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Exercise Countermeasures Demonstration Project During the Lunar-Mars Life Support Test Project Phase IIA

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Acronyms

ANOVA	analysis of variance
CTSD	Crew and Thermal Systems Division
DBP	diastolic blood pressures
EXL	Exercise Physiology Laboratory
HR	heart rate
ISS	International Space Station
JSC	Johnson Space Center
LMLSTP	Lunar-Mars Life Support Test Project
RPE	rating of perceived exertion
SBP	systolic blood pressures
SE	standard error
SMP	Space Medicine Project
VO2	oxygen consumption
VO2pk	Peak oxygen consumption

Abstract

The purpose of this demonstration project was to assess the compliance of crew members to a portion of the exercise countermeasures planned for use during stays onboard the International Space Station (ISS) and to assess the outcomes of performing these countermeasures. Although these countermeasures have been used separately in other projects and investigations, this was the first time they had been used together for an extended period of time (60 days) in an investigation of this nature. Crew members exercised every day for six days, alternating every other day between aerobic and resistive exercise, and rested on the seventh day. On the aerobic exercise days, subjects exercised on an electronically braked cycle ergometer using a protocol which has been previously shown to maintain aerobic capacity in subjects exposed to a spaceflight analogue (6° head-down tilt bed rest). On the resistive exercise days, crew members performed five major multi-joint resistive exercises—bench press, seated press, lat pull, squats, and heel raises—in a concentric mode, targeting those muscle groups and bones which are believed to be most severely affected by spaceflight. Subjects performed maximal efforts with each repetition. Both exercise protocols were well tolerated by the subjects, demonstrated by a 98% compliance to aerobic exercise prescription and a 91% adherence to the resistive exercise protocol. Subjects also reported favorable comments. After 60 days, the crew members improved their peak aerobic capacity by an average of 7%. Strength gains during bench press, shoulder press, lat pull, heel raise, and squat exercises were noted in all subjects. The results of this investigation suggest that these aerobic and resistive exercise protocols can be performed during an ISS, lunar, or Mars mission. However, more frequent bouts of both resistive and aerobic exercise are anticipated to be required to maintain crew health during long-duration spaceflight. Future projects should investigate the impact of increased exercise duration and frequency on the compliance of subjects and the efficacy of such exercise prescriptions.

I. Introduction

A. Lunar-Mars Life Support Test Project (LMLSTP) Objectives

The LMLSTP Phase IIA was the third in a series of four life support system technology investigations by the Crew and Thermal Systems Division (CTSD) at Johnson Space Center (JSC). Previous experimental projects have included a 15-day chamber test (Phase I) in which plants provided the air revitalization for a single subject and a 30-day chamber test (Phase II) in which an integrated regenerative life support system was demonstrated with four humans in a closed chamber (Figure 1). This chamber, the Life Support Systems Integration Facility, was also used during Phase IIA. Phase IIA was a 60-day demonstration of life support technologies, the air revitalization system and the water recovery system, intended for use onboard the International Space Station (ISS) [13]. During this test, investigators and medical support personnel from the Medical Sciences Division, including the Exercise Physiology Laboratory (EXL), were invited to evaluate their planned protocols for ISS.

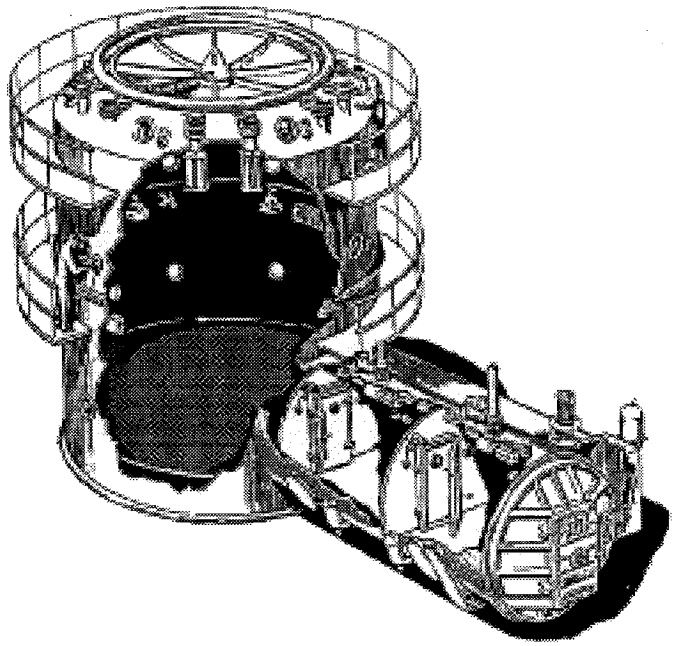

Figure 1. Life Support Systems Integration Facility.

B. Exercise Countermeasures Demonstration Project Objectives

The Exercise Countermeasures Demonstration Project had two objectives:

- Examine the efficacy of exercise testing and prescription methods planned for use in the development of exercise countermeasures onboard ISS.
- Provide realistic perturbations of the carbon dioxide production and oxygen utilization as anticipated onboard ISS to challenge the environmental control systems.

Specifically, this demonstration project sought to provide data in four areas:

- the quality of information provided by the pre- and in-chamber testing protocols for the assessment of crew health
- the training effects provided by long-term performance of the planned exercise countermeasures
- the tolerance of subjects to both the aerobic and the resistive exercise countermeasures
- the methods planned to document the performance of the exercise countermeasures

Further, the performances of these exercise countermeasures were used to manipulate the conditions within the chamber such that the performances of the environmental control systems could be assessed in their ability to correct undesired changes in ambient gas concentrations. In previous chamber testing, crew member exercise was found to significantly increase ambient carbon dioxide concentrations [13].

C. Protocol Overview

CTSD selected eight subjects for participation in this study based upon their familiarity with operation of the chamber environmental systems and/or their ability to perform specific required tasks. Four individuals, three males and one female, were chosen to be prime crew members. The remaining four subjects served as backups in case one or more of the prime crew members were disqualified from participation before entering the chamber. Subjects were screened for participation using a modified Air Force Class III Physical and a modified Cunningham treadmill exercise protocol. These tests were administered by the JSC Flight Medicine Clinic. Prime crew members, three males and one female, were 31±4 years, 175±5 cm, and 70.4±10.9 kg. Backup crew members, also three males and one female, were 32±5 years, 173±5 cm, and 62.7±9.7 kg.

Subjects received written and verbal explanation of the procedures specific to the exercise countermeasures demonstration project and signed written consent confirming their understanding and acceptance.

All eight subjects participated in the pre-chamber testing. Pre-chamber testing included a graded cycle ergometer test to volitional fatigue, submaximal cycle ergometer exercise tests, resting metabolic rate measures, and a validation session of the aerobic exercise countermeasure. Subjects also received two training sessions on the resistive exercise countermeasure device.

Only the prime crew members participated in exercise training and testing after the pre-chamber testing was complete. During the chamber test, on alternate days the crew members completed the aerobic and the resistive countermeasures three times per week. In several instances, exercise was delayed or cancelled due to malfunction of environmental control systems. Three times during the 60-day period—on days 15, 30, and 58—crew members completed the submaximal exercise test in place of the aerobic exercise training. At the conclusion of the chamber test, the four prime crew members returned to the EXL for a graded cycle ergometer test to volitional fatigue.

II. Exercise Testing Methods and Results of Pre-Chamber Tests

The aerobic exercise testing protocols chosen for this investigation were those proposed for use in the Space Medicine Project (SMP) on ISS as a means to monitor crew health. This investigation served as a test bed, or practice session, for these testing protocols. Data included in this section are from all eight subjects, prime and backup, and are intended to indicate expected results for a larger population. Data specific to the prime crew are presented in Chapter IV, "LMLSTP Phase IIA Data and Results."

No resistive exercise testing was performed in the pre-chamber phase of the LMLSTP IIA program.

A. Peak Aerobic Exercise Test

Subjects completed a maximal exercise test to quantify their individual fitness levels and to aid in the prescription of the exercise countermeasure and the submaximal exercise test. Subjects pedaled on an electronically braked cycle ergometer in the upright position at a constant pedaling cadence of 75 rpm. Expired gases were collected and analyzed using a Quinton Qplex Metabolic Cart (Quinton Industries, Seattle, WA) interfaced with a mass spectrometer (MG-1100, Marquette, Inc., Minneapolis, MN). Heart rate was monitored using a three-lead ECG configuration (Quinton Q5000 Stress Test System, Quinton Industries, Seattle, WA).

The maximal exercise test began with three 3-minute stages of increasing workloads (Figure 2). For male subjects, these workloads were 50, 100, and 150 watts. Female subjects completed workloads of 50, 75, and 100 watts. Thereafter, for both subject groups the workload was increased in 25-watt increments each minute until volitional fatigue. Peak oxygen consumption (VO2pk) was accepted as the mean of the last two 30-second measurements of oxygen consumption (VO2). Heart rate (HR) was recorded in the last 15 seconds of each minute, and rating of perceived exertion (RPE; Borg's revised 10-point scale) [9] was recorded in the last 20 seconds of each stage. Blood pressure was measured manually by the auscultatory method in the last 30 seconds of each 3-minute stage.

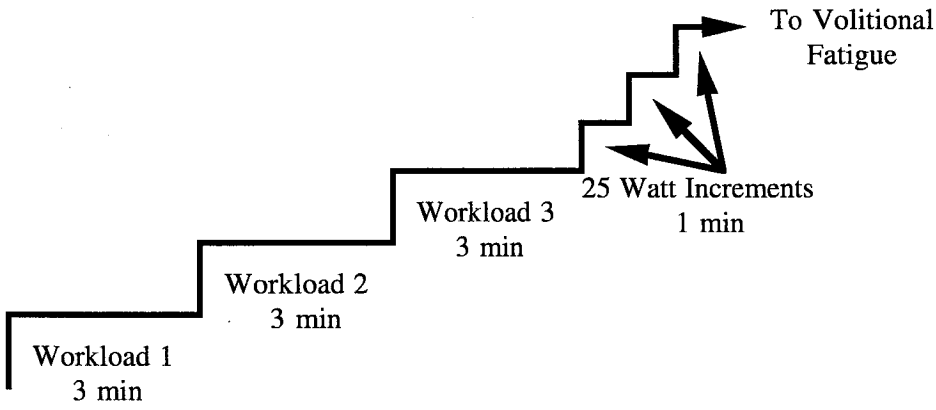

Figure 2. Peak aerobic exercise test protocol.

Subjects (n=8) completed a mean (±SD) workload of 225±44 watts with a total test time of 12.6±1.1 minutes. The mean peak absolute oxygen consumption was 2.67±0.58 L/min, or expressed relative to body weight, 40.3±4.9 mL/kg/min. Heart rate at the peak exercise intensity was 186±6 bpm, and the peak RPE was 8±2.

B. Submaximal Aerobic Exercise Test

The submaximal cycle exercise test was individually prescribed for each subject according to their performance in the VO2pk exercise test. Subjects completed three 5-minute exercise intensities of 25%, 50%, and 75% of VO2pk (Figure 3) on the same electronically braked upright cycle ergometer. Subjects recovered by cycling for five minutes at 25% of VO2pk. The pedaling cadence was maintained at 75 rpm. Expired gases were collected as the subjects exercised using a Quinton Qplex Metabolic Cart interfaced with a mass spectrometer. Heart rate was measured using a heart rate monitor (Polar Vantage XL, Polar, Inc., Stamford, CN), previously validated in our laboratory [12]. Heart rate data were saved in 15-second intervals. The mean VO2 and HR for each stage of this submaximal exercise test were calculated.

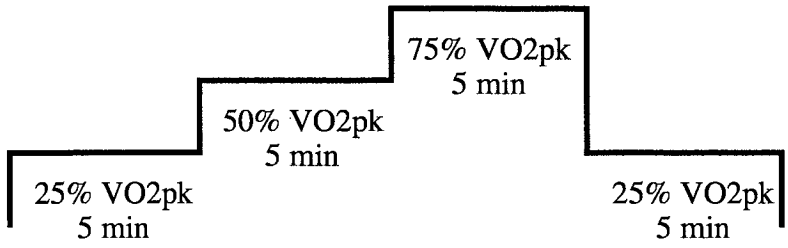

Figure 3. Submaximal aerobic exercise test protocol.

The exercise intensities (n=8) at 25, 50, and 75% of VO2pk were equivalent to mean (±SD) power outputs of 23±11, 87±22, and 151±32 watts, respectively. Mean VO2 at these exercise intensities were 0.76±0.16 L/min (11.3±1.4 mL/kg/min), 1.40±0.19 L/min (20.8±2.7 mL/kg/min), and 2.25±0.46 L/min (33.6±4.4 mL/kg/min). The mean HRs were 95±6, 124±8, and 164±8 bpm, and the mean RPEs were 1±0, 3±0, and 5±1.

The differences between the actual VO2 at each exercise intensity and those predicted from data from the VO2pk test were 0.09±0.4, 0.06±0.04, and 0.25±0.10 L/min. The differences between the actual HR at each exercise intensity and those predicted from data from the VO2pk test were 3±10, 1±8, and 8±9 bpm.

C. Muscle Strength and Endurance Assessment

The planned testing protocols for the ISS crew members include isokinetic exercise testing of the knee, back, and ankle. Due to the limited time available for testing before entering the chamber, these tests were not performed for this demonstration project. Future demonstration projects with CTSD will incorporate these muscle strength and endurance assessments.

The efficacy of the resistive exercise countermeasure protocol was assessed in this project by examining the daily resistive exercise records for each subject. These data and analyses are presented in Chapter IV, Section B, "LMLSTP Phase IIA Data and Results: Resistive Exercise Countermeasure."

D. Metabolic Calibrations

Although not a test for ISS, CTSD requested metabolic calibrations of each crew member who would potentially be entered into the chamber study. The purpose of this data collection was to provide information regarding the expected loads on the environmental control systems. Metabolic measurements were made during supine and seated rest, the aerobic exercise countermeasure, and the submaximal aerobic exercise tests.

Subjects (n=8) were tested at rest in both the supine and seated positions. Subjects were fitted with a face mask with a one-way, non-rebreathing valve (Hans Rudolph, Inc., Kansas City, MO) for the collection of expired gases, and rested quietly in the supine position for a period of at least 20 minutes. During this time, expired gases were collected in a 120-liter gasometer (Warren E. Collins, Inc., Braintree, MA) in 5-minute increments and subsequently expelled to wash out the room air in the tank. Thereafter, three successive 5-minute collections of expired gases were collected in the gasometer. The volume of each sample was determined, and the relative concentrations of oxygen and carbon dioxide were measured using a mass spectrometer. Subjects moved to the seated posture for at least 5 minutes before three additional 5-minute data collections were repeated in the seated posture. Oxygen consumption and carbon dioxide production were calculated [7] for each 5-minute period. The data from each of the three samples for each posture were averaged and accepted as representative of that posture. Respiratory water production was calculated during supine and seated rest and during the exercise countermeasure using the equation:

$$Me = 0.019 \times VO2 \times (44-Pa),$$

where Me is the rate of respiratory water loss (g/min), VO2 is the oxygen uptake of the subject (L/min), and Pa is ambient water vapor pressure (mmHg) [10].

