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Attached is a preliminary copy of a recommended exercise program we have been asked to prepare for Shuttle. Although Dr. Dietlein has given an oral approval of the approach, there has been no official action. I would appreciate any questions or comments you may have.

John R.

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PROPOSED

Functional and Clinical Exercise Response Criteria And Exercise Training Requirements for Shuttle Crews

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1.0 Introduction

The purpose of this document is to define exercise response criteria (both physical fitness and clinical) for Shuttle crew selection and to propose a structured but flexible exercise training program which can be utilized by Shuttle crewmembers.

Exercise is a physiological stress which places severe demands on many body systems in order to maintain homeostasis. Thus, exercise is a valuable stressor for evaluating several aspects of overall body function. The application and significance of exercise response tests is well documented (1, 11, 16, 23, 28). Tests of this type have been found to be suitable for diagnosis, prognosis, and functional evaluation (10). Two of these three (functional and diagnostic evaluation) are directly applicable to the space program.

We are primarily interested in how adaptation to the weightless environment affects functional capacities both during and after space flight. Postflight functional changes in exercise response have been observed (19, 24, 25) even though inflight capacities remained high when vigorous training programs were utilized (27). Data from the Skylab flights, which employed inflight exercise, permitted us to hypothesize that exercise capacity would have been decreased inflight if exercise had not been employed as a physiological countermeasure. Decreased exercise capacity has been observed following ground-based bed rest studies (26).

We must address the definition of minimal physical fitness (functional capability) standards as we consider selection criteria for future space flight participants. Additionally, we must consider inflight exercise training as a physiologic countermeasure.

At this point in the manned space flight programs, the diagnostic capabilities of exercise stress testing become important. Our present astronauts are at an age where susceptibility to cardiovascular dysfunction is a distinct possibility (18). We currently perform an annual stress evaluation on all active astronauts as well as participating former astronauts. In order to contemplate flying non-crew scientists and technicians, we must develop a reliable clinical selection processes. This clinical selection process will help ensure that both NASA and the participating flight personnel have the most complete clinical information possible to assure them that the rigors of space flight can be endured and that latent pathology will not impact mission success. For these reasons it is imperative that appropriate clinical exercise response criteria be included in the overall Shuttle crewmember selection process.

At present we can identify three specific applications of the functional and diagnostic capabilities of exercise stress testing: (1) astronaut and nonastronaut crew selection, (2) annual physical examinations of the astronaut population, and (3) evaluation of inflight personal exercise as an effective physiologic countermeasure to deconditioning associated with weightlessness. The second application is currently an ongoing program and will not be discussed in this document. The third application is directly related to personal exercise training programs and is an integral portion of fitness selection criteria.

2.0 Functional (Physical Fitness) Exercise Response Criteria

Although the term fitness is general and includes many aspects of a person's being, cardiopulmonary fitness is best evaluated by determining maximum aerobic capacity. This measurement quantitatively describes the maximum capacity of the respiratory and cardiovascular systems to deliver oxygen to working muscles. A recent symposium (15) discusses physical fitness in relation to flyers. Although many of the participants attested to the value of aerobic fitness, it is interesting that no regulatory groups have instituted minimal standards of aerobic fitness. Minimal standards were not even used during the selection of U.S. astronauts. Therefore, one immediately questions whether it is advisable to establish minimal fitness standards for Shuttle crews. The answer is complex considering the lack of precedent in establishing such standards.

Space flight is a unique environment which causes adaptative changes (some known, some unknown) in physiological systems. Conversely, short term airplane flights do not cause physiological adaptation in the present sense. In the select group of men who have participated in U.S. space flights, as long as 84-days, physiologic changes were minimal and reversible. However, we must consider that these men were at "good" fitness levels at launch and that they exercised heavily inflight. Therefore, we believe it would be an extremely risky policy if the Agency did not adopt minimal aerobic standards for participation in

Shuttle. Undoubtedly there are individuals who would like to fly but who have little if any physiological reserves. Given any amount of inflight deconditioning plus some unplanned physiological cost of adaptation, the survival of these individuals could be compromised during any emergency situation or during their return to earth. Until the time that we thoroughly understand physiologic adaptation to space flight, we recommend the establishment of minimal fitness standards, but nevertheless sufficient for the purpose intended.

