A SUGGESTED EXERCISE PROGRAM FOR USE IN CONDITIONS OF WEIGHTLESSNESS OR REDUCED GRAVITATIONAL STATES

I. INTRODUCTION

Several reasons exist for an astronaut to be in good physical condition prior to a space mission. (1) To withstand accelerative forces associated with leaving the earth. (2) To perform routine or emergency tasks in space flight that require strength and/or endurance. (3) To tolerate the stresses of re-entry. (4) To quickly and completely re-adjust to earth's constant 1 G environment and the return to upright posture.

Bed rest studies and water immersion experiments indicate certain effects are highly probable under weightless conditions. (a) Loss of cardiovascular tone. (b) Muscle and bone atrophy, with resulting:

(1) negative nitrogen balance and loss of protein stores,
(2) osteoporosis with calcium loss in the urine,
(3) urolithiasis.

Effects which are less probable but may occur in weightlessness include digestive alterations, motion sickness and disorientation, pulmonary atelectasis, fluid shifts within the body, and possible visual and psychomotor disturbances.

The first eight orbital flights involving men, none of which exceeded 4 days in duration, have demonstrated: (a) Increased urinary output. (b) Transient vestibular disturbances (Titov only). (c) Transient orthostatic hypotension after return to earth (Schirra only). (d) Increased urinary calcium (Nikolaev and Popovich).

Let us review some important favorable findings in hypodynamic environments to date.

1. Bed rest and water immersion studies indicate: (a) Exercises in bed rest will not prevent loss of vascular tone but will maintain muscle and bone mass. (b) Intermittent inflation of tourniquets located proximally on the extremities will maintain vascular tone. Such tourniquets can be incorporated easily into space suits.

2. Short duration orbital flights indicate: (a) Normal blood pressure and pulse during the weightless state up to 33 hours. (b) Normal pulse and blood pressure responses to simple, repetitive exercises with a bungee device. (c) No lasting derangements result from launch, weightlessness, re-entry or return to the constant 1 G environment and upright posture.

What conclusions can we draw from the above information? (1) Man can probably function well in the weightless state. (2) When in good physical condition, he can tolerate the stresses of leaving and returning to earth very well. (3) Tourniquet devices should be able to maintain vascular tone in the weightless state. (4) Exercises should be able to maintain muscle and bone mass in the weightless state.

II. EXTRATERRESTRIAL EXERCISE PROGRAM

There are two main objectives of an extraterrestrial exercise program: (1) Maintain muscle and bone mass. (2) Maintain endurance. In basic terms, maintenance of muscle and bone mass means the maintenance of strength. Stresses must be imposed on the body structure that will require maximal or near maximal effort and will stress the skeletal architecture enough to prevent calcium loss. At the same time, the stress should be adequate to maintain muscle strength and bulk, which will prevent loss of muscle protein. Such exercises should require maximal energy output but have a duration of only a few seconds.

Endurance in this paper means maintaining a high capability to perform for many minutes exercises requiring high but sub-maximal energy output. Such exercises stress aerobic energy producing mechanisms and impose sustained requirements on the combined and coordinated efforts of the respiratory, cardiovascular, neuromuscular, hormonal and thermal regulatory systems of the body.

The combined programs for strength and endurance should maintain the space crew member in excellent physical condition by terrestrial standards. The application of terrestrial standards is important because the desired end result of every space venture is the safe return of crew members to earth with rapid and complete re-adjustment to the terrestrial environment. Emergency conditions might necessitate return to earth unexpectedly with possible disastrous results for poorly conditioned or deconditioned crew members.

A. STRENGTH

On earth the most common method of building and maintaining strength is weight lifting. This is not practical in space slight. It would be very desirable to have exercises requiring little time, space or equipment, yet with results equivalent to weight training on earth. The best answer known at this time is the use of static contraction exercises, frequently called "isometrics."

Extensive work in Germany and America in the past 15 years has demonstrated that maximal increase in mass and strength of a given muscle will result from one single muscular contraction per day, if the contraction is more than 1/3 of the maximum strength of the muscle. This can be compared with a weight training program in which the weight is increased until it can't be moved at all. The contractions are isometric, which means muscular exertion without shortening of the muscle. Any muscle group can be exercised in this manner by straining against an immovable resistance.

Isometric exercises have been developed for almost all sports. The duration of the strain (i.e., the exertion of a muscle group against an immovable resistance) has been established at approximately 6 seconds. This is called a "bout." One to three bouts of each exercise are done daily using about 75% of maximum effort. Experiments have demonstrated that such a program can build muscle groups to the maximum possible strength in a matter of weeks or months with daily exercising. The same results can be obtained somewhat more slowly by exercising less frequently.

Once a given level of strength is attained, it can be maintained by exercising less frequently than daily. Exercising weekly will retain almost the same level as exercising daily. With cessation of exercise, strength is lost at approximately the same rate at which it was developed, except that there is a small but measurable increase in residual strength.