Data from the pre-chamber aerobic exercise countermeasure and the submaximal exercise tests were collected during the normal testing procedures and were expressed as the mean oxygen consumption, carbon dioxide production, and water vapor production per minute across the entire exercise period.

Table 1. Metabolic Calibration Data (n=8)

	VO2 (L/min)	VO2 (mL/kg/min)	VCO2 (L/min)	Me (g/min)
Supine Rest	0.22±0.03	3.34±0.34	0.19±0.03	0.15±0.02
Seated Rest	0.23±0.03	3.44±0.29	0.19±0.02	0.15±0.02
Exercise Countermeasure	1.59±0.33	23.83±2.99	1.62±0.36	1.06±0.22
Submaximal Test	1.37±0.29	20.30±2.64	1.39±0.30	0.87±0.19

Data for the prime crew are presented in Chapter IV, Section E, "LMLSTP Phase IIA Data and Results: Metabolic Calibrations."

III. Exercise Countermeasure Methods and Results of Pre-Chamber Tests

The aerobic exercise countermeasure protocol chosen for this investigation is similar to that proposed for use in the SMP on ISS as a means to maintain crew health. This investigation served as a test bed, or practice session, for this countermeasure protocol. Data included in this section are from all eight subjects, prime and backup, and are intended to indicate expected results for a larger population. Data specific to the prime crew are presented in Chapter IV, Section C, "LMLSTP Phase IIA Data and Results: Maximal Aerobic Exercise Test Results," and Chapter IV, Section D, "LMLSTP Phase IIA Data and Results: Submaximal Aerobic Exercise Test Results."

The resistive exercise countermeasure protocol was designed to be similar to the exercise protocol under development for ISS. Data collected during the resistive exercise training are presented in Chapter IV, Section B, "LMLSTP Phase IIA Data and Results: Resistive Exercise Countermeasure." No data on pre-chamber resistive exercise familiarization training are presented here.

A. Aerobic Exercise Countermeasure

Based upon the results of the VO2pk exercise test, an aerobic exercise countermeasure which has been previously used to maintain exercise capacity in bed rest subjects [2, 3, 5] was prescribed. The exercise protocol is shown in Figure 4. The exercise began with a warm-up period of seven minutes at an exercise intensity equivalent to 40% of VO2pk. Thereafter, the exercise intensity alternated in 2-minute intervals between 40% VO2pk and 60%, 70%, 80%, 90%, and 80% VO2pk. This interval training period was then followed by 5 minutes of exercising cool-down at 40% VO2pk.

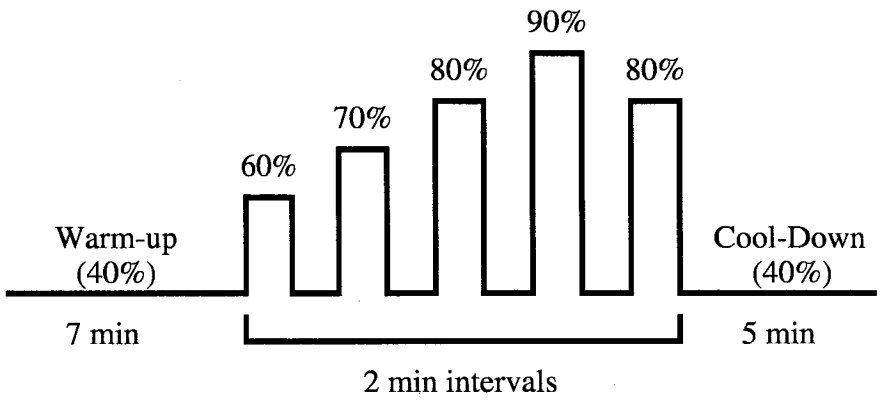

Figure 4. Aerobic exercise countermeasure protocol.

Subjects completed the exercise protocol in the EXL and were monitored for VO2 and carbon dioxide production using a Quinton Qplex Metabolic Cart interfaced with a mass spectrometer. Heart rate was measured using a heart rate monitor. The mean (±SD) VO2 and HR (Figure 5) for each stage of this exercise countermeasure were calculated.

The mean difference across all subjects between actual VO2 and the VO2 predicted by the data from the VO2pk exercise test was not greater than 0.11 L/min for an individual exercise intensity. Similarly, the mean difference across all subjects between actual HR and the HR predicted by the data from the maximal exercise test was not greater than 4 bpm for an individual exercise intensity.

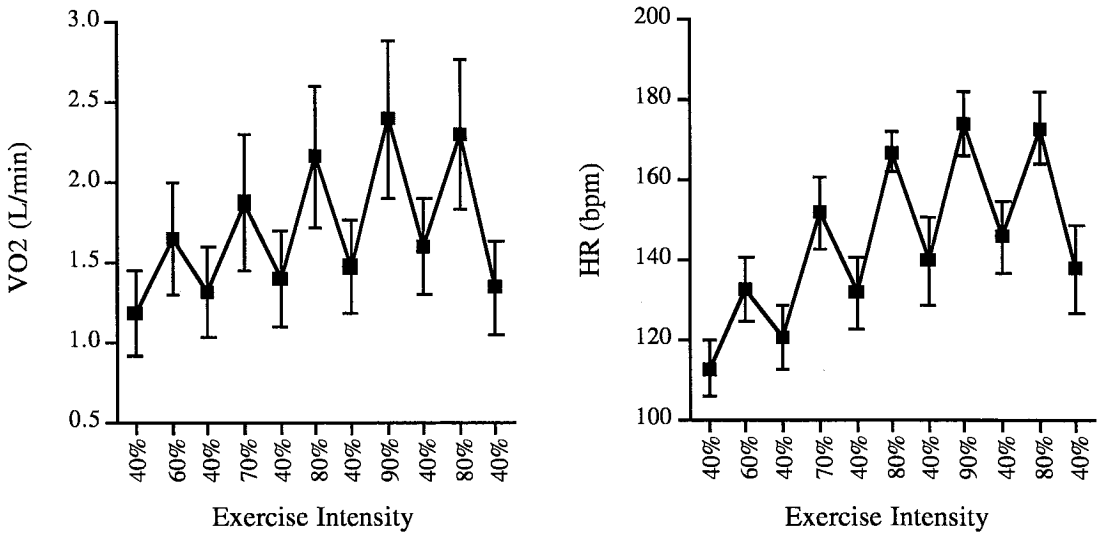

Figure 5. Mean (±SD) oxygen consumption and heart rate during aerobic exercise countermeasure (n=8).

B. Resistance Exercise Countermeasure

Data from this laboratory and others suggest that high-intensity resistive exercise may assist in the maintenance of muscle and strength [1] and of bone density [4]. The protocol used in this demonstration project was a whole body resistive exercise protocol similar to one previously demonstrated to increase muscle mass, muscle strength, and bone density after 10 weeks of training in ambulatory subjects [8].

In this demonstration project, crew members trained isokinetically three days per week for a total of 9 weeks on a computer-controlled resistive exercise device. The Computerized Exercise System (CES) by Ariel Life Systems, Inc. (San Diego, CA), consists of a single, multifunction exercise station, using passive hydraulic resistance, integrated with a laptop computer. This multifunction station allows for the performance of several multi-joint exercises. In this demonstration project, subjects performed bench press, seated shoulder press, lat pull, squats, and heel raises. All training was in the concentric mode. Crew members were familiarized with the CES before entering the chamber and were instructed on proper exercise form.

Throughout the study, subjects performed four sets of each exercise, one warm-up set at approximately 50% of their maximum effort followed by three sets of maximal effort with each repetition. The first week of resistance training in the chamber was treated as a familiarization period. Each day of the first week, crew members performed four sets of 10 repetitions of each exercise at 40°/sec with the exception of the heel raise which was performed at 15°/sec. From weeks 2 to 9, crew members performed a mini-periodization of resistance exercise within each week. The number of sets was maintained at four throughout, one warm-up and three maximal effort, but the velocity of movement, number of repetitions per set, and amount of muscle tension developed varied across the week (Table 2). On the first day of resistance training within the week, the bench press, lat pull, seated shoulder press, and squats were performed at a slow speed (LO) of 20°/sec for six repetitions per set. The second day of training was performed at the fastest speed (HI) of 50°/sec for 12 repetitions, and the third day was performed at a moderate speed (MED) of 35°/sec for eight repetitions. Crew members performed the same number of repetitions for the heel raises as the other exercise, but the velocities

of movement were 10°/sec on LO, 15°/sec on MED, and 20°/sec on HI. In this way, by performing maximal efforts with each repetition on each day, the subjects generated the greatest muscle forces on the first day (LO) during the slow speed of movement, the least muscle tension on the second day (HI) during the fastest movement speed, and a moderate amount of muscle tension during moderate movement speed (MED).

Table 2. Movement Velocity and Repetitions for Each Resistive Exercise Day

Movement Speed	Calf Raise		Others	
	Speed (°/sec)	Repetitions	Speed (°/sec)	Repetitions
LO	10	6	20	6
MED	15	8	35	8
HI	20	12	50	12

The torque profile for each repetition performed during the resistance training was automatically stored on the laptop computer for later analysis. Variables of interest in this demonstration project were peak torque, average peak torque, and total work. Peak torque was taken as the highest torque output from a single repetition measured in each individual set averaged across the three sets. Average peak torque was the average of the peak torque from every individual repetition from all three sets. Total work was the summation of work performed in all three sets. The data from the warm-up set and from the first week of training were not included in this analysis.

IV. LMLSTP Phase IIA Data and Results

This section contains data collected only from the prime subjects who participated in the chamber run. All data are expressed as mean ± standard error (SE), unless otherwise noted. Although the sample size is small, the data were analyzed statistically to provide objective information regarding the trends in the data. Pre- to post-maximal and submaximal aerobic exercise data were statistically analyzed using dependent t-tests. Pre- to post-submaximal exercise data from the VO2pk exercise test were analyzed using a repeated measures analysis of variance (ANOVA).

A. Aerobic Exercise Countermeasure

Over the course of the nine weeks of the chamber confinement, crew members were prescribed to perform a total of 23 aerobic exercise countermeasure sessions. The range of compliance to this prescription was from 91% to 100% with a mean of 98±4%. Two crew members completed all requested exercise sessions. Reasons for other crew members not completing all exercise sessions included work scheduling and failure of environmental control systems.

During the chamber test, each crew member's individual aerobic exercise prescription was pre-programmed into the cycle ergometer. Heart rate was recorded in 15-second intervals during each exercise session using a heart rate monitor. The data were downloaded on a weekly basis and added to each individual's database. The mean HR response (±SE) across all exercise sessions for each subject is displayed in Figure 6. Each subject attained the desired exercise intensity for this counter-measure protocol.

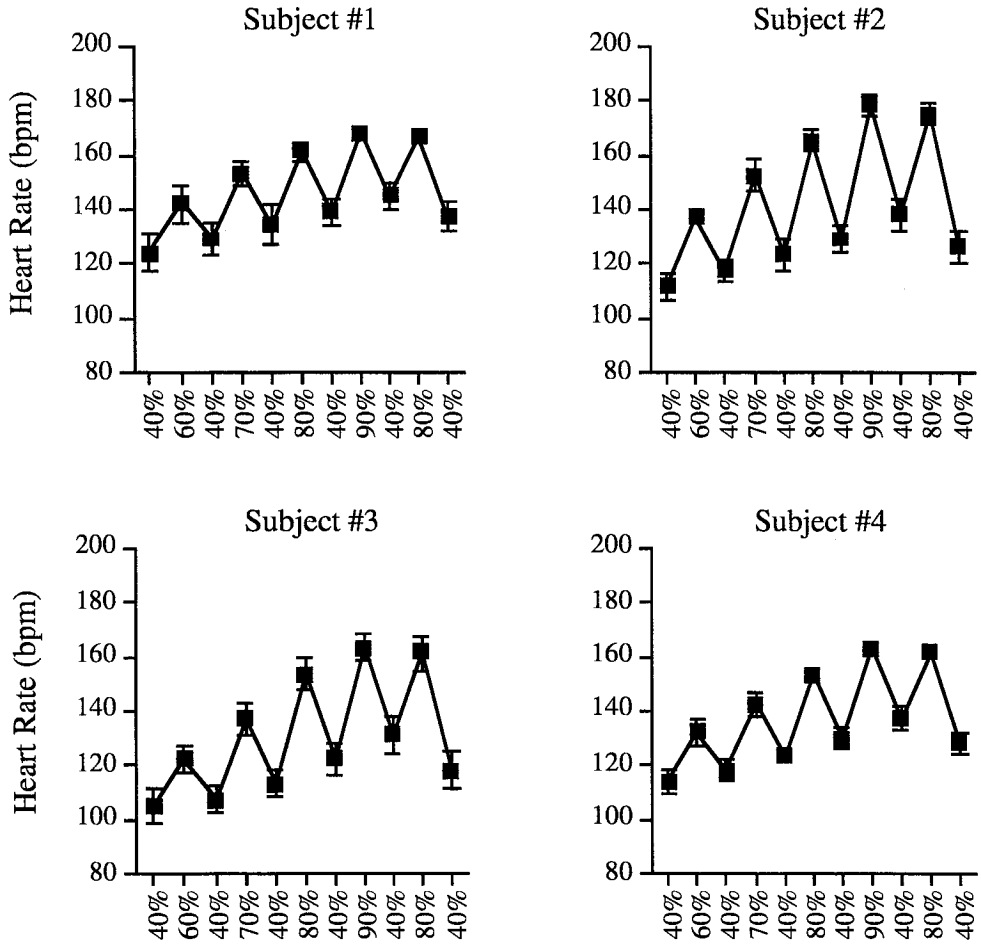

Figure 6. Prime crew members' individual mean (±SE) heart rate response to aerobic exercise countermeasure across chamber confinement.

B. Resistive Exercise Countermeasure

Crew members were prescribed to perform a total of 26 resistive exercise countermeasure sessions. The range of compliance to completing all or part of the daily resistive exercise prescription was from 81% to 100% with a mean of 91±10%. Two subjects completed all the exercises prescribed each day, and one subject completed all the exercises on 21 out of the 26 resistance training days. No specific reason was given as to why this subject did not exercise on these days. Another subject completed the upper body exercises on 22 of the 26 resistance exercise days, but due to a recurring back pain completed the squats and heel raises during only 58% of the exercise sessions. This subject had a previous history of back injury.

Peak torque, average peak torque, and total work data were reduced at early (week 2), mid (week 5), and late (week 8) chamber stay (Figure 7). Because of the varying amount of compliance within subjects, data were not statistically analyzed. The graphics display the mean (±SE) of peak torque for each exercise session for the subjects who completed the exercise at all three time periods.