Published physical fitness scales (2, 12) show some disagreement between rating systems. A recent pamphlet (4) published by the American Heart Association (Table 1) reviews available literature and provides a composite scale for both men and women. This scale takes into account the "normal" effect of age (approximately 10% decrease in aerobic capacity per decade) observed by most investigators (3, 21). The American Heart Association scale also agrees with our own for the two groups we have evaluated (astronauts and volunteer executives (Table 2)). Based on these values and our overall experience with exercise testing, and the measured responses following exposure to weightlessness, we recommend the following criteria (Reference Table 1):

(1) Any person with a measured aerobic capacity in the "low" category would be considered unacceptable as a Shuttle crewmember.

(2) Any person with a measured aerobic capacity in the "fair" category would be considered acceptable only after an indepth clinical review by the medical selection committee. A waiver would be required.

TABLE 1

Cardiorespiratory Fitness Classification[4]

WOMEN

Age (yrs)	Maximal Oxygen Uptake (ml/kg/min)				
	Low	Fair	Average	Good	High
20-29	<24	24-30	31-37	38-48	49+
30-39	<20	20-27	28-33	34-44	45+
40-49	<17	17-23	24-30	31-41	42+
50-59	<15	15-20	21-27	28-37	38+
60-69	<13	13-17	18-23	24-34	35+

MEN

Age (yrs)	Maximal Oxygen Uptake (ml/kg/min)				
	Low	Fair	Average	Good	High
20-29	<25	25-33	34-42	43-52	53+
30-39	<23	23-30	31-38	39-48	49+
40-49	<20	20-26	27-35	36-44	45+
50-59	<18	18-24	25-33	34-42	43+
60-69	<16	16-22	23-30	31-40	41+

TABLE 2

Aerobic Response Comparisons

Group	$\dot{V}_{O_2}$-cc/kg/min (160 H.R.)	$\dot{V}_{O_2}$-cc/kg/min (180 H.R.)	MAX $\dot{V}_{O_2}$-cc/kg/min
Apollo 7-17 Flight Crews	32.6 ±5.7	40.0 ±6.8	
Skylab Prime & Backup (Average Age - 42)	34.3 ±5.8	40.0 ±6.9	43.2 ±5.3
Total Astronaut Population (Annual Physicals)	32.5 ±5.8		42*
Astronauts at Selection (Average Age - 32 ±2.5)			44.5 ±5.2
JSC Voluntary Executive Population (Average Age - 45)	28.3 ±7.6		30-38*
Cardiac Patients[1] (Average Age - 50 ±6.0)			25 ±5
Healthy Males[2] (Average Age - 51 ±7.8)			36.9 ±5.8
Healthy Females[2] (Average Age - 44 ±8.4)			26.8 ±5.8
Asymptomatic Men[3] (Average Age - 40-45			31.3 ±6.9

*Estimated

1 Benestad
2 Bruce
3 Cumming

(3) Any subject having a measured aerobic capacity of "average" or above would be acceptable.

(4) Any subject having a measured aerobic capacity "good" or above would not be required to engage in a prescribed inflight exercise program. Subjects at a lower rating would be required to exercise (at a level of their choice - see section 4 of this document) on all missions longer than 14 days in duration. Although there would be no required personal exercise on missions shorter than 14 days, a minimal exercise evaluation program (as discussed in section 4) would be required.

3.0 Clinical Exercise Response Criteria

Many references are available regarding the clinical termination of an exercise response test (4, 5, 6, 8, 9, 10, 14, 16, 17, 23). With the exception of ECG changes most of the criteria are non-quantitative. Table 3 summarizes the physiological criteria which will be cause for terminating an exercise stress test. These criteria are based on available literature and our inhouse experience with exercise testing. A test terminated according to these criteria would be the basis for elimination from the crew selection. The Medical Selection Committee shall determine whether to repeat any terminated test. As will be discussed in Appendix I, selection tests will provide physiological stresses between 85 and 100% of maximum.

