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CONDITIONING Effects OF THE BICYCLE AND TOTAL-BODY ERGOMETERS

RESEARCH PROSPECTUS

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Introduction

Exercise is a method presently applied to prevent deconditioning in space flight. It is based on the ability of 0.6 of the body's cells, the locomotor cells, to increase metabolic activity 50 to 100 times the basal level. Such an increase in metabolic rate demands extraordinary quantities of fuel and oxygen. Such transport requirements, in turn, place the ultimate demands on the organs of respiration and circulation. Therefore, physical activity has profound chronic as well as acute effects on the cardiopulmonary as well as the musculoskeletal systems. The basic principle operating is that these systems improve with greater-than-usual demands and degrade with less-than-usual demands.

The weightless environment of space presents less-than-usual metabolic and weight-bearing stress and the tendency is toward deconditioning of the systems involved. By exercising, the tendency is to counteract these deconditioning effects in the musculoskeletal and cardiopulmonary systems. By exercising large masses of musculature, the magnitude of deconditioning counteraction is great. By exercising the major segments of the body, the capability to do hard work continuously with arms, trunk or legs is preserved without undue fatigue (e.g., securing hatches, repair work, extravehicular activity and emergency activity). One's readiness and fitness are comprehensive and it is this concept that is proposed for study.

If the duration of exercise is short and the load heavy, then the musculoskeletal systems are markedly affected and the cardiopulmonary hardly at all. If the duration of exercise is long and the load light, then the reverse is true. The compromise, of a duration between 0.5 and 1.0 hour and a load as heavy as practical, has significant effects that counteract deconditioning in the musculoskeletal and cardiopulmonary systems (e.g., strength, endurance, tone and size of muscle, bone, articular and connective tissues; magnitude of cardiac output, maximal oxygen consumption, plasma volume, red cell mass, and total body water). This is called heavy endurance exercise and also is proposed for this study.

Even young, healthy subjects need to be trained in order to perform heavy endurance work without undue fatigue. The method of choice for training is to assess the individual's aerobic capacity in a fitness test, then to train him at gradually increasing fractions of that capacity. This gradient is efficiently and safely executed by monitoring blood pressure, heart rate, metabolic rate, and work rate during the training. These monitored parameters also give the capability of answering the ancillary question of whether work efficiency increases with such training, as some literature indicates. If this can be confirmed, then the sparing of oxygen, of food and of weight of the environmental control system takes on the utmost importance for extended manned space missions. This question will be looked at with great care in this study. And it is for this reason that the most accurate ergometer and metabolic rate apparatus will be employed.

The agonist and antagonist muscles of each major body segment must be employed in order to involve the greatest mass of musculature. By this matched, comprehensive employment of musculature, other advantages also accrue. For example, the exercise stress on the skeletal and the articular tissue structures is comprehensive and balanced. This would be more effective in counteracting the atrophy of disuse in these structures than the employment of agonist muscles only. In addition, this matched employment of muscles insures for any segment greater vascularization, greater demand for blood flow, and greater tissue tension than if only agonists are used. The full physiologic benefits of these vascular demands have not been seen in space flight or simulation studies to date because exercise regimes have used only agonist musculature.

The latest evidence in the literature indicates that a high work rate can be maintained twice as long if shared by arms and legs rather than by legs alone. In other words, spreading the work load over a greater muscle mass reduces the stress per unit of muscle. This means that for any given space flight and any given level of fitness, muscle atrophy by virtue of mass reduction alone will increase the fatigue burden of significant work. (That is, for any given quantity of work, the load on the heart is heavier, heart rate is higher, the feeling of strain is greater, and the lactic acid level in the blood is greater.) This also suggests that the way to economize on crew conditioning time, without sacrificing fitness, is to increase simultaneously the intensity of the exercise and the mass of musculature involved. Data on this corollary will be sought as an ancillary part of this proposal.

For the runner, evidence in the literature indicates that the maximal oxygen consumption using arms alone is 2.2 L/min, using legs alone is 4.0 L/min, and using arms and legs is 4.0 L/min. If one trained to a plateau with legs alone, then continued training with arms and legs, would the maximal oxygen consumption increase? It is well known that exercising a sedentary muscle mass will increase the number of capillaries fivefold and the size of the capillaries twofold. There will be an augmented demand for blood volume, cardiac output, and arterial O_2. If the increase in maximal oxygen consumption from training is mainly from an increased $A\text{-}VO_2$, then the answer to the question probably would be negative. Recent evidence indicates, however, that increases in maximal oxygen consumption are caused by equal enhancement of cardiac output and A-VO_2. Therefore, the expectation of a finding of fundamental physiologic importance profoundly affecting the design of crew conditioning regimes and devices seems good. This is proposed as the main question to be answered by this study.