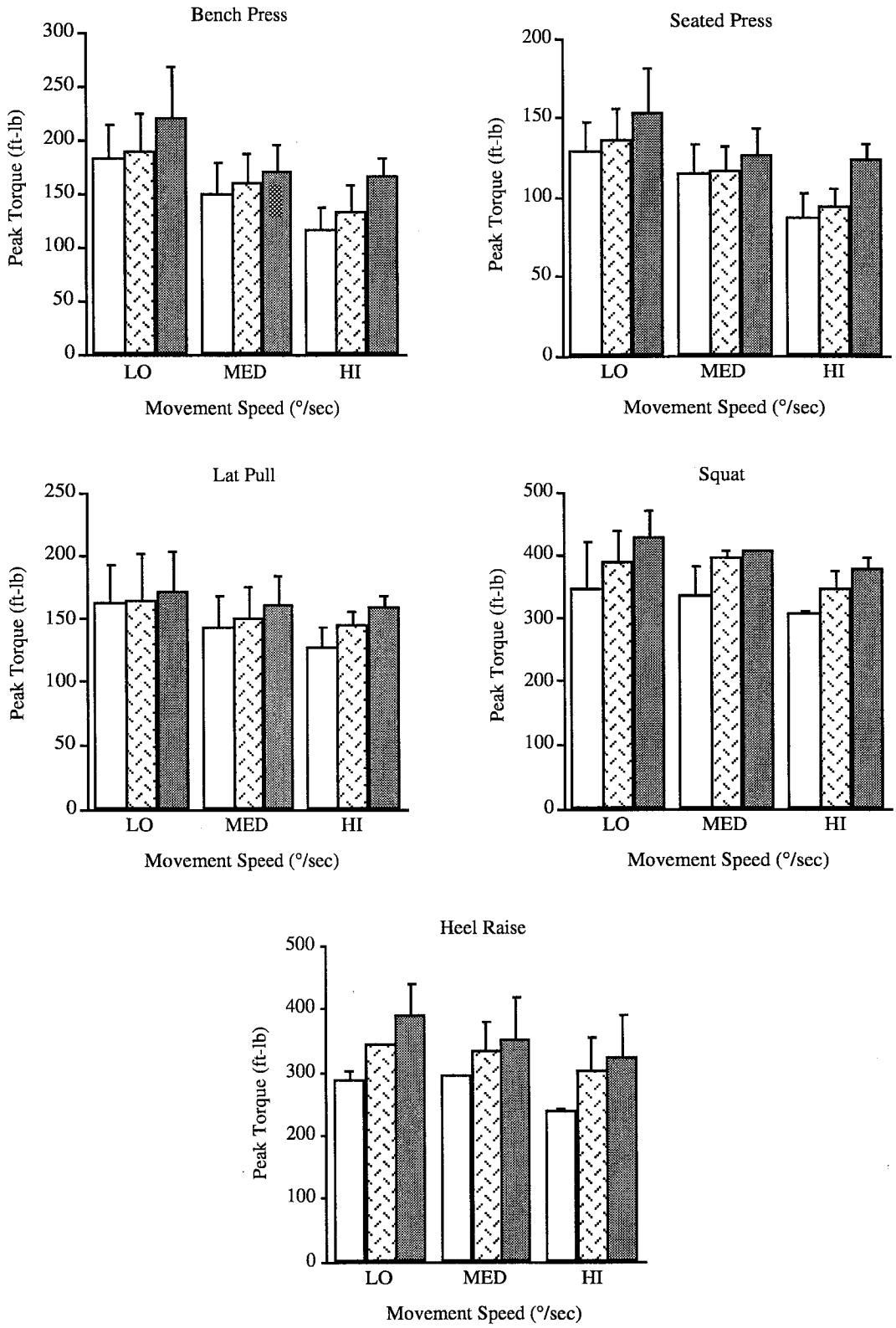

Figure 7. Peak torque developed during bench press (n=3), seated press (n=3), lat pull (n=3), squat exercise (n=2), and heel raise (n=2) exercises across time at each training speed. Open bar is early (week 2), hatched bar is mid (week 5), and solid bar is late (week 8) chamber stay.

C. Pre- to Post-Chamber Maximal Aerobic Exercise Test Results

The primary crew members' (n=4) mean (±SE) VO2pk was 2.82±0.32 L/min (39.9±5.5 mL/kg/min) before entering the chamber (Figure 8). This corresponded to a mean test time of 13.0±0.5 min and a peak workload of 238±22 watts. After the chamber stay, crew members significantly ($p<0.05$) increased their total test time (13.9±0.4 min) and the peak workload achieved (269±24 watts). Although this resulted in a mean increase in VO2pk of 7%, the improvement in VO2pk was not statistically significant when expressed as either absolute ($P=0.06$) or relative ($P=0.11$) oxygen consumption. Peak oxygen consumption increased to some degree in all crew members, ranging from 1% to 20%. The crew member who was most fit before entering the chamber had the least increase in aerobic fitness. Mean peak HR was not changed from before (190±2 bpm) to after the chamber stay (190±3 bpm).

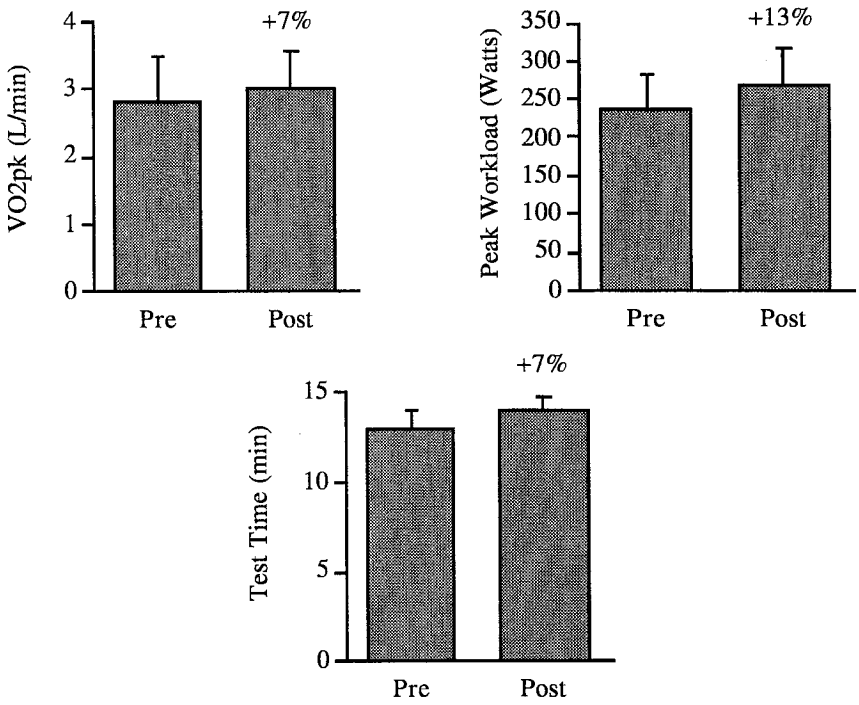

Figure 8. Changes in peak aerobic exercise responses after chamber confinement (n=4).

The mean submaximal HR and blood pressure responses during the maximal exercise test were analyzed (Figure 9). The HR response to the first two submaximal exercise workloads was unchanged from pre- to post-chamber. However, the HR response at the third submaximal exercise stage was significantly less ($P<0.02$) after the exercise training in the chamber (159±3 vs 149±6 bpm). Time principally affected, pre- to post-chamber, systolic blood pressures (SBP), but pressures were not significantly different pre- to post-chamber at any particular submaximal exercise stage. The diastolic blood pressures (DBP) during the submaximal exercise stages were significantly lower during the second (82±2 vs 67±2 mmHg) and third stages (78±2 vs 68±3 mmHg). There was also a main effect of time on the RPE reported during the submaximal exercise stages, but, similar to SBP, there was no specific submaximal exercise stage in which the RPE were significantly different from pre- to post-chamber.

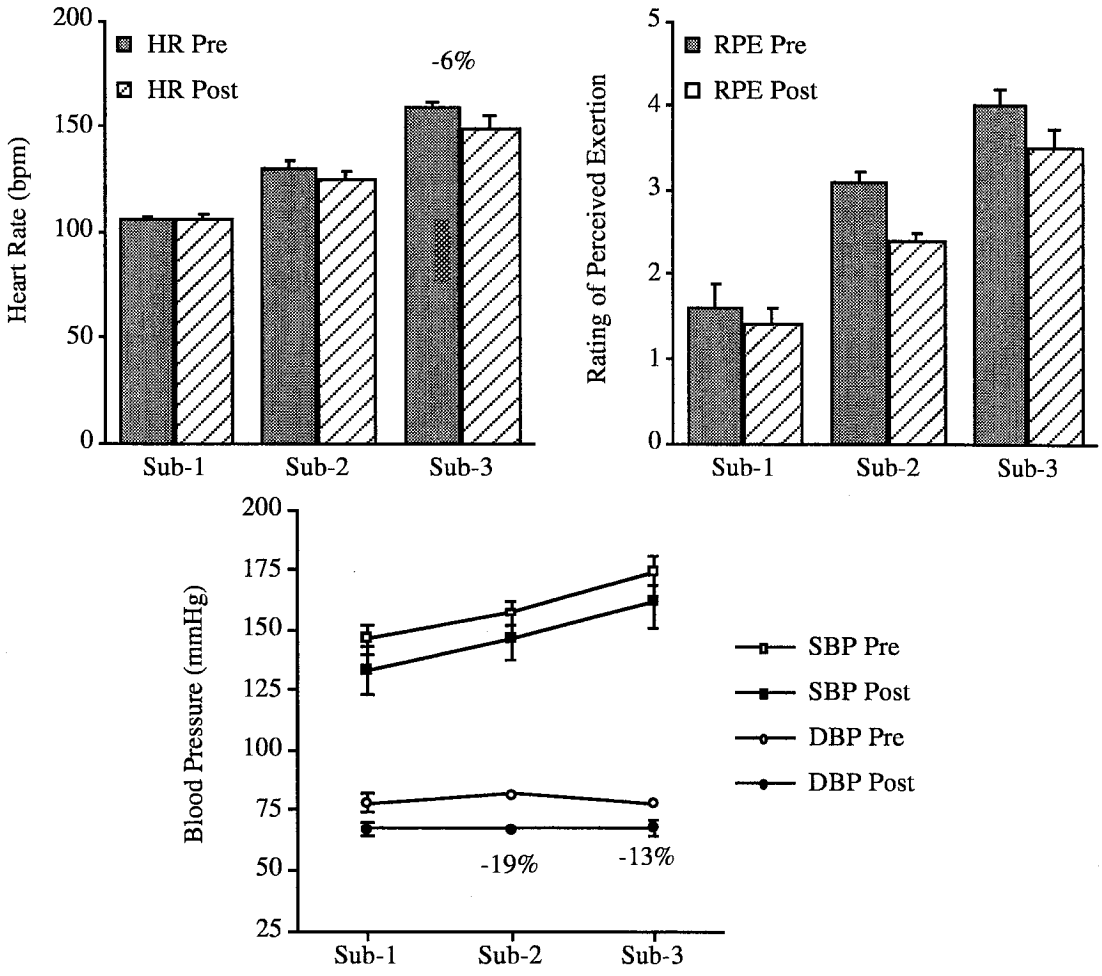

Figure 9. Mean (±SE) heart rate, rating of perceived exertion, and blood pressure responses to submaximal exercise stages.

D. Pre- to In-Chamber Submaximal Aerobic Exercise Test Results

All four prime crew members completed five submaximal exercise tests, two prior to and one each on day 15, day 30, and day 58 of the chamber stay. Testing days were chosen to be similar to those anticipated for crew members aboard ISS. Submaximal exercise tests consisted of cycling on an electronically braked ergometer at 25%, 50%, and 75% of pre-chamber VO2pk in 5-minute stages. Subjects performed an active recovery for five minutes at 25% of VO2pk. The pedaling cadence was maintained at 75 rpm. Tests conducted before the chamber stay were performed in the EXL. The other tests were self-administered by the subjects in the chamber. Although the pre-chamber tests included measurements of VO2 and RPE, only HR data were collected in 15-second intervals using a HR monitor during the in-chamber tests. Heart rate data were averaged over the last two minutes of each stage.

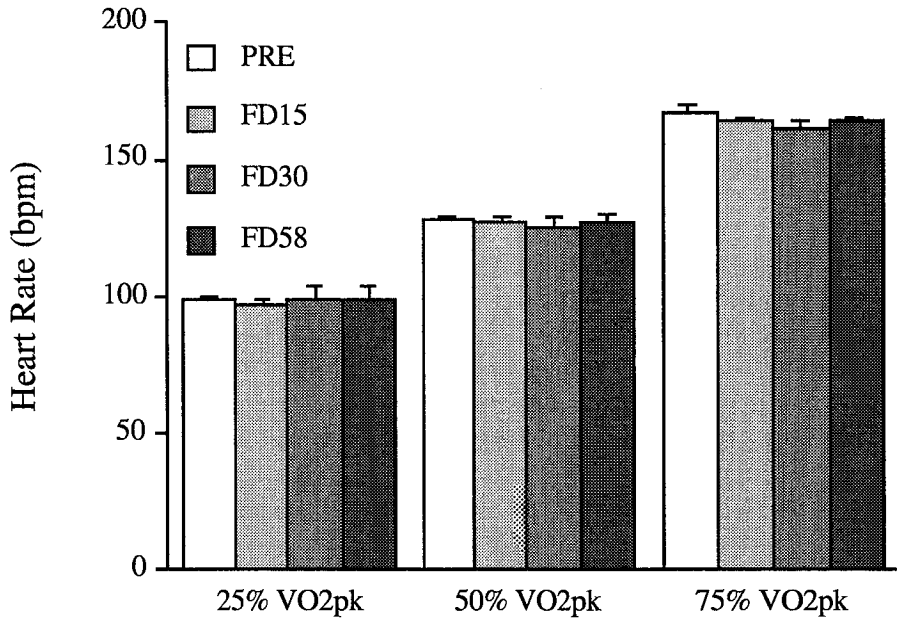

Figure 10. Mean heart rate (±SE) during submaximal aerobic exercise tests for prime crew across chamber confinement.

An ANOVA revealed no difference in HR at each of the workloads during the duplicate pre-chamber submaximal aerobic exercise tests. Therefore, the data from the two pre-chamber tests were averaged as a baseline measurement. Previous experience with other data sets [5, 6, 11] has suggested that the HR response to the higher workloads is most affected by changes in training status. Therefore, an ANOVA was performed on the HR response to the third submaximal exercise stage, 75% VO2pk, across the four test times. Although there was a trend (P=0.12) toward a decrease in HR across time, there was no significant difference between the HR during the submaximal exercise test from pre-chamber to day 58 (Figure 10).