4.0 Exercise Training Requirements

Our current working hypothesis is that exercise is a physiological countermeasure to deconditioning normally associated with exposure to the weightless environment. Because time requirements for personal exercise

TABLE 3

Clinical Exercise Test Termination Criteria
(Stress Level to be a Minimum of 85% of Calculated Maximum Heart Rate)

VARIABLE	CRITERIA
Systolic Blood Pressure	≧250 mmHg Failure to increase with exercise or a decrease
Diastolic Blood Pressure	≧110 mmHg
ECG	≧1.0 mm ST - Depression (X Lead) 3 successive PVC's (Mult - Focal) Second or third degree block Supraventricular Tachycardia
Subject Condition	Ataxia Angina Inappropriate Dyspnea Faintness, Dizziness, or Nausea General Pallor Mental Disorientation

will impact mission timelines, it is imperative that quantitative information be obtained early in the Shuttle program. This information will provide valuable guidelines to pilot astronauts as well as scientist astronauts. Therefore, we recommend a continuing study which will involve all members of all flight crews. In this way we can evaluate a more complete matrix of initial physical fitness levels in relation to inflight prophylactic programs. This necessitates a study design which requires considerably less crew time than the Skylab M171 exercise response test and one which requires fewer measurements. During the Shuttle program basic physiological mechanisms will be studied separately in more acute and more detailed human and animal experiments.

There is another factor which must be considered. Exercise is a major physiological stress, it causes adaptative changes in many body systems. There are extensive plans to study all aspects of man's physiology during weightlessness, and exercise becomes a major independent variable which must be accounted for in designing these experiments. Our study will provide a quantitative assessment of this factor. Information from these studies would be applicable to the broad scope of human scientific studies anticipated during the Shuttle era.

