investigations were extended to include catecholamine determinations and Valsalva maneuvers on missions of 8-14 days. Power spectral density analyses of R-R interval data were accomplished to determine shifts in sympathetic/ parasympathetic autonomic nervous system function. Both norepinephrine and epinephrine levels were significantly increased on landing day but returned to normal within 3 days after landing. Therefore, space flight provoked functionally significant changes in sympathetic and vagal cardiovascular control. A third study provided normative baseline data for microgravity decreases in heart rate and arterial pressure in crew subjects. Heart rate, arterial pressure, and cardiac rhythm disturbances were monitored for 24-hour periods before, during, and after space flight while astronauts performed their normal routines. Heart rate, diastolic pressure, variability of heart rate and diastolic pressure, and premature ventricular contractions (PVCs) all were significantly reduced in flight. Systolic pressure and premature atrial contractions (PACs) also tended to

be reduced in flight. These data were obtained by use of Holter monitors in conjunction with automatic auscultative blood pressure devices during 24-hour monitoring. Although there was a trend toward a reduced frequency of PACs and PVCs during flight, the only significant difference on any day was a reduction in PVCs during the early stages of flight relative to the averaged preflight frequency. Reductions in diastolic pressure seen during flight may reflect reductions in sympathetic activity and peripheral vascular resistance. These results suggest that space flight itself had a benign effect on the cardiovascular system. Finally, results from these studies did not support the idea that loss of plasma volume was the primary cause of postflight orthostatic hypotension, rather they supported previous findings from bed rest studies, which showed that restoration of plasma volumes did not fully restore post bed rest orthostatic tolerance.

Potential new or improved countermeasures were evaluated, including (1) improved use of existing anti-g suits, (2) a potential new anti-g suit, (3) use of a liquid cooling garment (LCG), (4) ingestion of hypotonic and hypertonic solutions prior to landing, (5) use of lower body negative pressure (LBNP) during flight, and (6) the use of fludrocortisone (Florinef) as a plasma volume expander during the last days of flight.

Studies were conducted to determine if early inflation of the standard five-bladder anti-g suit prior to centrifuge simulation of Shuttle landing would provide better protection against orthostasis than the standard symptomatic inflation regimen. Preinflation protected eye-level blood pressures better and resulted in lower maximum heart rates during these simulations. The second portion of these studies led to development of an improved anti-g suit, which was designated the Reentry Anti-G Suit (REAGS). This suit provided more complete lower torso coverage but deleted the abdominal bladder found in the standard CSU-13 B/P suit. Although REAGS was shown to provide greater protection at lower absolute inflation pressures, it was not incorporated into the Launch and Entry Suit (LES) because it decreased mobility and increased bulkiness of the total garment.

NASA evaluated an LCG as a countermeasure to the thermal load imposed by the LES. This thermal load is believed to be largely responsible for the increased incidence of orthostatic intolerance noted following resumption of Shuttle flights after the Challenger accident. The metabolic heat produced by an average astronaut is about 100 watts. Prior to use of the LCG, the only means of dissipating body heat was via cabin air circulated across the chest area within the LES. This provided modest benefit in a cool cabin and no benefit post landing when cabin air temperatures often reached 80-90 °F (27-32 °C). The LCG employs a thermoelectric cooler to chill water before its circulation through a full torso coverage, tube-filled garment. The LCG is presently worn both for launch and landing; it has proven extremely effective, both for general comfort and orthostatic protection. The frequency of occurrence of orthostatic symptoms has decreased to pre-Challenger levels (approximately 5%) since incorporation of the LCG; also the incidence of postflight nausea has decreased 50%.

Fluid loading with hypotonic and hypertonic solutions was evaluated by ground-based studies. Hypertonic solutions resulted in diarrhea for many subjects. Hypotonic solutions were totally ineffective. Various isotonic solutions provided increased plasma volume and were judged suitable for use in the fluid load countermeasure.

LBNP treatment protocols did not provide significant protection from orthostatic tolerance on participants in these missions. The high crew-time overhead associated with the LBNP soak protocol greatly offset potential benefits judged by improved orthostatic tolerance. The LBNP countermeasure was judged impractical for Shuttle missions.

A common clinical prescription for orthostatic intolerance, fludrocortisone or Florinef, was evaluated in several ground-based studies and then during flight. Pharmacological countermeasures are complex because absorption kinetics are different in the microgravity environment of orbital flight. Dosage regimens that proved effective in subjects after bed rest were not beneficial in flight trials. When an effective dose was tried during flight (0.1 mg, twice a day for the last 5 flight days), the side effects (head fullness, headache, congestion, etc.) made it unacceptable.