It must be emphasized that isometric exercises develop and maintain strength and muscle mass, not endurance.

Applying isometric exercise principles to space flight means determining how to exercise the muscle groups of the body under the limitations of confinement, semi-fixed body position and protective garments. Where body position is not limited to one arrangement, the space crew member should be able to secure himself so reactions to forces of tension, compression or rotation that he exerts against immovable structures will not impart undesired motion to his own body. To be certain to provide adequate stress to the musculo-skeletal system in weightlessness, isometric exercises should be done once or twice daily.

Let us examine a few of the isometric exercises possible in a situation such as the Mercury couch with the crew member in a pressure suit that is uninflated and permits maximum mobility. Each exercise should be performed with maximal effort for about 6 seconds with a rest period of 30 to 60 seconds between exercises.

Neck Muscles:

1. Strain head forward against resistance of both hands.
2. Strain head backward against resistance of both hands.
3. Strain to the right against resistance of the right hand.
4. Strain to the left against resistance of the left hand.

Arm Muscles:

1. With arms in front of body at shoulder level, compress palms together.
2. With arms in front of body at shoulder level, hook bent finger-tips of one hand to bent finger-tips of the other hand and try to pull arms apart.
3. With both arms on arm rests, force the forearms and clenched fists down against the arm rests. (This should be done with the restraint harness on so the body and arms cannot move during the strain.)

Trunk Muscles:

1. With the restraint harness affixed, strain entire trunk forward against the harness. (This can be done in various degrees of trunk flexion, depending on tight or loose adjustment of the harness.)
2. With thighs and legs securely restrained, extend trunk and head forcibly backward against the couch.

Abdominal Muscles:	1.	Lying in the couch with relaxed retraint harness, maximally tense all abdominal muscles.
Gluteal Muscles:	1.	Lying in couch with relaxed restraining harness, maximally tense all gluteal muscles.
Hip Flexors:	1.	With restraint harness secure over trunk and thighs, flex one thigh maximally against restraint. After a brief rest, repeat for the other thigh.
Hip Extensors:	1.	With trunk and thigh restraint secured firmly extend one thigh maximally against the couch. Repeat after brief rest for the other thigh.
Knee Flexors:	1.	With trunk and thigh restraints secured firmly, flex lower leg against couch. After brief rest, repeat for other lower leg.
Knee Extensors:	1.	With trunk and thigh restraints secured firmly, extend lower leg maximally against restraint. After brief rest, repeat for other lower leg. (Note: Looseness of ankle restraint can be varied to permit variation of angle of extension of knee.)

Isometric exercises can be developed for the wrists, fingers, leg adductors and abductors, and for dorsiflexing, extending, rotating, inverting and everting the feet. Any other muscle group can be exercised just by applying knowledge of anatomy and body kinematics to devise appropriate isometric maneuvers. Rotation exercises should be devised and executed very carefully to prevent traumatic damage to muscle groups, tendons or ligaments.

In the Gemini and Apollo space craft, volume may or may not confine exercising to the couch. In a space station, volume will certainly permit lying, standing and various sitting positions. Almost any sort of isometric exercise would be possible. The immovable resistance could be a bulkhead, a seat, another crew member, a strap or chain attached to the ceiling, floor or wall, or a portion of the body of the exercising crew member. In a space station, two excellent exercises to stress the skeletal system would be:

1. Place hands on ceiling and feet on floor. Push maximally against both surfaces for 6 seconds.

2. Extend arms sideways at shoulder level with palms on firm surfaces. Push maximally for 6 seconds.

Isometric programs for use in space should be devised and tested on earth. Use of dynamometers is essential in the exercise development and training programs to indicate how much muscle strength is available. Once a crew member has trained up to the program that should be standardized for him, dynamometer readings every few weeks will assure that desired exertions are being attained.

B. ENDURANCE

On earth, running, swimming, bicycling, rowing, rope skipping, tennis, handball and other methods of exercise can require sustained, submaximal energy output. All of these would be impractical (as we know them on earth) under conditions of weightlessness, reduced G or the limited volume of a spacecraft. The U.S. Navy has had a rowing machine developed by Biodynamics, Inc. of Cambridge, Mass. for exercise aboard submarines. This might prove useful in space or on the moon since it provides whole body exercise in one device.

The bicycle ergometer has been used extensively in the study of exercise physiology. Work output can be adjusted easily by varying resistance to pedaling and rate of pedaling. Moderately high oxygen consumptions per kilogram of body mass can be obtained, but only the leg and lower trunk muscles are used. Incorporating with the bicycle a device to permit simultaneous rotatory or alternating tension and compression for the arms would bring the upper back and arm muscles into play and provide exercise for the entire body, thus raising the maximal oxygen consumption. A prototype machine might look like one bicycle on top of another with the upper pedals mounted somewhat forward for arm use. Since wheels would get in the way and friction devices might generate undesirable heat, the resistances might be adjustable vane fluid devices. Other forms might apply capture of the energy of exercise in an electrical generating system to contribute to battery or other power stores, realizing, of course, that the horsepower output would be slight and infrequent.