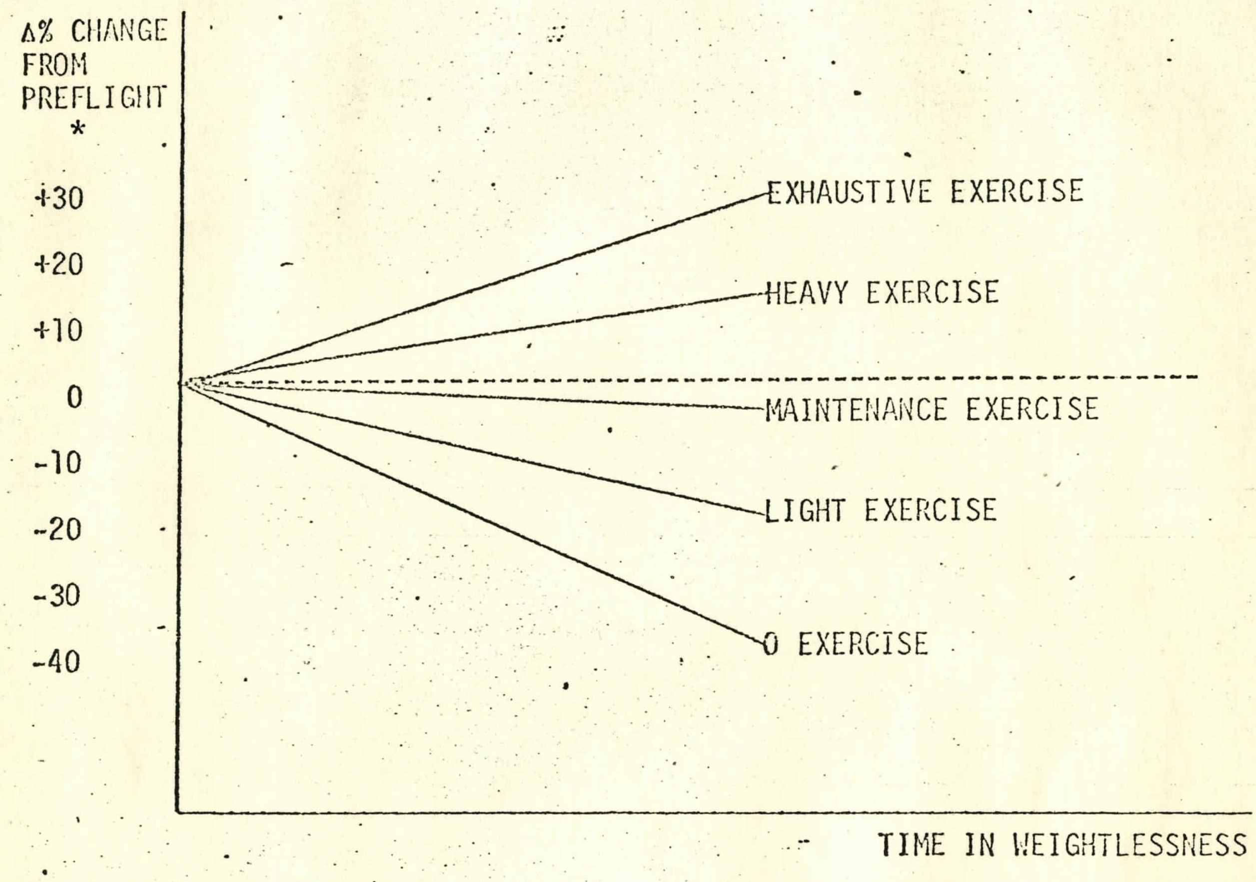
There are two basic types of exercise (endurance or aerobic and muscle strength) and their corresponding physiological counterparts (cardiopulmonary fitness and muscle tone/mass) which are influenced by space flight. Since we have not controlled or varied these parameters in any systematic way, we presently have no basis for generalization. The present recommendation is designed to obtain this information as rapidly as possible, while still providing safe guidelines, and without impacting the operational aspects of the Shuttle missions. In this context, basic study design was considered. The end point from this evaluation (if our working hypothesis is true) will be the information required to construct a graph such as shown in Figure 2. It is essential that this graph be constructed not only for inflight responses but also for postflight responses. In other words, it is important to understand the effect of exercise not only on conditioning during weightlessness but also its role in the 1-g readaptative processes. The abscissa is time spent in weightlessness while the ordinate is a measure of changes in either cardiopulmonary fitness or muscle strength. These two dependent variables should change in response to exercise intensity, the independent variable. Thus, an individual should be able to select an inflight exercise protocol which would either maintain or improve his status in relation to launch values. It is possible that the initial fitness levels at launch (we will use fitness in this context to cover both endurance and muscle factors) will determine the shape of the curves. In this case, a series of graphs would be required. Hopefully, this can be avoided by looking at delta changes in fitness and exercise intensities, both corrected for body weight. Age factors will also be evaluated.

Prior to flight, each crewman will select one of five inflight exercise intensity regimens (no work, light work, maintenance work, heavy work, or exhaustive work). The actual work levels for each of these are being finalized. Table 4 is preliminary and may require ammendment. The maintenance work level will hopefully be that level

FIGURE 2

THE RELATIONSHIP BETWEEN INFLIGHT EXERCISE AND CONDITIONING

(WORKING HYPOTHESIS)



*EITHER ENDURANCE OR MUSCLE CONDITIONING

TABLE 4

Preliminary Requirements For

Shuttle Inflight Exercise

Exercise Category	Watt-Min/Day/kg Body Wt
None	0
Light	30-50
Maintenance	51-70
Heavy	71-80
Exhausting	81+ → 100

which just maintains preflight condition. Obviously this scale will change as we gain more information. Skylab has provided numbers which are utilized as a starting point. Initially, we will recommend a no work protocol (on missions longer than 14 days) only for those individuals whose initial fitness level is classified as "good" (Table 1). As more experience accumulates these criterias will be adjusted accordingly. Quantitative numbers are not yet available for muscle strength training. The evaluation methods for exercise training are discussed in Appendix II.