E. Metabolic Calibrations

Data listed in this section (Table 3) are specific to the prime crew members. The pre-chamber data are expressed as mean ± standard deviation. These data were provided to CTSD as a means to assess the functioning of the environmental control systems.

Table 3. Metabolic Calibration Data for Prime Subjects Only (n=4)

	VO2 (L/min)	VO2 (mL/kg/min)	VCO2 (L/min)	Me (g/min)
Supine Rest	0.22±0.03	3.13±0.35	0.19±0.03	0.15±0.02
Seated Rest	0.23±0.02	3.30±0.36	0.19±0.02	0.16±0.02
Exercise Countermeasure	1.65±0.34	23.38±2.97	1.68±0.36	1.14±0.24
Submaximal Test	1.43±0.33	19.90±3.02	1.45±0.32	0.88±0.22

F. Post-Chamber Debrief

All crew members reported sporadic performance of leisure and recreational exercise sessions before entering the chamber. Exercise in which they engaged before chamber entry included cycling, jogging, in-line skating, team sports, and calisthenics. All crew members reported that the exercise routines performed during the chamber stay was of greater intensity and frequency than that which they normally perform.

Each crew member reported perceptions of increased exercise endurance, muscular strength, and general fitness by the conclusion of the chamber stay. Some reported increased feelings of well-being as well as improved attitude as a result of the exercise sessions. However, there were a few reported occasions in which exercise was not looked upon favorably because of fatigue from work schedules. There were some reported incidents of muscle pain, at the beginning of exercise training, probably delayed onset muscle soreness, but each was resolved without lingering effects.

The length of the exercise routines was reported as an appropriate minimum. In general, the crew members perceived the exercise intensity and duration to be adequate, but there were occasions when additional or more intense exercise was desired. On some days due to scheduling conflicts or hard-ware malfunctions, some subjects performed both aerobic and resistive exercise on the same day. Although the subjects reported that these exercise routines were adequate for the length of this demonstration project, they recommended increased variety of routines for longer stays. Subjects also reported that the frequency of exercise, six days of exercise with one day of rest, as a rest period was adequate.

Crew members enjoyed the pre-programming of both exercise devices. The exercise on the cycle ergometer was viewed favorably, but more variety of the exercise protocols was desired. A previous crew had strongly recommended the use of the treadmill during the chamber stay, but this crew felt that the cycle ergometer was adequate for their length of stay.

Each crew member responded favorably to the use of the resistive exercise device, despite some minor problems with the computer controller. The feedback provided by the resistive exercise device computer controller was seen as motivating. However, crew members recommended additional exercises during the chamber stay and more training on use of the equipment and proper exercise techniques. Arm curls and tricep pushdowns were attempted by some crew members on the current exercise device during their chamber stay. The tricep exercise was acceptable but the arm curl exercise was not. A supplementary resistive exercise device was suggested. Having EXL personnel observe the crew members performing normal resistive exercise during the chamber stay was suggested as a means to receive feedback on form.

There were positive comments regarding the mini-periodization routine employed in the resistive exercise prescription. Interestingly, the crew members reported that at the beginning of the study the resistive exercise on which slow speed of movement was employed with a low number of repetitions within a set was the most difficult, but that at the end of study the exercise routine with a high speed of movement and more repetitions of the exercise within a set was hardest.

All subjects reported that their intention was to maintain an exercise routine after completion of the study. They each suggested that they would like to include more regular aerobic and/or resistive exercise into their weekly routines. Post-chamber exercise routines may include cycling, jogging, resistance training, swimming, in-line skating, and calisthenics.

Overall, the crew members enjoyed their experiences with the exercise demonstration project. Each crew member perceived a decrease in the level of effort required to perform the exercise routines as the chamber stay progressed. Their experiences appear to have had a positive impact on their plans for post-chamber exercise routines.

V. Discussion

A. Peak Aerobic Exercise Test

The performance of this exercise test before and after the chamber stay appears to have been well tolerated. The duration of the exercise test allowed for adequate warm-up by the subject before reaching high exercise intensities. The length of the tests was slightly longer than that suggested by Shepherd [14]. A more personalized prescription of the maximal exercise protocol might resolve this, but would require at least one additional test as a baseline prior to the exercise test which would be accepted as the pre-chamber test.

All four crew members demonstrated an increase in peak workload achieved and total test time completed, and improvements in submaximal exercise responses during the maximal exercise test. However, the increase in VO2pk was not statistically significant.

B. Submaximal Exercise Test

One crew member showed a "classical" training response of decreasing HR at each submaximal exercise test over test times (Figure 11). Two subjects showed a decline in HR on days 15 and 30, but the HR response on day 58 was unchanged from the pre-chamber test. One subject showed essentially no change in HR across testing times. There was no apparent difference between the subjects in relation to their exercise prescription adherence which would explain the differences in the individual responses. All four subjects trained at the same relative exercise intensity during the aerobic exercise countermeasure.

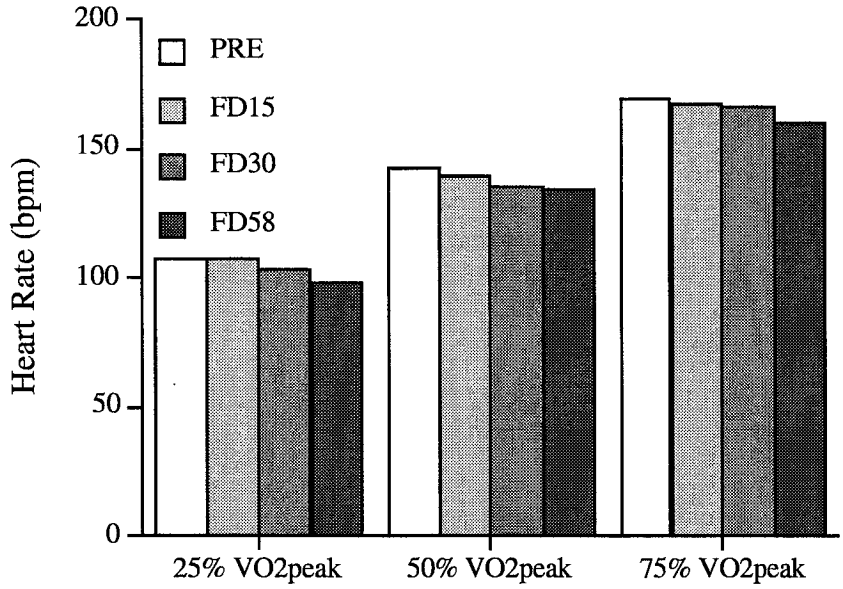

Figure 11. "Classical" effect of aerobic exercise training on heart rate response to submaximal aerobic exercise as seen in one subject.

It is interesting to note that lower submaximal HR responses were seen during the maximal exercise test after the chamber test than before it. It is possible that the active work schedules and disrupted sleep patterns of the subjects influenced the HR responses during the submaximal exercise tests in the chamber. The more controlled atmosphere of the laboratory for the VO2pk exercise test after the chamber run had been completed may have provided for better data acquisition to assess responses to submaximal exercise intensities.

C. Muscular Strength Testing

There was no isokinetic muscular strength testing performed before or after the chamber stay. The only data available to assess changes in muscular strength are those data collected as part of the crew members normal exercise routines. These data are discussed in an earlier section (Chapter IV, Section B, "LMLSTP Phase IIA Data and Results: Resistive Exercise Countermeasure").

D. Aerobic Exercise Countermeasure

Crew members from previous chamber tests participated in regular exercise, but this was the first time exercise was prescribed for each crew member on an individual basis with respect to the aerobic exercise protocol anticipated for use on ISS. Further, although previous crews believed that they increased their fitness through the exercise training [13], this was the first time during LMLSTP that improvements in fitness were objectively quantified.

Crew members increased their VO2pk by an average of 7% with a range of 1% to 20%. The subject that experienced the least improvement in aerobic capacity as a result of the training performed within the chamber had the highest aerobic capacity before the study. Conversely, the subject with the lowest aerobic capacity had the greatest improvement. From this limited data set, it appears that the performance of these exercise countermeasure protocols most benefits less fit subjects. Less fit subjects are generally expected to benefit more than more fit subjects from the initiation of a structured exercise regimen. Although the performance of a more intense protocol, one of longer duration, may be indicated to improve the aerobic capacity of more fit ambulatory subjects, this protocol has been shown to adequately maintain the aerobic capacity of bed-rested subjects [2, 3, 5], and therefore may be satisfactory for spaceflight.

E. Resistive Exercise Countermeasure

Data from the resistive exercise countermeasure are difficult to interpret in two of the four subjects. However, it appears that muscular strength was increased in all subjects who performed the exercise requested. Improved subject motivation, increased variety in exercises performed, and more objective testing protocols may improve results from future demonstration projects.

F. Recommendations for Future Studies

To improve the exercise countermeasure demonstration project and the quality of data collected, we recommend implementing the following items for future chamber studies:

- Modify exercise countermeasures to more accurately reflect current concepts for ISS. For example, include treadmill exercise as well as more resistive exercises.
- Use exercise hardware which is more flight-like.
- Add VO2 and RPE measurements to in-chamber submaximal exercise tests. Also, note ambient temperature and humidity when testing is conducted. This information may assist in the interpretation of in-chamber data.

- Add pre- and post-chamber muscular strength and endurance assessments to more objectively quantify changes in muscular fitness as a result of the resistive exercise countermeasure.
- Complete more pre-chamber resistive exercise training with subjects to increase familiarity with the hardware.
- Add more variety in the aerobic and resistive exercise routines.

VI. References

[1] Bamman, M.M., G.R. Hunter, B.R. Stevens, M.E. Guilliams, and M.C. Greenisen. Resistance exercise prevents plantar flexor deconditioning during bed rest. *J. Appl. Physiol.*, In Review.

[2] Ertl, A.C., D.E. Watenpaugh, S.M. Fortney, S.M.C. Lee, R.E. Ballard, J.M. William, and A.R. Hargens. Daily supine LBNP treadmill exercise maintains upright exercise capacity during 14 days of bed rest (Abstract). *Aviat. Space Environ. Med.*, 68(7): 638, 1997.

[3] Greenleaf, J.E., E.M. Bernauer, A.C. Ertl, T.S. Trowbridge, and C.E. Wade. Work capacity during 30 days of bed rest with isotonic and isokinetic exercise training. *J. Appl. Physiol.*, 67(5): 1820-1826, 1989.

[4] Heinonen, A., P. Oja, P. Kannus, H. Sievanen, A. Manttari, and I. Vuori. Bone mineral density of female athletes in different sports. *Bone and Mineral*, 23: 1-14, 1993.

[5] Lee, S.M.C., B.S. Bennett, A.R. Hargens, D.E. Watenpaugh, R.E. Ballard, G. Murthy, and S.M. Fortney. Upright exercise or supine LBNP exercise maintains exercise responses after bed rest. *Med. Sci. Sports Exer.*, 29(7): 892-900, 1997.

[6] Lee, S.M.C., W.J. Williams, S.F. Siconolfi, R. Gonzalez, J.E. Greenleaf, V. Mikhaylov, Y. Kobszev and S.M. Fortney. Temperature regulation in crew members after a 115-day spaceflight (Abtsract). *FASEB J.*, 10(3): A573, 1996.

[7] McArdle, W.D., F.I. Katch, and V.L. Katch. *Exercise Physiology: Energy, Nutrition, and Human Performance*. Philadelphia, PA: Williams & Wilkins, 1996.

[8] McCarthy, J.P., M.M. Bamman, J.M. Yelle, A.D. LeBlanc, R.M. Rowe, M.C. Greenisen, S.M.C. Lee, E.R. Spector, and S.M. Fortney. Resistance exercise training and orthostatic response. *Eur. J. Appl. Physiol.*, 76: 32-40, 1997.

[9] Mahler, D.A., V.F. Froelicher, N.H. Miller, and T.D. York. *ACSM's Guidelines for Exercise Testing and Prescription*. Baltimore: Williams & Wilkins, 1995.

[10] Mitchell, J.W., E.R. Nadel, and J.A.J. Stolwijk. Respiratory water losses during exercise. *J. Appl. Physiol*, 32(4): 474-476, 1972.

[11] Moore, A.D., S.M.C. Lee, S.M. Fortney, and M.C. Greenisen. In-flight maximal exercise as a countermeasure to exercise tachycardia after spaceflight (Abstract). *FASEB J.*, 9(4): A873, 1995.

[12] Moore, A.D., S.M.C. Lee, M.C. Greenisen, and P.A. Bishop. Validity of the heart rate monitor for use during work in the laboratory and on the Space Shuttle. *Am. Ind. Hygiene Assoc. J.*, 58: 299-301, 1997.

[13] Pickering, K., S. Brasseaux, and C. Verostko. *Early Human Testing Initiative Phase II Test: Quick Look Test Report*, 1996.

[14] Shepherd, R.J. Tests of maximum oxygen consumption: a critical review. *Sports Medicine*, 1: 99-124, 1984.