Other endurance exercise possibilities include tension-compression devices operated against adjustable fluid resistances, cable exercisers (such as weight lifters use), rubber bungees, compression springs, or even the upper body and arm movements employed with a long oscillating handle, such as children use to power kiddie cars. The objective is to exercise leg, trunk and arm muscle masses at the same time to place a high but submaximal load on the cardio-respiratory, neuromuscular, hormonal and thermal regulatory systems of the body. Whatever devices are used must be firmly anchored to the space craft, and the space crew member must be anchored to the exercise device. Hand held devices need not be anchored. It might be possible to incorporate some exercise devices in the controls, since weight will be a primary consideration in all space ventures.

Since time will be important for all space crew members, the endurance program should require no more than 20 minutes daily or perhaps every other day. As with the strength program, experiments on earth must be conducted to devise the proper equipment and the optimum exercise programs. It might be found that the endurance program would provide adequate muscular and skeletal stress to eliminate the strength program. For example, it might be possible to have a 20 minute endurance workout with sub-maximal loading, and then, after a short rest, have a one or two minute workout with resistances increased to a level maximal for the particular space crew member. The few muscle groups not exercised could be stressed with an isometric program.

It must be emphasized that each program must be tailored to each individual space crew member, both in strength and endurance performance requirements.

C. EXERCISE IN REDUCED GRAVITATIONAL FIELDS

The same principles apply as would apply in weightless conditions. The small amount of "G" likely will not contribute much to the exercise program, such as the 1/6 G field of the moon or the 1/10 G that might be encountered in a slowly rotating space station. The ultimate objective is still fitness for the return to earth, and terrestrial criteria for physical fitness should apply.

III. GENERAL COMMENTS

Some might argue that a certain degree of deconditioning could be allowed when away from earth. This would not seem prudent until much experience is gained in space. Persons who develop illnesses or injuries requiring periods of physical inactivity (but not return to earth), should, upon recovery, progressively recondition to their own pre-established exercise levels.

Exercising will cause sweating and increased body odors as well as increasing the oxygen intake, carbon dioxide output and caloric intake. These requirements should be anticipated and provided for. The sweating may prove beneficial in the difficult problems expected regarding skin hygiene in orbital and lunar missions.

Exercising in pressure suits may be necessary in the Gemini and Apollo programs, but in space stations and on the moon it would seem desirable to be free of such encumbrances, as long as life support equipment for energency use is handy.

IV. RESEARCH

Before exercise programs are used in space or on the moon, they should be developed and tested under appropriate experimental conditions on earth. The water immersion and bed rest techniques offer good hypodynamic environments. A man could spend 23 hours a day immersed (or in bed) and be up for 20 to 40 minutes of exercise followed by 20 minutes for personal needs. While immersed (or in bed), tourniquets could be applied intermittently to maintain vascular tone and reflexes. If muscle and bone mass, strength and endurance could be maintained over weeks and months, then the exercise programs would be ready for space applications. Research on earth could help to establish the period of time a well conditioned man could spend in space without the need for a conditioning program. Research on earth could also establish if there really is a need for separate programs for strength and endurance when one might do the job.

An optimal exercise program in terms of specific exercises, energy output and duration should be established and verified on earth for each space crew member. This prescribed program would then be the norm for that individual in the extra-terrestrial environment. This could provide excellent physiological data with a standardized program before flight, during flight or lunar stay, and after return to earth.

Research on earth will produce well educated guesses. The proof of the pudding will be actual trials in space and on the moon where carefully controlled programs can be carried out. Perhaps answers will be obtained to such questions as: (1) How long does the excellent physical condition of a man at launch time last under conditions of weightlessness without tourniquets or exercise? (2) What happens to the body in de-conditioning due to weightlessness? (3) If a man becomes de-conditioned during weeks or months under weightless or sub-gravity conditions, is his survival jeopardized during re-entry? Will he be subject to a period of convalescence and re-conditioning to tolerate earth's 1 G environment and the upright posture? (4) Is it realistic or practical to use terrestrial criteria for physical fitness for existence under weightless or sub-gravity states?

V. SUMMARY

Suggested exercise programs for use in weightlessness and reduced gravitational states have been presented. The space crew member must maintain both strength and endurance, and terrestrial criteria for both should be employed. Each crew member should have an optimal program determined for himself on earth before flight. Equipment development programs are necessary to optimize exercise routines and minimize weight. Research on earth now, and later, in space and on the moon, can help to solve the many unanswered questions related to optimum maintenance of health and performance in non-terrestrial environments.

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