APPENDIX I

Test Methods for Clinical and Functional Exercise Screening

Unfortunately, there is no standardized, dynamic exercise test method utilized by all investigators. There are presently single step, graded, continuous, discontinuous, submaximal, maximal, workload control, and heart rate control protocols just to list a few of the major variations. The "step", the bicycle ergometer, and the treadmill have all been utilized as the stress device.

The crew selection test as well as the astronaut annual physical test will be a graded bicycle ergometer test using target heart rates as the stress indicators. There will be two versions of this test, submaximal and maximal. For the submaximal portion, four 4-minute steps will be utilized to increase heart rate from rest to 85% of maximum (age corrected). A 4-minute rest period will precede and a 4-minute recovery period will follow exercise.

In those instances where the attending physician is satisfied with the subject's status, an additional portion will be added to the test. At the end of the standard 16-minute work period, work rate will be increased gradually to maximal or near maximal stress levels. The maximum point will be denoted as the point where $\dot{V}_{O_2}$ no longer increases with workload or where voluntary fatigue occurs. For some subjects (particularly those in excellent condition) this protocol may cause fatigue before a true aerobic maximum is reached. Under these circumstances an alternate test may be prescribed. This test is one in which the work level is continuously increased (~15 watts/min) until the subject is unable to proceed. The advantage of these is that the workload is applied faster and muscle fatigue per se is minimized relative to cardiovascular fitness. If the NASA Medical Selection Committee so desires, it would be possible to substitute a maximal treadmill test.

The following physiological measurements will be made during the selection and annual physical tests: ECG/VCG, heart rate, blood pressure, non-invasive cardiac output, vibrocardiogram, and carotid pulse.

APPENDIX II

Test Methods for Exercise Training Evaluation

The variable selected for measuring changes in endurance or cardio-pulmonary fitness is oxygen pulse (oxygen consumption/heart rate). Although an argument could be made for looking at maximum aerobic capacity, we believe that for the purposes of this study oxygen pulse is a much more realistic measure. The bradycardia of training is well established as is the tachycardia of deconditioning (20). This approach requires a known physiological stress (i.e. oxygen consumption) level. Skylab demonstrated there is little if any change in mechanical efficiency inflight. Therefore, if the workload is known, the oxygen consumption (determined from preflight tests) can be estimated inflight with sufficient accuracy (less than 5 percent error). This means that a bicycle ergometer must be used as the exercise stress device, since we do not know that information when using a treadmill. Although oxygen consumption could be measured in conjunction with treadmill exercise, this adds undersirable hardware requirements.

The monitoring protocol for endurance changes will be a single, low-level (such that it elicits heart rates below training stimulus but above normal psychogenic levels) workload on a calibrated bicycle ergometer for five minutes during which time heart rate is measured. A five-minute rest and five-minute recovery would preceed and follow the exercise stress (15 minutes total). This would be repeated every third day inflight for all crewmembers. Preflight, each subject would perform the graded exercise screening test described eariler. This would serve to define each individual's mechanical efficiency as well as his oxygen pulse curve through a range of heart rates. The low level monitor protocol would be performed at least three times preflight to establish baseline values. Postflight, the low level monitor protocol would be repeated on R+0 and R+1. Significant deviations from preflight would be followed every third day until a return to normal or a satisfactory explanation was obtained. Additional physiological measurements (gas exchange, ECG/VCG, cardiac output) will be made during the pre- and postflight tests.

Muscle mass, strength, and tone are much more difficult to quantitate than endurance fitness. Anthropometric measurements will be employed for muscle mass determinations and a simplified procedure will be utilized for muscle strength. Isokinetic exercise will be employed both in testing strength as well as for muscle training. A modified "Mini-Gym" device with the capability to register continuous force will be provided. An accurate governor will regulate speed and we will obtain measurements of the forces generated during a maximum effort "Big Four"*. This procedure employes a wide range of muscle groups and should give an indication of the status of different muscle groups as well as an integrated measure of muscle strength.

These tests would be done at the same time as the endurance monitoring tests pre- and postflight. Inflight, they would be done only every other test period (i.e. every six days).

*An exercise mode in which a deep knee bend is continued into a military press.

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