APPENDIX A
Subject Characteristics

Group	Age (yrs)	Height (cm)	Weight (kg)	Sex
Prime	26	175	69.1	M
Prime	31	182	73.4	M
Prime	33	172	56.4	F
Prime	34	170	82.7	M
Backup	31	172	61.4	M
Backup	35	170	56.6	M
Backup	37	180	76.8	M
Backup	26	170	56.1	F

Mean	Prime	31	175	70.4
SD	Prime	4	5	10.9

Mean	Backup	32	173	62.7
SD	Backup	5	5	9.7

Mean	All	32	174	66.6
SD	All	4	5	10.4

APPENDIX B
Pre-Chamber Peak Aerobic Exercise Test Data - All Subjects

Workloads (Watts)

Subject	1	2	3	4	5	6	7	8	Mean	SD
Workload 1	50	50	50	50	50	50	50	50	50	0
Workload 2	100	100	75	100	100	100	100	75	94	12
Workload 3	150	150	100	150	150	150	150	100	138	23
Max Workload	275	250	175	250	225	175	275	175	225	44
Test Time (min)	14	13	11.75	13.2	12.2	11	14	11.75	12.6	1.1

Oxygen Consumption (L/min)

Subject	1	2	3	4	5	6	7	8	Mean	SD
Workload 1	1.07	1.13	0.88	1.08	0.89	1.01	1.26	1.08	1.05	0.12
Workload 2	1.55	1.66	1.12	1.55	1.41	1.42	1.67	1.21	1.45	0.20
Workload 3	2.13	2.08	1.48	2.13	2.01	2.02	2.25	1.50	1.95	0.29
Max Workload	3.19	3.04	1.87	3.18	2.54	2.39	3.28	1.89	2.67	0.58

Oxygen Consumption (mL/kg/min)

Subject	1	2	3	4	5	6	7	8	Mean	SD
Workload 1	15.5	15.5	15.6	13.1	14.4	18.1	17.2	19.2	16.1	2.0
Workload 2	22.5	22.7	20.0	18.7	22.9	25.5	22.9	21.4	22.1	2.1
Workload 3	30.9	28.5	26.2	25.8	32.5	36.2	30.8	26.6	29.7	3.6
Max Workload	46.3	41.6	33.2	38.5	41.2	42.9	44.9	33.6	40.3	4.9

Heart Rate (bpm)

Subject	1	2	3	4	5	6	7	8	Mean	SD
Workload 1	109	105	104	101	119	100	100	124	108	9
Workload 2	138	127	130	123	147	131	120	141	132	9
Workload 3	160	160	160	154	163	162	141	167	158	8
Max Workload	185	196	190	188	188	175	185	184	186	6

Rating of Perceived Exertion

Subject	1	2	3	4	5	6	7	8	Mean	SD
Workload 1	1.5	1.5	2.5	1	2.5	1	2	2	1.8	0.6
Workload 2	3	3	3.5	3	3	2	2.5	2.5	2.8	0.5
Workload 3	3.5	4.5	4	4	5	3	4.5	5	4.2	0.7
Max Workload	9	9	9	10	9	4	9	9.5	8.6	1.9

Systolic Blood Pressure (mmHg)

Subject	1	2	3	4	5	6	7	8	Mean	SD
Workload 1	143	162	136	144	130	140	148	144	143	9
Workload 2	151	168	146	164	165	162	163	166	161	8
Workload 3	161	186	168	180	180	180	190	174	177	9

APPENDIX B
Pre-Chamber Peak Aerobic Exercise Test Data - All Subjects

Diastolic Blood Pressure (mmHg)

Subject	1	2	3	4	5	6	7	8	Mean	SD
Workload 1	74	82	86	70	80	70	68	74	76	6
Workload 2	79	84	88	78	80	66	71	64	76	8
Workload 3	75	82	80	74	84	68	76	64	75	7

APPENDIX C
Pre- and Post-Chamber Peak Aerobic Exercise Test Data - Prime Subjects Only

Workloads (Watts)

	Pre				Post			
Subject	1	2	3	4	1	2	3	4
Workload 1	50	50	50	50	50	50	50	50
Workload 2	100	100	75	100	100	100	75	100
Workload 3	150	150	100	150	150	150	100	150
Max Workload	275	250	175	250	300	275	200	300
Test Time (min)	14.0	13.0	11.8	13.2	14.5	14.0	12.7	14.5

	Pre		Post			
Subject	Mean	SE	Mean	SE	Δ	%Δ
Workload 1	50	0	50	0	0	0%
Workload 2	94	6	94	6	0	0%
Workload 3	138	13	138	13	0	0%
Max Workload	238	22	269	24	31	13%
Test Time (min)	13.0	0.5	13.9	0.4	0.9	7%

Oxygen Consumption (L/min)

	Pre				Post			
Subject	1	2	3	4	1	2	3	4
Workload 1	1.07	1.13	0.88	1.08	1.08	1.13	0.80	1.10
Workload 2	1.55	1.66	1.12	1.55	1.58	1.62	1.24	1.56
Workload 3	2.13	2.08	1.48	2.13	2.17	2.18	1.52	2.09
Max Workload	3.19	3.04	1.87	3.18	3.26	3.17	2.24	3.39

	Pre		Post			
Subject	Mean	SE	Mean	SE	Δ	%Δ
Workload 1	1.04	0.05	1.03	0.08	-0.01	-1%
Workload 2	1.47	0.12	1.50	0.09	0.03	2%
Workload 3	1.96	0.16	1.99	0.16	0.03	2%
Max Workload	2.82	0.32	3.02	0.26	0.20	7%

Oxygen Consumption (ml/kg/min)

	Pre				Post			
Subject	1	2	3	4	1	2	3	4
Workload 1	15.5	15.5	15.6	13.1	15.8	15.5	15.7	13.1
Workload 2	22.5	22.7	20.0	18.7	23.1	22.1	21.9	18.6
Workload 3	30.9	28.5	26.2	25.8	31.6	29.6	27.1	24.9
Max Workload	46.3	41.6	33.2	38.5	47.6	43.1	39.8	40.4

	Pre		Post			
Subject	Mean	SE	Mean	SE	Δ	%Δ
Workload 1	14.9	0.6	15.0	0.6	0.1	1%
Workload 2	21.0	1.0	21.4	1.0	0.4	2%
Workload 3	27.9	1.2	28.3	1.5	0.5	2%
Max Workload	39.9	2.7	42.7	1.8	2.8	7%

APPENDIX C
Pre- and Post-Chamber Peak Aerobic Exercise Test Data - Prime Subjects Only

Heart Rate (bpm)

	Pre				Post			
Subject	1	2	3	4	1	2	3	4
Workload 1	109	105	104	101	104	113	107	96
Workload 2	138	127	130	123	126	131	124	117
Workload 3	160	160	160	154	150	162	151	134
Max Workload	185	196	190	188	186	196	184	193

	Pre		Post			
Subject	Mean	SE	Mean	SE	Δ	%Δ
Workload 1	105	2	105	4	0	0%
Workload 2	130	3	125	3	-5	-4%
Workload 3	159	2	149	6	-9	-6%
Max Workload	190	2	190	3	0	0%

Rating of Perceived Exertion

	Pre				Post			
Subject	1	2	3	4	1	2	3	4
Workload 1	1.5	1.5	2.5	1	1	1	2	1.5
Workload 2	3	3	3.5	3	2.5	2	2.5	2.5
Workload 3	3.5	4.5	4	4	3.5	3	4	3.5
Max Workload	9	9	9	10	9.5	9	10	9.5

	Pre		Post			
Subject	Mean	SE	Mean	SE	Δ	%Δ
Workload 1	1.6	0.3	1.4	0.2	-0.3	-15%
Workload 2	3.1	0.1	2.4	0.1	-0.8	-24%
Workload 3	4.0	0.2	3.5	0.2	-0.5	-13%
Max Workload	9.3	0.3	9.5	0.2	0.3	3%

Systolic Blood Pressure (mmHg)

	Pre				Post			
Subject	1	2	3	4	1	2	3	4
Workload 1	143	162	136	144	119	161	123	129
Workload 2	151	168	146	164	140	173	130	146
Workload 3	161	186	168	180	149	195	144	160

	Pre		Post			
Subject	Mean	SE	Mean	SE	Δ	%Δ
Workload 1	146	6	133	10	-13	-9%
Workload 2	157	5	147	9	-10	-6%
Workload 3	174	6	162	11	-12	-7%

APPENDIX C
Pre- and Post-Chamber Peak Aerobic Exercise Test Data - Prime Subjects Only

Diastolic Blood Pressure (mmHg)

	Pre				Post			
Subject	1	2	3	4	1	2	3	4
Workload 1	74	82	86	70	60	75	70	63
Workload 2	79	84	88	78	62	70	65	70
Workload 3	75	82	80	74	60	72	66	72

Subject	Mean	SE	Mean	SD	SE	Δ	%Δ
Workload 1	78	4	67	7	3	-11	-14%
Workload 2	82	2	67	4	2	-16	-19%
Workload 3	78	2	68	6	3	-10	-13%

APPENDIX D
Pre-Chamber Submaximal Aerobic Exercise Test Data - All Subjects

Workloads (Watts)

Subject	1	2	3	4	5	6	7	8	Mean	SD
Workload 1	33	28	10	35	27	21	28	3	23	11
Workload 2	110	99	59	105	89	78	105	53	87	22
Workload 3	186	169	109	175	152	135	181	103	151	32

Oxygen Consumption (L/min)

Subject	1	2	3	4	5	6	7	8	Mean	SD
Workload 1	0.89	0.83	0.50	0.95	0.74	0.74	0.87	0.55	0.76	0.16
Workload 2	1.68	1.57	0.94	1.62	1.38	1.32	1.68	1.02	1.40	0.29
Workload 3	2.71	2.43	1.64	2.65	2.22	2.20	2.64	1.53	2.25	0.46

Oxygen Consumption (mL/kg/min)

Subject	1	2	3	4	5	6	7	8	Mean	SD
Workoad 1	12.8	11.2	8.8	11.3	11.9	13.1	11.4	9.8	11.3	1.4
Workload 2	24.0	21.4	16.4	19.2	22.4	23.3	22.1	18.0	20.8	2.7
Workload 3	38.8	33.1	28.7	31.5	36.0	38.8	34.7	27.1	33.6	4.4

Heart Rate (bpm)

Subject	1	2	3	4	5	6	7	8	Mean	SD
Workload 1	105	98	91	99	85	92	93	97	95	6
Workload 2	138	126	112	125	118	123	121	132	124	8
Workload 3	165	173	163	161	154	162	154	176	164	8

Rating of Perceived Exertion

Subject	1	2	3	4	5	6	7	8	Mean	SD
Workload 1	1	1	2	1	1	0.5	1	1	1.1	0.4
Workload 2	2.5	2	3	3	3	2	3	2.5	2.8	0.4
Workload 3	5.5	5	4	5	5	3	6	5	4.6	0.9

Systolic Blood Pressure (mmHg)

Subject	1	2	3	4	5	6	7	8	Mean	SD
Workload 1	128	133	115	132	120	104	130	113	122	11
Workload 2	152	165	119	151	163	148	148	144	149	14
Workload 3	168	200	144	175	185	160	180	164	172	17

Diastolic Blood Pressure (mmHg)

Subject	1	2	3	4	5	6	7	8	Mean	SD
Workload 1	70	78	64	68	70	80	76	70	72	5
Workload 2	58	68	61	60	69	72	76	68	67	6
Workload 3	50	68	80	60	64	74	68	71	67	9

APPENDIX E
Pre-Chamber Predicted Responses to Submaximal Aerobic Exercise Tests - All Subjects

Predicted VO2 (L/min)

Subject	1	2	3	4	5	6	7	8	Mean	SD
Workload 1	0.80	0.76	0.47	0.80	0.64	0.60	0.82	0.47	0.67	0.15
Workload 2	1.60	1.52	0.94	1.59	1.27	1.20	1.64	0.95	1.34	0.29
Workload 3	2.39	2.28	1.40	2.39	1.91	1.79	2.46	1.42	2.01	0.44

Difference Between Actual and Predicted VO2 (L/min)

Subject	1	2	3	4	5	6	7	8	Mean	SD
Workload 1	0.09	0.06	0.03	0.15	0.10	0.14	0.05	0.08	0.09	0.04
Workload 2	0.08	0.05	0.00	0.03	0.11	0.12	0.04	0.06	0.06	0.04
Workload 3	0.32	0.15	0.24	0.26	0.31	0.41	0.18	0.11	0.25	0.10

Heart Rate (bpm)

Subject	1	2	3	4	5	6	7	8	Mean	SD
Workload 1	99	89	82	89	105	88	89	93	92	7
Workload 2	130	125	117	123	133	117	120	124	124	6
Workload 3	162	162	152	156	162	147	151	154	156	6

Difference Between Actual and Predicted Heart Rate (bpm)

Subject	1	2	3	4	5	6	7	8	Mean	SD
Workload 1	6	9	9	10	-20	4	4	4	3	10
Workload 2	8	1	-5	2	-15	6	1	8	1	8
Workload 3	3	11	11	5	-8	15	3	22	8	9

APPENDIX F
Pre- and In-Chamber Submaximal Aerobic Exercise Test Data - Prime Subjects Only

Subject 1

	Pre 1	Pre 2	Pre Mean	FD15	FD30	FD58
Workload 1	105	109	107	107	102	98
Workload 2	138	146	142	138	135	134
Workload 3	165	173	169	166	165	160

Subject 2

	Pre 1	Pre 2	Pre Mean	FD15	FD30	FD58
Workload 1	98	99	99	92	90	94
Workload 2	126	124	125	122	119	121
Workload 3	173	174	174	166	163	166

Subject 3

	Pre 1	Pre 2	Pre Mean	FD15	FD30	FD58
Workload 1	91	96	94	90	94	93
Workload 2	112	121	117	115	114	116
Workload 3	163	163	163	160	153	163

Subject 4

	Pre 1	Pre 2	Pre Mean	FD15	FD30	FD58
Workload 1	99	97	98	97	109	109
Workload 2	125	127	126	128	133	133
Workload 3	161	164	163	158	162	162

APPENDIX G
Pre-Chamber Aerobic Exercise Countermeasure Data - All Subjects

Workload (Watts)

Subject	1	2	3	4	5	6	7	8	Mean	SD
40%-Warm-Up	79	70	39	77	64	55	74	33	61	17
60%	141	127	79	133	114	101	135	73	113	26
40%	79	70	39	77	64	55	74	33	61	17
70%	171	155	99	161	139	123	166	93	138	30
40%	79	70	39	77	64	55	74	33	61	17
80%	202	183	119	189	164	146	197	113	164	35
40%	79	70	39	77	64	55	74	33	61	17
90%	232	212	139	217	189	169	227	133	190	39
40%	79	70	39	77	64	55	74	33	61	17
80%	202	183	119	189	164	146	197	113	164	35
40%-Cool Down	79	70	39	77	64	55	74	33	61	17

VO2 (L/min)

Subject	1	2	3	4	5	6	7	8	Mean	SD
40%-Warm-Up	1.38	1.32	0.89	1.38	1.19	1.09	1.48	0.73	1.18	0.26
60%	2.02	1.82	1.18	1.72	1.63	1.47	2.10	1.16	1.64	0.35
40%	1.54	1.36	0.98	1.58	1.34	1.24	1.63	0.86	1.31	0.28
70%	2.30	2.02	1.32	2.10	1.91	1.74	2.35	1.23	1.87	0.42
40%	1.62	1.46	0.99	1.63	1.42	1.34	1.75	0.94	1.39	0.30
80%	2.59	2.27	1.58	2.39	2.22	1.98	2.71	1.51	2.16	0.44
40%	1.67	1.68	1.10	1.79	1.45	1.40	1.69	1.00	1.47	0.29
90%	2.88	2.54	1.67	2.72	2.48	2.17	2.94	1.74	2.39	0.49
40%	1.83	1.70	1.23	1.92	1.56	1.50	1.86	1.10	1.59	0.30
80%	2.80	2.50	1.62	2.56	2.47	2.14	2.74	1.62	2.30	0.47
40%-Cool Down	1.59	1.47	0.89	1.53	1.31	1.43	1.63	0.90	1.34	0.29

VO2 (mL/kg/min)

Subject	1	2	3	4	5	6	7	8	Mean	SD
40%-Warm-Up	19.9	17.9	15.8	16.8	19.4	19.2	19.3	13.1	17.7	2.3
60%	29.4	24.7	20.9	20.9	26.6	25.9	27.4	20.7	24.5	3.4
40%	22.4	18.4	17.4	19.1	21.8	21.9	21.3	15.2	19.7	2.6
70%	33.3	27.6	23.5	25.4	31.2	30.7	30.7	21.9	28.0	4.1
40%	23.5	20.0	17.5	19.7	23.2	23.6	22.9	16.6	20.9	2.8
80%	37.6	31.0	28.1	29.0	36.2	35.0	35.4	26.8	32.4	4.2
40%	24.3	22.9	19.6	21.7	23.7	24.7	22.0	17.8	22.0	2.4
90%	41.8	34.6	29.7	33.0	40.6	38.3	38.3	31.0	35.9	4.5
40%	26.5	23.2	21.8	23.3	25.5	26.4	24.3	19.6	23.8	2.4
80%	40.6	34.0	28.8	31.0	40.3	37.8	35.8	28.9	34.6	4.8
40%-Cool Down	23.1	20.1	15.9	18.5	21.3	25.2	21.2	16.0	20.2	3.3