REGULATORY PHYSIOLOGY

It was uncertain how the effects of limited physical activity, combined with the potential for increased stress would affect nutritional requirements. Earlier space flight studies indicated changes in protein turnover that were consistent with a stress reaction during Shuttle flights. Energy expenditure requirements were studied during space flights of 8-14 days duration. Methods employed were developed from the doubly labeled water (DLW)

technique modified to account for baseline isotopic differences associated with the Shuttle potable water system, whose water is a product of fuel cells that operate with liquid oxygen and hydrogen. Baseline metabolic studies were accomplished approximately 2 months before flight, while flight studies typically began on the third flight day to avoid confounding effects associated with space motion sickness. The energy requirements associated with physical activity in microgravity were largely unknown, and the relatively close confines of spacecraft tended to limit the extent of physical activity. During flight, energy intake (8.8+/-2.3 Mj/day) was less than total energy expenditure or TEE (11.7+/-1.9 Mj/day). Body weight was less at landing than at 2 days before launch. No differences were found between ground-based and in-flight energy expenditures. Interpretation of body weight changes during space flight was confounded by the fluid loading countermeasure, although typically most fluid load was lost through a combination of diuresis and perspiration. Total weight loss, recorded at landing, reflected a combination of tissue and water loss.

We have observed low dietary intake during space flight. Furthermore, it has previously been shown that relative proportions of energy sources shifted during flight, with the carbohydrate component increasing, protein remaining stable, and fat declining.

Exposure to the microgravity environment of space produced a number of physiological changes of metabolic and environmental origin that increased the potential for renal stone formation. Metabolic, environmental, and physicochemical factors that influence renal stone risk potential were examined. Decreased fluid intake and vomiting associated with space motion sickness in some people during early phases of space flight probably contributed to decreases in urine volume, which added to the risk of stone formation. Urinary calcium levels increased during flight, reflecting the overall negative calcium balance during space flight. Total fluid intake from foods and liquids was approximately 2 liters per day or less. Statistically significant changes were shown for pH, calcium, and citrate in the direction of increased stone-forming risk. At landing, crew members exhibited hypercalciuria, hypocitraturia, decreased magnesium excretion, and decreased urinary pH and volume. A decrease in pH typically increases stone-forming potential by decreasing the solubility of uric acid and increasing the availability of uric acid crystals, which in turn can act as a nidus for calcium oxalate stones.

FUNCTIONAL PERFORMANCE EVALUATION

Both physical and psychological benefits were received from in-flight exercise sessions. As a result of these investigations a flight rule was established requiring exercise on missions greater than 10 days in duration. A

key objective was to determine the optimal combination of a crew member's fitness before flight and continued exercise in flight to result in minimal performance decrements. Conducting well-controlled investigations proved extremely difficult because of multiple conflicting priorities during each mission. In general, moderate to more intense levels of cycle exercise resulted in improved sub-maximal exercise responses after flight. This response required exercising more than 3 times per week for greater than 20 minutes per session at intensities of 60-80% preflight maximum work loads. Changes in muscle morphology were studied by pre- and postflight biopsy of the *vastus lateralis* muscle in the thigh. Significant changes were evident after 6-9 day Shuttle missions, including a 15% reduction in the cross sectional area of Type I and a 22% reduction in cross sectional area of Type II muscle fibers.

Muscle function was measured by a LIDO[®] dynamometer. Large decrements in trunk flexor and extensor strength, both concentric and eccentric, and significant losses in concentric quadriceps extension were seen. Muscle strength typically recovered within 7-10 days with the exception of concentric back extension. Significant additional effort is still required to define an optimal exercise program which gives consideration to (1) aerobic vs. resistive, (2) upper body vs. lower body, (3) eccentric (force while lengthening) vs. concentric (force while shortening), and (4) high-intensity interval vs. low-intensity continuous protocols.

ENVIRONMENTAL HEALTH

The Environmental Health activity developed an overall strategy for safeguarding crew members from potential airborne hazards anticipated on missions of extended duration. Degradation of air quality had the potential to affect crew performance during all mission phases, and increased risk was anticipated with extended duration flights. Second, there was the potential to reach unacceptable levels of volatile organic compounds, or excessive airborne particulate matter, and finally the potential for excessive levels of microorganisms.