APPENDIX G
Pre-Chamber Aerobic Exercise Countermeasure Data - All Subjects

Heart Rate (bpm)

Subject	1	2	3	4	5	6	7	8	Mean	SD
40%-Warm-Up	124	109	110	111	114	122	105	112	113	7
60%	146	132	125	127	134	142	125	138	133	8
40%	132	116	125	115	114	135	114	120	121	8
70%	155	156	157	148	148	158	133	159	152	9
40%	145	127	137	126	129	144	119	131	132	9
80%	169	171	166	158	162	171		172	167	5
40%	153	136	144	132	133	155	125	145	140	11
90%	175	185	178	169	173	180	158	179	174	8
40%	154	141	149	140	143	161	131	149	146	9
80%	174	183	175	166	170	181	157	178	173	9
40%-Cool Down	148	129	136	130	136	158	126	138	138	11

Rating of Perceived Exertion

Subject	1	2	3	4	5	6	7	8	Mean	SD
40%-Warm-Up	1.5	1	2	1	3	1	2	1	1.6	0.7
60%	3	2.5	3	3	4	1	2	2	2.6	0.9
40%	2	2.5	2	2	3	1	2.5	1	2.0	0.7
70%	4	4	3	4	4.5	2	4	3	3.6	0.8
40%	3	3	2	2	3	2	3.5	1.5	2.5	0.7
80%	5	5	4	5	6	3	5	3.5	4.6	1.0
40%	3	3	3	2	3	3	3	2	2.8	0.5
90%	6.5	7.5	5	7	9	3.5	6	5	6.2	1.7
40%	3	3	3	2	3.5	3	4	2	2.9	0.7
80%	6.5	8	4	6	7.5	3	5.5	3.5	5.5	1.9
40%-Cool Down	3	3	2.5	2	3	2	4	2	2.7	0.7

Systolic Blood Pressure (mmHg)

Subject	1	2	3	4	5	6	7	8	Mean	SD
40%-Warm-Up	118		128	140	140	139	140	132	134	8
60%	154		134	148	162	153	159	132	149	12
40%			124			148	158		143	17
70%	154		145	154	164	149	177	140	155	12
40%			140			143	163		149	13
80%	160		151	164		158	178	144	159	12
40%			145			140	169		151	16
90%	165		156	184	204	170	185	140	172	21
40%			143			136	169		149	17
80%	166		149	174	202	148	189	150	168	21
40%-Cool Down	158		133	132		125	166		143	18

APPENDIX G
Pre-Chamber Aerobic Exercise Countermeasure Data - All Subjects

Diastolic Blood Pressure (mmHg)

Subject	1	2	3	4	5	6	7	8	Mean	SD
40%-Warm-Up	70		80	74	70	75	72	80	74	4
60%	64		76	70	80	78	80	60	73	8
40%			81			65	79		75	9
70%	58		84	70	70	78	80	64	72	9
40%			80			68	70		73	6
80%	64		81	72		60	68	58	67	8
40%			68			64	68		67	2
90%	60		84	70	80	64	82	68	73	9
40%			79			62	75		72	9
80%	56		82	70	64	74	64	66	68	8
40%-Cool Down	56		74	66		68	62		65	7

APPENDIX H
Pre-Chamber Predicted Responses to Aerobic Exercise Countermeasure - All Subjects

Predicted VO2 (L/min)

Subject	1	2	3	4	5	6	7	8	Mean	SD
40%-Warm-Up	1.28	1.22	0.75	1.27	1.02	0.96	1.31	0.76	1.07	0.23
60%	1.91	1.82	1.12	1.91	1.52	1.43	1.97	1.13	1.60	0.35
40%	1.28	1.22	0.75	1.27	1.02	0.96	1.31	0.76	1.07	0.23
70%	2.23	2.13	1.31	2.23	1.78	1.67	2.30	1.32	1.87	0.41
40%	1.28	1.22	0.75	1.27	1.02	0.96	1.31	0.76	1.07	0.23
80%	2.55	2.43	1.50	2.54	2.03	1.91	2.62	1.51	2.14	0.47
40%	1.28	1.22	0.75	1.27	1.02	0.96	1.31	0.76	1.07	0.23
90%	2.87	2.74	1.68	2.86	2.29	2.15	2.95	1.70	2.41	0.53
40%	1.28	1.22	0.75	1.27	1.02	0.96	1.31	0.76	1.07	0.23
80%	2.55	2.43	1.50	2.54	2.03	1.91	2.62	1.51	2.14	0.47
40%-Cool Down	1.28	1.22	0.75	1.27	1.02	0.96	1.31	0.76	1.07	0.23

Difference Between Actual and Predicted VO2 (L/min)

Subject	1	2	3	4	5	6	7	8	Mean	SD
40%-Warm-Up	0.10	0.10	0.14	0.11	0.17	0.13	0.17	-0.03	0.11	0.06
60%	0.11	0.00	0.06	-0.19	0.11	0.04	0.13	0.03	0.04	0.10
40%	0.26	0.14	0.23	0.31	0.32	0.28	0.32	0.10	0.24	0.09
70%	0.06	-0.11	0.01	-0.13	0.13	0.07	0.05	-0.09	0.00	0.10
40%	0.34	0.24	0.24	0.36	0.40	0.38	0.44	0.18	0.32	0.09
80%	0.04	-0.16	0.08	-0.15	0.19	0.07	0.09	-0.01	0.02	0.12
40%	0.39	0.46	0.35	0.52	0.43	0.44	0.38	0.24	0.40	0.08
90%	0.00	-0.20	-0.01	-0.14	0.19	0.02	-0.02	0.04	-0.01	0.12
40%	0.55	0.48	0.48	0.65	0.54	0.54	0.55	0.34	0.52	0.09
80%	0.25	0.07	0.12	0.02	0.44	0.23	0.12	0.11	0.17	0.13
40%-Cool Down	0.31	0.25	0.14	0.26	0.29	0.47	0.32	0.14	0.27	0.11

Predicted Heart Rate (bpm)

Subject	1	2	3	4	5	6	7	8	Mean	SD
40%-Warm-Up	118	111	103	110	122	106	108	111	111	6
60%	143	140	131	136	145	129	132	136	137	6
40%	118	111	103	110	122	106	108	111	111	6
70%	156	154	145	150	156	141	145	148	149	6
40%	118	111	103	110	122	106	108	111	111	6
80%	169	169	159	163	167	153	157	161	162	6
40%	118	111	103	110	122	106	108	111	111	6
90%	181	184	173	177	179	165	169	173	175	6
40%	118	111	103	110	122	106	108	111	111	6
80%	169	169	159	163	167	153	157	161	162	6
40%-Cool Down	118	111	103	110	122	106	108	111	111	6

APPENDIX H
Pre-Chamber Predicted Responses to Aerobic Exercise Countermeasure - All Subjects

Difference Between Actual and Predicted Heart Rate (bpm)

Subject	1	2	3	4	5	6	7	8	Mean	SD
40%-Warm-Up	6	-3	7	1	-9	16	-4	1	2	8
60%	3	-9	-7	-10	-12	13	-7	2	-3	8
40%	14	5	22	5	-8	29	6	9	10	11
70%	-1	2	12	-3	-8	17	-12	11	2	10
40%	27	16	34	16	7	38	11	20	21	11
80%	0	2	7	-6	-6	18		11	4	9
40%	35	25	41	22	11	49	17	34	29	13
90%	-6	1	5	-8	-6	15	-12	6	-1	9
40%	36	30	46	30	21	55	23	38	35	12
80%	5	14	16	3	3	28	-1	17	11	10
40%-Cool Down	30	18	33	20	14	52	18	27	26	12

APPENDIX I
In-Chamber Aerobic Exercise Countermeasure Data - Prime Subjects Only

Subject 1

Session	40%	60%	40%	70%	40%	80%	40%	90%	40%	80%	40%	Notes
1	118	134	124	149	127	159	134	170	142	167	139	
2	120	134	127	148	134	158	142	170	150	169	130	
3	131	154	137	162	140	170	144	173	156	173	144	
4	125	146	129	153	130	162	137	168	144	166	135	
5	127	143	131	155	135	163	139	169	146	167	137	
6	125	141	128	154	128	160	135	166	140	166	135	
7												Submax
8	137	149	143	154	148	166	151	169	153	168	136	
9	130	151	134	156	139	165	142	172	147	170	145	
10	126	141	131	152	138	162	139	167	143	165	134	
11												HW Problems
12	123	143	126	152	133	162	138	167	142	165	131	
13	117	137	123	151	124	157	130	161	139	163	137	
14												Submax
15		140	125	150	127	159	136	167	144	165	139	
16	121	149	127	155	142	162	140	169	145	165	137	
17	120	143	132	155	134	162	140	169	145	166	143	
18	139	152	139	160	148	167	148	173	152	169	145	
19												HW Problems
20	117	136	121	149	130	155	134	163	136	164	130	
21	117	137	124	150	127	158	138	165	144	161	133	
22	114	134	118	145	129	156	133	164	139	163	139	
23												Submax
Mean	124	142	129	153	134	161	139	168	145	166	137	
SD	7	7	6	4	7	4	5	3	5	3	5	

APPENDIX I
In-Chamber Aerobic Exercise Countermeasure Data - Prime Subjects Only

Subject 2

Session	40%	60%	40%	70%	40%	80%	40%	90%	40%	80%	40%	Notes
1	108	135	114	151	115	165	126	180	139	176	125	
2	112	141	119	160	117	169	130	182	143	179	131	
3	119	140	119	162	133	171	138	184	150	181	135	
4	115	140	117	159	126	175	136	182	148	183	129	
5	113	141	119	155	130	170	133	183	142	181	127	
6	107	135	121	151	125	168	129	181	136	177	126	
7												Submax
8	103	134	113	160	135	165	132	181	148	178	137	
9	109	132	117	145	120	163	137	180	135	176	121	
10	111	137	119	151	122	168	128	176	138	174	118	
11	105	136	111	152	120	160	122	174	134	171	128	
12	109	135	106	146	126	159	121	175	128	174	126	
13	119	138	121	154	118	167	131	179	136	175	123	
14												Submax
15		132	113	145	117	161	121	172	140	170	119	
22	108	136	117	145	122	162	129	172	131	174	130	
23	111	138	124	153	123	163	130	174	133	170	119	
24	119	139	118	149	126	162	129	171	135	171	124	
25												Submax
Mean	111	137	117	152	123	165	129	178	138	175	126	
SD	5	3	4	6	6	4	5	4	6	4	6	

APPENDIX I
In-Chamber Aerobic Exercise Countermeasure Data - Prime Subjects Only

Subject 3

Session	40%	60%	40%	70%	40%	80%	40%	90%	40%	80%	40%	Notes
1												HW Problems
2	105	125	111	139	115	155	124	164	139	162	120	
3	104	120	107	132	111	149	124	158	131	155	116	
4	116	131	119	148	126	162	140	170	138	167	123	
5	108	126	107	141	113	152	117	161	130	155	116	
6	107	127	111	148	115	161	128	168	139	170	126	
7												Submax
8	107	122	111	144	114	162	125	171	140	168	118	
9	97	117	102	142	115	155	121	166	132	165	114	
10	108	126	112	143	117	159	125	169	143	165	124	
11	101	118	106	126	111	140	119	153	130	156	111	
12	121	122	112	136	115	147	121	160	130	156	112	
13	106	123	108	140	114	152	125	162	130	161	115	
14												Submax
15	99	123	107	136	109	150	115	162	123	154	113	
16	98	115	96	128	110	146	116	160	125	154	116	
17	101	119	104	138	118	154	118	164	133	160	120	
18	98	109	99	126	99	144	110	150	114	154	111	
19	111	125	114	141	118	161	126	171	134	164	120	
20	111	120	104	138	113	152	122	164	127	169	114	
21	104	128	111	139	108	152	120	162	127	161	120	
22	106	125	108	134	115	149	118	162	123	165	116	
23	101	121	107	135	114	156	122	163	127	168	143	
24												Submax
Mean	105	122	107	137	113	153	122	163	131	161	118	
SD	6	5	5	6	5	6	6	5	7	6	7	

APPENDIX I
In-Chamber Aerobic Exercise Countermeasure Data - Prime Subjects Only

Subject 4

Session	40%	60%	40%	70%	40%	80%	40%	90%	40%	80%	40%	Notes
1												Did Submax
2	119	136	121	145	124	156	131	165	138	164	130	
3	113	129	115	137	124	149	128	164	134	159	129	
4	109	128	114	139	121	151	127	162	137	163	128	
5	113	132	115	136	121	152	127	165	136	164	125	
6	104	124	111	137	117	151	124	164	137	162	125	
7												Submax
8	113	128	115	137	121	152	126	163	134	161	124	
9	117	142	125	148	128	161	134	167	144	167	133	
10	120	138	122	148	127	154	135	167	141	163	133	
11	117	136	123	143	125	153	134	165	140	163	134	
12	110	130	120	140	128	153	130	164	142	164	133	
13	116	127	113	141	120	151	134	163	139	162	125	
14												Submax
15	105	127	113	137	121	152	131	164	140	162	128	
16	113	132	121	143	123	153	130	160	137	159	126	
17	113	133	120	148	124	156	138	164	142	164	130	
18	117	135	121	143	125	156	132	165	140	160	127	
19	120	136	120	141	120	153	129	161	137	160	124	
20	118	133	119	144	124	152	127	161	134	158	127	
21	116	134	116	145	122	153	127	160	132	157	132	
22	116	135	123	147	125	156	131	162	139	161	130	
23	122	141	125	148	129	158	136	164	142	164	136	
24	115	134	118	142	120	148	123	160	132	157	125	
25	116	130	119	143	117	151	125	159	130	156	119	
26												Submax
Mean	114	132	118	142	123	153	130	163	137	161	128	
SD	4	5	4	4	3	3	4	2	4	3	4	

APPENDIX J
In-Chamber Resistive Exercise Countermeasure Data

Subject 1 - Bench Press

HI (12 repetitions @ 50°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	5441	109.5	127.6
WEEK 3	5222	112.7	138.8
WEEK 4	5627	116.3	142.7
WEEK 5	5969	122.7	151.4
WEEK 6	5995	126.9	153.7
WEEK 7	6002	127.7	151.2
WEEK 8	5957	128.2	152.4
WEEK 9	7248	141.4	166.3

LO (6 repetitions @ 20°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	3910	184.6	213.3
WEEK 3	3056	187.9	205.0
WEEK 4	4331	196.5	220.8
WEEK 5	4427	199.0	216.4
WEEK 6	4223	201.2	228.8
WEEK 7	4204	207.5	233.0
WEEK 8	4227	210.4	234.4
WEEK 9	4442	216.1	235.6

MED (8 repetitions @ 35°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	4626	150.4	170.0
WEEK 3	4689	149.9	171.5
WEEK 4	4723	156.3	180.1
WEEK 5	4650	157.4	178.9
WEEK 6	4390	155.2	178.7
WEEK 7	4459	164.8	187.5
WEEK 8	5495	168.5	191.1
WEEK 9			

APPENDIX J
In-Chamber Resistive Exercise Countermeasure Data

Subject 1 - Seated Press

HI (12 repetitions @ 50°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	4495	82.8	92.8
WEEK 3	4563	87.3	99.2
WEEK 4	5272	86.0	100.6
WEEK 5	4813	88.0	99.7
WEEK 6	5109	89.3	128.7
WEEK 7	4520	91.1	101.0
WEEK 8	4753	96.7	110.4
WEEK 9	5361	101.8	116.3

LO (6 repetitions @ 20°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	4137	128.3	168.6
WEEK 3	3512	126.5	158.5
WEEK 4	3607	130.5	176.5
WEEK 5	3776	140.9	151.3
WEEK 6	3916	143.0	163.1
WEEK 7	3460	132.2	172.9
WEEK 8	4261	157.7	176.3
WEEK 9	3430	142.0	154.4

MED (8 repetitions @ 35°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	4764	108.7	139.7
WEEK 3	3892	110.1	144.9
WEEK 4	3646	107.9	119.7
WEEK 5	3693	110.5	124.3
WEEK 6	3804	119.9	134.2
WEEK 7	3879	131.6	149.9
WEEK 8	4494	134.6	147.8
WEEK 9			

APPENDIX J
In-Chamber Resistive Exercise Countermeasure Data

Subject 1 - Squat

HI (12 repetitions @ 50°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	14949	271.0	311.1
WEEK 3	17687	275.4	317.4
WEEK 4	18308	285.7	345.6
WEEK 5	18931	283.9	318.2
WEEK 6	19020	284.3	318.7
WEEK 7	18739	298.8	341.4
WEEK 8	19296	293.5	333.5
WEEK 9	19146	319.7	359.7

LO (6 repetitions @ 20°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	9616	346.4	420.6
WEEK 3	10977	363.2	403.3
WEEK 4	11764	366.5	413.4
WEEK 5	12013	399.6	437.4
WEEK 6	12284	390.3	446.0
WEEK 7	11794	406.3	461.4
WEEK 8	12950	421.1	476.0
WEEK 9	12645	419.8	472.0

MED (8 repetitions @ 35°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	13690	347.6	383.4
WEEK 3	14503	333.4	380.2
WEEK 4	12896	326.0	383.2
WEEK 5	14204	333.1	366.0
WEEK 6	13526	345.9	387.5
WEEK 7	14036	344.6	400.3
WEEK 8	14654	367.4	406.1
WEEK 9			

APPENDIX J
In-Chamber Resistive Exercise Countermeasure Data

Subject 1 - Heel Raises

HI (12 repetitions @ 50°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	3769	192.7	240.7
WEEK 3	2879	157.2	220.7
WEEK 4	3573	166.4	221.6
WEEK 5	3616	173.4	249.6
WEEK 6	3577	189.9	252.5
WEEK 7	3868	186.9	230.8
WEEK 8	3624	198.0	241.4
WEEK 9	4233	209.5	256.5

LO (6 repetitions @ 20°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	2334	282.1	303.7
WEEK 3	2460	257.3	317.1
WEEK 4	2161	280.4	307.8
WEEK 5	2600	286.7	340.9
WEEK 6	2634	292.3	333.7
WEEK 7	2734	271.6	334.4
WEEK 8	2669	304.1	346.9
WEEK 9	3108	309.9	339.9

MED (8 repetitions @ 35°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	2548	215.1	294.9
WEEK 3	2540	211.3	272.6
WEEK 4	2258	215.2	288.4
WEEK 5	2521	192.4	274.8
WEEK 6	2854	216.2	270.0
WEEK 7	3506	252.7	287.8
WEEK 8	3285	244.3	283.1
WEEK 9			

APPENDIX J
In-Chamber Resistive Exercise Countermeasure Data

Subject 1 - Lat Pull

HI (12 repetitions @ 50°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	6165	113.1	128.6
WEEK 3	6538	118.6	132.5
WEEK 4	7289	120.1	132.2
WEEK 5	6753	129.0	143.5
WEEK 6	6790	128.0	143.1
WEEK 7	6431	125.7	141.7
WEEK 8	6571	125.6	142.4
WEEK 9	7196	131.2	148.5

LO (6 repetitions @ 20°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	4052	154.9	173.0
WEEK 3	3962	159.9	174.9
WEEK 4	3823	162.4	177.7
WEEK 5	4533	168.5	188.4
WEEK 6	4515	167.0	184.7
WEEK 7	4049	158.6	174.8
WEEK 8	4546	165.2	185.1
WEEK 9	4424	167.9	183.9

MED (8 repetitions @ 35°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	5109	137.4	155.2
WEEK 3	4927	144.6	159.1
WEEK 4	4913	147.6	163.2
WEEK 5	5295	152.9	164.7
WEEK 6	5434	150.2	166.1
WEEK 7	5353	152.2	166.8
WEEK 8	5744	153.8	168.4
WEEK 9			

APPENDIX J
In-Chamber Resistive Exercise Countermeasure Data

Subject 2 - Bench Press

HI (12 repetitions @ 50°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	7590	145.1	164.5
WEEK 3	8682	160.8	179.1
WEEK 4	8767	150.9	174.6
WEEK 5	10038	167.5	189.9
WEEK 6	9043	169.8	191.8
WEEK 7	8699	164.1	185.8
WEEK 8	8810	164.8	185.9
WEEK 9	9139	171.4	195.8

LO (6 repetitions @ 20°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	5318	210.9	244.2
WEEK 3	5381	213.2	239.0
WEEK 4	5384	217.1	242.2
WEEK 5	5627	232.0	265.6
WEEK 6	2081	235.0	248.2
WEEK 7	6115	245.6	268.6
WEEK 8	5803	256.8	284.5
WEEK 9	5488	256.5	295.5

MED (8 repetitions @ 35°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	6751	187.1	214.6
WEEK 3	6294	180.5	210.2
WEEK 4	6069	168.7	213.9
WEEK 5	7069	200.8	218.3
WEEK 6	6533	180.1	212.1
WEEK 7	6590	203.4	220.0
WEEK 8	6614	207.5	224.9
WEEK 9			

APPENDIX J
In-Chamber Resistive Exercise Countermeasure Data

Subject 2 - Seated Press

HI (12 repetitions @ 50°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	6636	113.7	126.4
WEEK 3	6852	110.0	123.1
WEEK 4	7572	115.7	125.9
WEEK 5	7012	111.4	122.1
WEEK 6	7376	121.2	134.8
WEEK 7	7604	137.9	185.8
WEEK 8	7430	116.4	128.2
WEEK 9	8057	130.0	143.1

LO (6 repetitions @ 20°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	4054	140.0	151.0
WEEK 3	4924	156.5	193.7
WEEK 4	4477	146.9	156.9
WEEK 5	4360	147.8	156.3
WEEK 6	3034	151.8	163.5
WEEK 7	4611	155.9	166.4
WEEK 8	5196	163.6	180.5
WEEK 9	4195	159.1	184.9

MED (8 repetitions @ 35°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	5325	137.4	150.3
WEEK 3	5601	128.2	183.4
WEEK 4	5189	126.5	134.7
WEEK 5	5710	138.4	150.2
WEEK 6	4921	131.7	138.9
WEEK 7	4825	134.8	147.4
WEEK 8	5870	144.6	156.4
WEEK 9			

APPENDIX J
In-Chamber Resistive Exercise Countermeasure Data

Subject 2 - Squats

HI (12 repetitions @ 50°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	16441	224.8	306.9
WEEK 3	19119	287.5	331.6
WEEK 4	19653	295.2	364.4
WEEK 5	19928	327.3	375.5
WEEK 6	20921	314.5	362.3
WEEK 7	18722	309.7	351.8
WEEK 8	21141	332.0	374.6
WEEK 9	24231	347.8	397

LO (6 repetitions @ 20°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	7115	219.2	275.1
WEEK 3	9451	253.7	284.8
WEEK 4	10982	285.1	326.1
WEEK 5	9894	311.9	343.2
WEEK 6	10964	326.0	359.1
WEEK 7	12304	328.8	376.3
WEEK 8	12504	340.3	384.9
WEEK 9	10264	323.1	382.4

MED (8 repetitions @ 35°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	13163	249.0	288.2
WEEK 3	13579	251.9	276.7
WEEK 4	11546	262.6	307.2
WEEK 5	15416	325.4	405.8
WEEK 6	14746	321.7	370.4
WEEK 7	15037	327.4	389.8
WEEK 8	17537	365.6	408.1
WEEK 9			

APPENDIX J
In-Chamber Resistive Exercise Countermeasure Data

Subject 2 - Heel Raises

HI (12 repetitions @ 50°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	3769	179.1	236.2
WEEK 3	4722	228.7	280
WEEK 4	5770	263.9	307.2
WEEK 5	5253	296.8	354.8
WEEK 6	8723	326.4	376.1
WEEK 7	6479	105.0	123.6
WEEK 8	5355	321.9	353.5
WEEK 9	6966	345.5	390.8

LO (6 repetitions @ 20°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	2119	226.8	274.8
WEEK 3	2500	294.4	337
WEEK 4	2632	323.6	379.7
WEEK 5	2948	310.2	343.3
WEEK 6	3454	329.9	355.7
WEEK 7	3111	357.6	405.4
WEEK 8	2247	332.9	393.2
WEEK 9	3444	372.6	439

MED (8 repetitions @ 35°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	2616	248.3	296.7
WEEK 3	3508	278.6	326.9
WEEK 4	3225	287.2	340.8
WEEK 5	4156	326.7	378.7
WEEK 6	3966	325.0	366.8
WEEK 7	3456	317.9	360.9
WEEK 8	5729	367.4	420.1
WEEK 9			

APPENDIX J
In-Chamber Resistive Exercise Countermeasure Data

Subject 2 - Lat Pull

HI (12 repetitions @ 50°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	7949	137.9	154.3
WEEK 3	8592	141.9	160.2
WEEK 4	9680	150.1	166.9
WEEK 5	9568	153.7	165.0
WEEK 6	8699	164.1	185.8
WEEK 7	8934	142.1	156.9
WEEK 8	9950	148.3	168.1
WEEK 9	10940	161.6	176.9

LO (6 repetitions @ 20°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	4965	175.3	210.1
WEEK 3	5516	185.8	202.7
WEEK 4	5558	193.4	213.1
WEEK 5	5605	190.0	203.6
WEEK 6	6115	245.6	268.6
WEEK 7	6295	211.1	232.1
WEEK 8	6357	198.9	220.7
WEEK 9	5904	197.9	219.1

MED (8 repetitions @ 35°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	6691	173.9	199.7
WEEK 3	6844	171.0	183.5
WEEK 4	6485	162.0	178.4
WEEK 5	7757	187.0	198.5
WEEK 6	6919	176.7	194.6
WEEK 7	6594	172.8	185.2
WEEK 8	7882	180.5	203.4
WEEK 9			

APPENDIX J
In-Chamber Resistive Exercise Countermeasure Data

Subject 3 - Bench Press

HI (12 repetitions @ 50°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2			
WEEK 3	2425	52.8	63.3
WEEK 4	2485	57.5	70.9
WEEK 5	2210	54.4	73.2
WEEK 6	3150	60.6	76.9
WEEK 7	2821	61.2	72.4
WEEK 8			
WEEK 9			

LO (6 repetitions @ 20°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	1900	79.5	100.6
WEEK 3	1702	88.1	101.4
WEEK 4	1910	102.9	115.2
WEEK 5	1920	93.3	106.8
WEEK 6	1896	89.0	104.7
WEEK 7	2064	82.4	94
WEEK 8	2174	96.5	126.1
WEEK 9	1968	94.5	111.9

MED (8 repetitions @ 35°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	1831	61.6	76.9
WEEK 3			
WEEK 4			
WEEK 5	2410	81.5	91.2
WEEK 6			
WEEK 7	2285	83.4	100.4
WEEK 8	2500	83.3	110.6
WEEK 9			

APPENDIX J
In-Chamber Resistive Exercise Countermeasure Data

Subject 3 - Seated Press

HI (12 repetitions @ 50°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2			
WEEK 3	2357	46.7	56.4
WEEK 4	2485	50.7	63.7
WEEK 5	2473	49.8	62.9
WEEK 6	2625	51.2	60.8
WEEK 7	2300	50.2	63.5
WEEK 8			
WEEK 9			

LO (6 repetitions @ 20°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	1799	69.3	83.4
WEEK 3	1837	70.5	90.9
WEEK 4	2022	76.2	90.1
WEEK 5	1875	71.2	80.7
WEEK 6	2092	73.3	88.8
WEEK 7	2092	76.5	91.4
WEEK 8	2083	81.3	98.4
WEEK 9	2023	81.0	94.7

MED (8 repetitions @ 35°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	2388	65.2	73.4
WEEK 3			
WEEK 4			
WEEK 5	2536	63.8	74.2
WEEK 6			
WEEK 7	2334	64.2	74.0
WEEK 8	2552	70.9	81.2
WEEK 9			

APPENDIX J
In-Chamber Resistive Exercise Countermeasure Data

Subject 3 - Squats

HI (12 repetitions @ 50°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2			
WEEK 3	3598	69.9	95.1
WEEK 4	4395	78.2	100.7
WEEK 5	5806	96.9	119.7
WEEK 6	5491	100.6	149.9
WEEK 7	6747	115.2	136.1
WEEK 8			
WEEK 9			

LO (6 repetitions @ 20°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	3076	126.0	157.6
WEEK 3	2641	113.3	150.4
WEEK 4	3946	134.2	152.8
WEEK 5	3351	111.5	137.9
WEEK 6	4235	133.9	162.6
WEEK 7	4251	136.7	162.0
WEEK 8	4690	171.3	192.0
WEEK 9	5848	208.6	252.5

MED (8 repetitions @ 35°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	2783	83.8	114.3
WEEK 3			
WEEK 4			
WEEK 5	4358	111.1	145
WEEK 6			
WEEK 7	6218	161.6	202.3
WEEK 8	6323	158.9	187.6
WEEK 9			

APPENDIX J
In-Chamber Resistive Exercise Countermeasure Data

Subject 3 - Heel Raises

HI (12 repetitions @ 50°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2			
WEEK 3	1091	81.0	106.8
WEEK 4	1499	93.0	117.4
WEEK 5	1287	84.9	103.8
WEEK 6	1367	106.4	138.6
WEEK 7	1749	104.8	133.3
WEEK 8			
WEEK 9			