Data collected during the program indicated that volatile organic compounds (VOCs) in the cabin atmosphere were generally below allowable limits. Most pollutants reached equilibrium concentrations within the first few days of a mission. Exceptions to this were hydrogen, methane, and dichloromethane. Formaldehyde was found to be present at levels exceeding the allowable limits for each of three missions monitored. Although accidental air contamination problems originated from a variety of sources, the dominant source was thermodegradation of electronic devices. Nine such incidents occurred during 20 missions; four were the result of electronic burns. The necessity for real-time monitoring of critical combustion

products resulted in the development of the Combustion Products Analyzer that now flies on each Shuttle mission.

Quantification of airborne bacteria and fungi showed in general that bacterial levels increased moderately as the mission proceeded, whereas the fungal levels tended to decrease. Fungal levels likely decreased in response to the low humidity on typical Shuttle missions.

NEUROVESTIBULAR DYSFUNCTION

Flight surgeons frequently observed disequilibrium in crew members during the first few hours after space flight. These observations were in large part attributed to functional changes in the neurovestibular system. Neurovestibular investigations were designed to use sophisticated devices to evaluate these changes: specifically, a commercially available Neurocom Equitest Posture Platform, electrooculograms, a specially designed Tilt Translation Device, and a Device for Orientation and Movement Environments.

Four primary goals were (1) to establish a normative data base of vestibular and associated sensory changes in response to space flight, (2) to determine the underlying etiology of neurovestibular and sensory motor changes associated with exposure to microgravity and the subsequent return to Earth, (3) to provide immediate feedback to flight crews regarding potential countermeasures that could improve performance and safety during and after flight, and (4) to design appropriate countermeasures that could be implemented for future missions.

Perception of spatial orientation is determined by integrating information from several sensory modalities. This involves higher levels of processing within the central nervous system to control eye movements, stabilize locomotion, and maintain posture. Operational problems occur when reflex responses to perceived spatial orientation lead to inappropriate compensatory actions.

Target acquisition protocols used a cruciform tangent system where targets were permanently fixed at predictable angular distances in both the horizontal and vertical planes. The subject was required to use a time optimal strategy for all target acquisition tasks: to look from the central fixation point to a specified target indicated by the operator (right red, left green, up blue, etc.) as quickly and accurately as possible using both head and eye movement to acquire the target. During flight, measurements were obtained using a cruciform target display that attached to the Shuttle mid-deck lockers. In all cases, surface electrodes on the face enabled quantifying eye movements that were obtained with both horizontal and vertical electrooculography. Pursuit tracking, (i.e., visually moving from a central focal point to illuminated targets) was performed before flight and after flight, using two separate protocols: (1) smooth pursuit by the eyes only, and (2) pursuit tracking with the head and eyes together. The sinusoidal pursuit tracking

tasks were performed at moderate (0.33 Hz) and high (1.4 Hz) frequencies to investigate the relative contributions of eye and head movement in maintaining gaze. Significant difficulties were observed postflight, including multiple saccades; consequently, the time required to foveate the target increased by as much as 1 to 1.5 seconds relative to pre-flight times.

Two protocols investigating postural stability were performed before, during, and after Shuttle missions of varying duration. These tests used a clinical Neurocom Equitest posture platform which permitted challenging the subject's ability to maintain balance by six different sequential tests. The effect of space flight on neural control of posture was inferred from differences between preflight and postflight performance. The effect of mission duration was inferred from statistical comparison between the performance of subjects on short, medium, and long duration missions. Astronauts with previous flight experience demonstrated better postural stability which suggested retained neurosensory learning. Multiple protocols were employed to determine if exposure to the microgravity environment induced alterations in eye-head-trunk coordination during locomotion. The normally phased relationship between head pitch and vertical trunk position was not evident when observed 4 hours after flight. This alteration resulted in decreased capability to foveate targets. Findings reinforced the criticality of vision if astronauts were to be able to compensate for vestibular function changes associated with exposure to microgravity environments.

HUMAN FACTORS

These studies documented the strengths and limitations of human operators in a complex environment. Promising areas of inquiry included tools, habitat, environmental conditions, tasking, work load, flexibility, and individual control over work.