LO (6 repetitions @ 20°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	626	108.3	140.4
WEEK 3	841	103.7	138.0
WEEK 4	826	128.7	158.3
WEEK 5	648	99.2	112.8
WEEK 6	926	131.7	151.4
WEEK 7	1063	146.9	179.3
WEEK 8	1544	196.6	261.2
WEEK 9	1414	223.7	256.9

MED (8 repetitions @ 35°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	954	101.6	133.3
WEEK 3			
WEEK 4			
WEEK 5	830	95.3	133.4
WEEK 6			
WEEK 7	1366	151.4	190.6
WEEK 8	1699	146.1	179.5
WEEK 9			

APPENDIX J
In-Chamber Resistive Exercise Countermeasure Data

Subject 3 - Lat Pulls

HI (12 repetitions @ 50°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2			
WEEK 3	2294	43.2	54.8
WEEK 4	2679	54.2	62.6
WEEK 5	2897	58.7	72.8
WEEK 6	2960	60.4	68.8
WEEK 7	2638	57.0	70.1
WEEK 8			
WEEK 9			

LO (6 repetitions @ 20°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	2104	84.9	103.7
WEEK 3	1978	81.9	91.1
WEEK 4	2129	88.3	95.4
WEEK 5	1903	78.2	89.1
WEEK 6	2247	86.6	95.9
WEEK 7	2030	85.8	93.0
WEEK 8	2424	97.3	111.3
WEEK 9	2356	99.0	107.2

MED (8 repetitions @ 35°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	2392	68.1	80.1
WEEK 3			
WEEK 4			
WEEK 5	2753	75.4	82.6
WEEK 6			
WEEK 7	2489	76.0	84.3
WEEK 8	3012	83.8	97.5
WEEK 9			

APPENDIX J
In-Chamber Resistive Exercise Countermeasure Data

Subject 4 - Bench Press

HI (12 repetitions @ 50°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	4431	84.9	104.3
WEEK 3	5199	91.6	109
WEEK 4	4777	97.7	110.6
WEEK 5	5302	102.7	117.9
WEEK 6	4212	99.4	114.9
WEEK 7	4485	103.0	135.2
WEEK 8	5483	115.8	131.9
WEEK 9			

LO (6 repetitions @ 20°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	3666	138.4	168.1
WEEK 3	2990	130.6	141.7
WEEK 4	3765	149.7	168.6
WEEK 5	3317	142.2	156.5
WEEK 6	3669	159.4	175.5
WEEK 7	3685	152.9	166.0
WEEK 8			
WEEK 9			

MED (8 repetitions @ 35°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	3799	111.6	136.9
WEEK 3	3587	103.8	119.0
WEEK 4	3807	130.0	150.8
WEEK 5	3983	133.4	152.9
WEEK 6	3610	136.3	154.2
WEEK 7			
WEEK 8	3787	135.9	156.1
WEEK 9			

APPENDIX J
In-Chamber Resistive Exercise Countermeasure Data

Subject 4 - Seated Press

HI (12 repetitions @ 50°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	3504	60.8	71.8
WEEK 3	4328	68.4	79.9
WEEK 4	4032	76.6	91.9
WEEK 5	3922	72.0	87.9
WEEK 6	4116	71.9	83.9
WEEK 7	4029	84.2	96.2
WEEK 8	3603	93.9	107.6
WEEK 9			

LO (6 repetitions @ 20°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	2796	100.1	111.4
WEEK 3	2936	102.2	109.3
WEEK 4	3053	107.8	114.0
WEEK 5	2714	110.0	120.1
WEEK 6	3070	111.6	117.4
WEEK 7	2468	120.1	128.9
WEEK 8			
WEEK 9			

MED (8 repetitions @ 35°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	3361	84.0	96.3
WEEK 3	3068	82.5	93.4
WEEK 4	2998	90.7	101.4
WEEK 5	3412	92.7	103.1
WEEK 6	3664	103.1	113.5
WEEK 7			
WEEK 8	3543	108.0	118.7
WEEK 9			

APPENDIX J
In-Chamber Resistive Exercise Countermeasure Data

Subject 4 - Squats

HI (12 repetitions @ 50°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	9568	185.8	230.4
WEEK 3	10048	202.0	239.7
WEEK 4	11103	238.4	288.9
WEEK 5	13688	247.5	311.5
WEEK 6			
WEEK 7			
WEEK 8			
WEEK 9			

LO (6 repetitions @ 20°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	9115	316.7	360.4
WEEK 3	8923	348.9	416.9
WEEK 4	10184	398.2	474.0
WEEK 5	9188	388.6	433.6
WEEK 6	5966	250.9	317.2
WEEK 7			
WEEK 8			
WEEK 9			

MED (8 repetitions @ 35°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	10171	278.0	319.3
WEEK 3	8641	270.1	328.2
WEEK 4	9505	307.4	350.3
WEEK 5	8537	316.0	358.2
WEEK 6			
WEEK 7			
WEEK 8			
WEEK 9			

APPENDIX J
In-Chamber Resistive Exercise Countermeasure Data

Subject 4 - Heel Raises

HI (12 repetitions @ 50°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	5067	272.9	351.9
WEEK 3	3942	296.0	336.6
WEEK 4	6351	343.9	391.8
WEEK 5	6303	263.2	315.5
WEEK 6			
WEEK 7			
WEEK 8			
WEEK 9			

LO (6 repetitions @ 20°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	3167	365.8	419.8
WEEK 3	3015	398.1	436.8
WEEK 4	2466	374.7	438.6
WEEK 5	2366	356.1	419.3
WEEK 6	1783	269.3	308.6
WEEK 7			
WEEK 8			
WEEK 9			

MED (8 repetitions @ 35°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	3893	319.0	386.8
WEEK 3	2890	351.4	422.7
WEEK 4	2594	359.9	421
WEEK 5	2553	350.2	438.1
WEEK 6			
WEEK 7			
WEEK 8			
WEEK 9			

APPENDIX J
In-Chamber Resistive Exercise Countermeasure Data

Subject 4 - Lat Pulls

HI (12 repetitions @ 50°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	4528	85.1	101.5
WEEK 3	6114	99.5	120.9
WEEK 4	5613	107.7	133.5
WEEK 5	5699	107.9	124.5
WEEK 6	6490	112.5	1998
WEEK 7	6823	133.9	148.6
WEEK 8	5424	141.7	152.8
WEEK 9			

LO (6 repetitions @ 20°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	3834	141.4	155.8
WEEK 3	4220	153.6	166.0
WEEK 4	4441	167.0	178.6
WEEK 5	3996	167.6	180.1
WEEK 6	4460	171.8	179.2
WEEK 7	3937	180.7	191.9
WEEK 8			
WEEK 9			

MED (8 repetitions @ 35°/s)

	TOTAL TW (ft-lb)	AVERAGE PT (ft-lb)	PEAK PT (ft-lb)
WEEK 2	4635	123.3	138.7
WEEK 3	4303	125.4	138.1
WEEK 4	4658	135.9	150.5
WEEK 5	5041	143.8	157.5
WEEK 6	5456	151.8	164.3
WEEK 7			
WEEK 8	5435	163.4	173.8
WEEK 9			

APPENDIX K
Pre-Chamber Metabolic Calibration Data - All Subjects

Supine Rest

Subject	1	2	3	4	5	6	7	8	Mean	SD
VO2 (mL/kg/min)	3.42	3.30	3.17	2.62	3.82	3.49	3.43	3.43	3.34	0.34
VO2 (L/min)	0.24	0.24	0.18	0.22	0.24	0.20	0.26	0.19	0.22	0.03
VCO2 (L/min)	0.19	0.22	0.15	0.18	0.21	0.16	0.22	0.15	0.19	0.03
Me (g/min)	0.17	0.17	0.12	0.15	0.16	0.12	0.16	0.13	0.15	0.02

Seated Rest

Subject	1	2	3	4	5	6	7	8	Mean	SD
VO2 (mL/kg/min)	3.68	3.13	3.49	2.88	3.68	3.65	3.56	3.46	3.44	0.29
VO2 (L/min)	0.25	0.23	0.20	0.24	0.23	0.21	0.27	0.19	0.23	0.03
VCO2 (L/min)	0.21	0.20	0.17	0.19	0.18	0.17	0.22	0.15	0.19	0.02
Me (g/min)	0.18	0.16	0.14	0.16	0.15	0.13	0.17	0.13	0.15	0.02

Aerobic Exercise Countermeasure

Subject	1	2	3	4	5	6	7	8	Mean	SD
VO2 (mL/kg/min)	27.40	23.60	20.50	22.00	26.20	26.10	25.60	19.20	23.83	2.99
VO2 (L/min)	1.89	1.73	1.15	1.81	1.61	1.48	1.96	1.08	1.59	0.33
VCO2 (L/min)	1.92	1.79	1.14	1.87	1.65	1.54	2.00	1.04	1.62	0.36
Me (g/min)	1.34	1.21	0.80	1.22	1.06	0.89	1.21	0.74	1.06	0.22

Submaximal Exercise Test

Subject	1	2	3	4	5	6	7	8	Mean	SD
VO2 (mL/kg/min)	23.65	20.43	16.38	19.14	21.51	23.00	21.30	16.99	20.30	2.64
VO2 (L/min)	1.65	1.50	0.94	1.62	1.33	1.31	1.62	0.96	1.37	0.29
VCO2 (L/min)	1.66	1.54	0.97	1.61	1.38	1.39	1.68	0.90	1.39	0.30
Me (g/min)	1.04	0.94	0.55	0.97	0.92	0.89	1.02	0.59	0.87	0.19

APPENDIX L
Pre- and In-Chamber Exercise Log

NAME:_____ DATE:_____

Aerobic Exercise Log

Heart Watch #				
Heart Watch File #				
Time of Day				
Approx. Temp. (°F)				
Activity Type				
Duration (min)				

Resistance Exercise Log

Exercise	Weight/Reps	Weight/Reps	Weight/Reps	Weight/Reps	Weight/Reps

Rate the difficulty of effort on a scale of 1-10 (1 being light, 10 being greatest) of your exercise regime._____ Aerobic Exercise _____ Resistance Exercise

What are your general perceptions of the exercise you performed today?_____
_____
_____
_____

Bone Metabolism Questionnaire

Did you lift 10 lbs. (4.5 kg) or greater today? _____ yes _____ no

lbs/kg	# lifts	height	distance carried

Did you climb stairs today? _____ yes _____ no

Approximate number of steps up:_____ Number of steps down:_____

Approximate distance walked at normal pace:_____ rapid pace:_____

LMLSTP Exercise Countermeasures Demonstration Project Debrief

Thank you for your participation in this debrief and in this demonstration project. Your efforts, comments, and suggestions are greatly appreciated.

APPENDIX M
Post-Chamber Exercise Countermeasures Demonstration Project Debrief

Name:_____

LMLSTP Exercise Countermeasures Demonstration Project Debrief

A. Pre-Chamber Exercise

1. Briefly describe your normal exercise regimen before entering the chamber (type of exercise, frequency, and duration):

_____

_____

_____

2. On a scale of 1-10 (1 being the easiest, 10 being the hardest), rate the intensity of your exercise regimen prior to entering the chamber:

_____ Aerobic Exercise _____Resistance Exercise

B. In-Chamber Exercise

1. Briefly describe your perceptions of the exercise regimen prescribed in relation to the exercise you normally performed prior to entering the chamber (same, easier, harder):

_____

_____

_____

2. Briefly describe positive effects you experienced from performing

a. Aerobic exercise: _____

_____

_____

b. Resistance exercise:_____

_____

_____

3. Briefly describe any detrimental effects you experienced from performing

a. Aerobic exercise: _____

_____

_____

b. Resistance exercise:_____

_____

_____

4. On a scale of 1-10 (1 being the easiest, 10 being the hardest), rate the intensity of your exercise regimen during the chamber run:

a. Beginning of Study

_____ Aerobic Exercise

_____Resistance Exercise (High)

_____Resistance Exercise (Medium)

_____Resistance Exercise (Low)

b. Middle of Study

_____ Aerobic Exercise

_____Resistance Exercise (High)

_____Resistance Exercise (Medium)

_____Resistance Exercise (Low)

c. End of Study

_____ Aerobic Exercise

_____Resistance Exercise (High)

_____Resistance Exercise (Medium)

_____Resistance Exercise (Low)

5. Briefly describe your perceptions of the prescribed in-chamber exercise regimen:

_____

_____

_____

6. What recommendations would you make regarding this exercise prescription for future chamber and flight studies:

_____

_____

_____

C. Post-Chamber Exercise

1. Briefly describe the exercise regimen in which you plan to participate after the chamber run (type of exercise, frequency, and duration):

_____

_____

_____

2. How will the exercise you performed in the chamber influence your exercise choices after the chamber run?

_____

_____

_____

3. On a scale of 1-10 (1 being the easiest, 10 being the hardest), rate the intensity of the exercise regimen in which you plan to engage after the chamber run:

_____ Aerobic Exercise _____Resistance Exercise

D. Exercise Log

1. Briefly describe your perceptions of the exercise log used during this demonstration project:

_____

_____

_____

2. What recommendations would you make to improve this exercise log?

_____

_____

_____

E. Demonstration Project Administration

1. Briefly describe your perceptions of the administration of the exercise countermeasures demonstration project (enough information about expectations, feedback from exercise staff, etc.):

_____

_____

_____

2. What recommendations would you make to improve the administration of this demonstration project?

_____

_____

_____

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13. ABSTRACT *(Maximum 200 words)*

This demonstration project assessed the crew members' compliance to a portion of the exercise countermeasures planned for use onboard the International Space Station (ISS) and the outcomes of their performing these countermeasures. Although these countermeasures have been used separately in other projects and investigations, this was the first time they'd been used together for an extended period (60 days) in an investigation of this nature. Crew members exercised every day for six days, alternating every other day between aerobic and resistive exercise, and rested on the seventh day.On the aerobic exercise days, subjects exercised on an electronically braked cycle ergometer using a protocol that has been previously shown to maintain aerobic capacity in subjects exposed to a space flight analogue. On the resistive exercise days, crew members performed five major multijoint resistive exercises in a concentric mode, targeting those muscle groups and bones we believe are most severely affected by space flight. The subjects favorably tolerated both exercise protocols, with a 98% compliance to aerobic exercise prescription and a 91% adherence to the resistive exercise protocol. After 60 days, the crew members improved their peak aerobic capacity by an average 7%, and strength gains were noted in all subjects. These results suggest that these exercise protocols can be performed during ISS, lunar, and Mars missions, although we anticipate more frequent bouts with both protocols for long-duration spaceflight. Future projects should investigate the impact of increased exercise duration and frequency on subject compliance, and the efficacy of such exercise prescriptions.

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