Gloveboxes

Task performance within gloveboxes was affected by such factors as constrained arm movements, postural limitations, and visual constraints. The design of gloveboxes was primarily driven by task requirements with little or no consideration of the human interface. Three glovebox designs were flown on various Spacelab missions: (1) Material Sciences Glovebox (GBX), supporting crystal growth and other material science experiments; (2) the biorack, a facility to support investigations on cells, tissues, plants, bacteria, small animals, and other biological samples; and (3) the General Purpose Work Station (GPWS), a multifunctional facility that supported animal experimentation and microscope use. The GBX was generally rated unacceptable because of its small size,

limited range of motion, hand positioning, and resulting shoulder and neck pain. The GPWS was rated acceptable, although reaching loose items proved difficult at times. The biorack was not broadly evaluated.

Lower Body Negative Pressure (LBNP)

LBNP investigations included consideration of stowage and assembly, and operation of the controls and displays. Data from in-flight questionnaires enabled the crew to record comments and evaluations while studies were in progress. Postflight debriefs and video image analyses provided additional information.

Stowage, Restraints, Deployment and Cables

Crew members were monitored during waking hours via video downlink. Several problems were identified with stowage, ranging from locker design to practices associated with stowing individual items. It was determined that quick, simple methods for restraining small items should be supplied; these should include Velcro, adhesive surfaces, vacuum, or elastic bands.

Touchscreen Usability in Microgravity

Most of the subjects preferred the touchscreen on the ground and the Trackpoint in flight. Hand fatigue was experienced almost immediately when using the touchscreen in flight.

Vibration in Flight

The Space Acceleration Measurement System was used to measure and store acceleration data during flight. Vibration was perceptible to all subjects and annoying to some. Vibrations occurred at times when primary jets were firing, or when the treadmill or ergometer was in use.

Acoustic Noise Environment

Crew member perceptions of noise on Shuttle differed from one mission to another. In all cases, the major noise source was the Environmental Control and Life Support System. The Spacelab refrigerator/freezers emitted excessive noise (70 dB(A) with one compressor operating and 73 dB(A) with both compressors operating). The vacuum cleaner contributed significantly to the noise environment, operating at nearly 80 dB(A). The SAREX, or short wave amateur radio, resulted in sound level readings of 72 dB(A).

FACILITIES

Medical data collection facilities at both Dryden Flight Research Center (DFRC) and Kennedy Space Center (KSC) required design changes in order to implement the

EDOMP. While modifications to the KSC facility were feasible, expanding the clinic at DFRC was not; therefore, a new facility named the Postflight Science Support Facility was built.

Obtaining rapid access to the crew post landing was crucial for most studies. This resulted in the need for a crew transport vehicle (CTV) at both landing sites. Considerations leading to acquisition of the CTVs included (1) medical emergency activities could be more likely after longer duration flights, (2) medical/support personnel were required at hatch opening, and (3) accommodations were required which maintained crew privacy and allowed collection of physiological data as soon as possible after landing. The vehicles selected were airport passenger transporters because of their 568 sq. ft. interior, flexibility of design, and single operator capability. The addition of CTVs to the landing day complement contributed significantly to enhanced emergency medical capability, improved crew comfort and privacy, and reduced the time required to initiate biomedical data acquisition. At KSC a docking port was created for the CTV on the second floor of the Baseline Data Collection Facility; this feature further utilized the capabilities and benefits of the CTV.

HARDWARE

Development of flight hardware was a major element of the EDOMP, requiring a team effort among scientists, engineers, crew members, flight integration specialists, and others. Examples of EDOMP flight hardware that have been used on subsequent Shuttle flights, on Mir, and in development of ISS hardware are:

(1) Entry Blood Pressure Monitor. This hardware has been worn by long duration crew members upon their return from Mir. The automatic blood pressure monitor (ABPM) selected for the ISS blood pressure/ECG unit will be similar to the EDOMP ABPM.

(2) LBNP System. The designers of the LBNP system to be used on ISS are utilizing many features of the EDOMP system and are including modifications which resulted from experience gained during EDOMP flights.

(3) Data Acquisition System (DAS). The Generalized Controller Module, an imbedded processor control system that was developed for EDOMP and used in the DAS, has become the core of control systems for many subsequent projects. In addition, a modular concept for data acquisition and control systems was developed that reduced development time and cost.

(4) Bar Code Reader (BCR). Use of the BCR continued on Mir.

(5) Heart Rate Watch. Use of this hardware continued on Mir; a heart rate watch with enhanced capabilities will be used on ISS.

(6) Microbial Air Sampler (MAS). A MAS has been selected for use on ISS.

(7) Combustion Products Analyzer (CPA). Use of the CPA continued on subsequent Shuttle flights and on Mir; a CPA has been selected for use on ISS.

(8) Formaldehyde Monitor Kit (FMK). Use of the FMK continued on Mir.

(9) Cycle Ergometer, Ergometer Vibration Isolation System, and Passive Cycle Isolation System. This complement of hardware became the operational (or standard) exercise device for Shuttle flights. An improved version of this ergometer, with an Inertial Vibration Isolation System and upgraded electronics, will become the operational cycle ergometer in the U.S. segment of ISS.

(10) EDO Treadmill. This treadmill became the basis for the ISS treadmill.

CONCLUSIONS

Cardiovascular research received a high priority during this program because of concerns regarding decreased orthostatic tolerance and egress capability. Microgravity exposure up to 16 days was shown to be a relatively benign environment in that resting blood pressures and heart rates were below ground-based control levels. Electrocardiographic abnormalities were low for the group evaluated before flight and were even less during flight for these subjects. Multiple factors associated with orthostatic tolerance were evaluated in integrated cardiovascular investigations. Lower epinephrine responses of a group of astronauts who were relatively more susceptible to presyncope showed high correlation with their lower total peripheral vascular resistance. Further, it was shown that plasma volume replenishment per se did not prevent presyncopal episodes during laboratory stand tests. These data were consistent with multiple observations of alterations in autonomic control during space flight.

Notable advances were made in the development or improvement of cardiovascular countermeasures. Centrifuge studies conducted with the United States Air Force Armstrong Laboratory led to guidelines for use of anti-g suits. The resulting mandatory preinflation schedule optimized protection during reentry. The liquid cooling garment was integrated into the Launch and Entry Suit to solve thermal problems, thereby improving orthostatic tolerance and crew comfort. Alternative isotonic fluid loads were verified and optimized by determining total volume in relation to the subject's preflight body weight. Finally, although fludrocortisone treatment could restore plasma volume using certain protocols late in the mission, the side effects precluded its use as an operational countermeasure. Present guidelines that require use of the liquid cooling garment and the anti-g suit preinflated before reentry, together with revised fluid loading, have greatly reduced the incidence of orthostatic intolerance.

Nutritional assessments showed that ground-based and flight energy expenditures were comparable. Energy intake during flight was decreased relative to preflight levels, and a preference was noted for carbohydrates versus fat in choice of foods by astronauts. Renal stone risk profiles were established for large numbers of astronauts by collecting urine samples before and after flight.

Assessment of exercise protocols for maintenance of aerobic capacity and orthostatic tolerance led to the conclusion that aerobic capacity did not correlate with orthostatic tolerance in our subjects. Minimal losses in aerobic function were seen for crew members who exercised more than three times weekly at levels reaching 60-80% of preflight maximum work loads. Muscle biopsies were used to determine morphological changes following medium duration space flights. The most striking finding was that changes in morphology became evident following flights of only 5 days in duration. Muscle performance was evaluated in several astronauts, and significant decrements were noted in major postural muscles. It was determined that heavy resistive exercise should be evaluated for protection of major muscle function. Higher intensity aerobic interval exercise protocols were recommended and are being implemented. Finally, treadmill exercise appeared to be important for maintenance of neuromuscular patterns required for walking or running.

Environmental monitoring indicated that VOCs in the cabin atmosphere were generally below allowable limits. The need for real-time monitoring of critical combustion

products led to the development of the Combustion Products Analyzer. Quantification of airborne bacteria and fungi showed no safety concerns.

Neuroscience investigations dealt with complex, integrated systems where it was difficult to factor out underlying mechanisms associated with changes known to occur in the vestibular system. Studies were conducted to evaluate changes in visual target acquisition, postural and locomotion changes, assessment of perceived self orientation or motion, and eye-head-trunk coordination during locomotion. Exposure to simulated flight spatial environments using ground-based training devices reduced the occurrence of space motion sickness during actual space flights. Time required to foveate images increased by as much as 100% following space flight. This resulted in some Shuttle commanders altering their pattern of instrument monitoring during final approach and landing, to minimize potential hazard.

Valuable new information was gained with respect to development of productive work stations that support scientific requirements. Vibration and acoustic environments were monitored for excessive or stressful levels.

In summary, the EDOMP was a highly successful 5-year, operational research program that yielded many improvements, such as enhanced crew member safety and decreased risks to mission success.