The total-body ergometer was designed at Douglas specifically as a crew conditioning device for extended manned space missions. It was designed to employ the greatest mass of skeletal musculature possible in a simple movement pattern on a fixed, convenient device of less weight and volume than other ergometers. It was designed to employ all major body segments to effectively maintain total-body strength and endurance (i.e., total-body fitness). It further was designed to employ both agonist and antagonist musculature permitting the stress on the muscular, skeletal, articular, and vascular structures to be comprehensive, balanced, and more effective in counteracting the atrophy of disuse than in using agonist muscles only. This was accomplished by attaching two handles to loops of cable to power an alternator to obtain resistance for the exercise and a useful method of handling part of the energy expended. With feet tethered, the handles are translated from the level of the feet to beyond the head (extension phase) and back again (flexion phase) (Fig. 1). The legs (as well as the arms) act together, rather than alternately as in pedaling, and permit large forces. In addition, the action of the legs move the body's center of gravity about 1 meter in about 0.5 sec thereby yielding a substantial kinetic energy pool (about 140 joules for a 70 kg man) with no weight penalty. Compared to other devices, this permits large, steady power to any system or subsystem (like emergency life support and communication), and saves weight by sparing the environmental control system. For the entire exercise (extension and flexion phases), 186

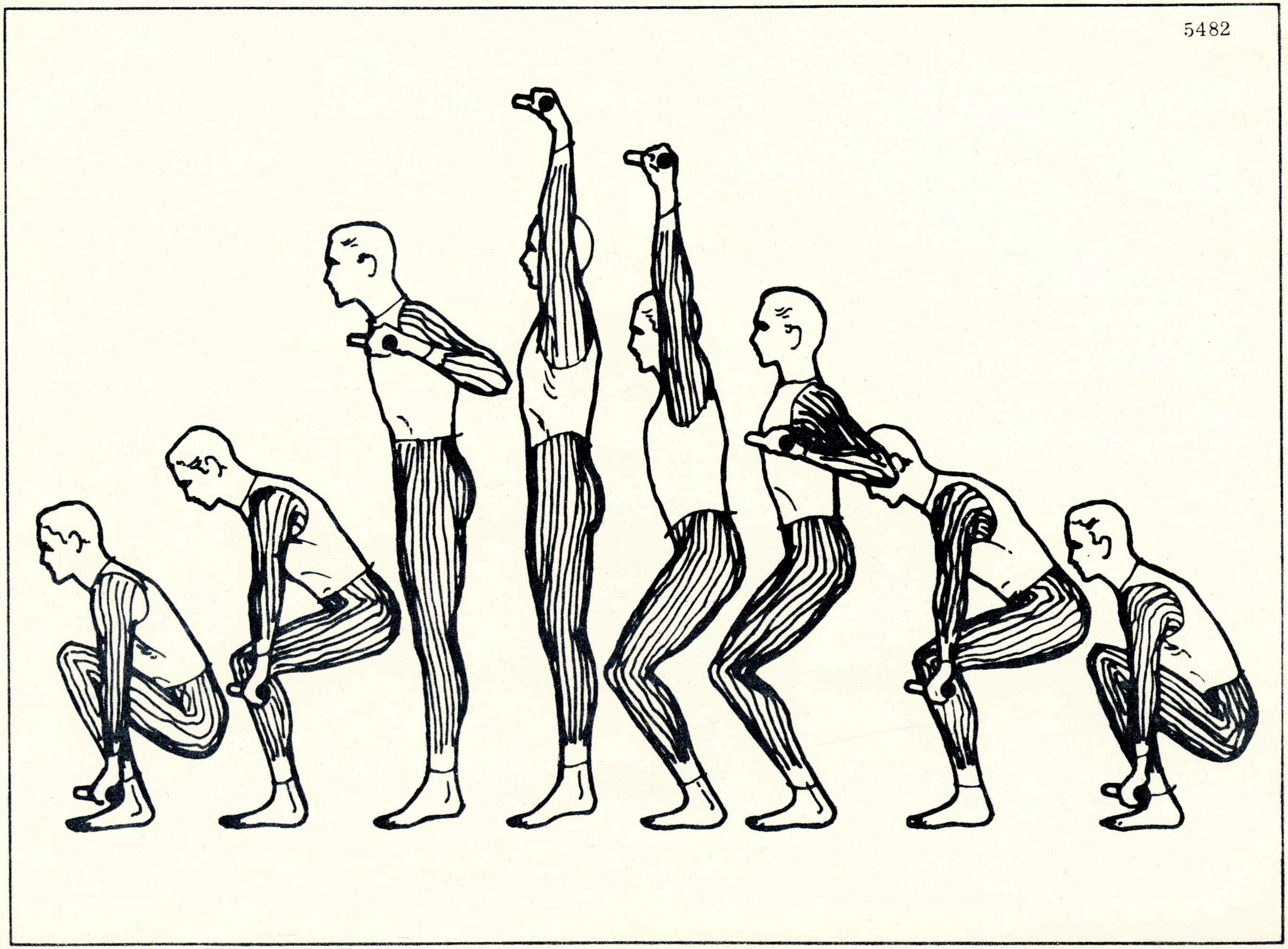


Figure 1. Power Strokes for ~~Translating a Handle~~ Total-Body Ergometer

different agonist and antagonist muscles are employed (Figs. 2 and 3), including the 20 agonist muscles employed in pedaling a bicycle (Fig. 4). (Muscles employed in lengthening, stabilizing, respiration, or in any minor role have been omitted from these analyses.) Compared to the bicycle, it seems reasonable that this system will employ significantly greater musculature to significantly greater physiological and engineering advantage for extended manned space missions.

The Experiment

The purpose of the study is to compare the total-body ergometer with the bicycle ergometer as a crew conditioning device. The subjects will consist of 12 sedentary men, 20-30 years old, who can demonstrate a maximal oxygen consumption on test 1. The subjects will train progressively 5 weeks, 5 days a week, 0.5 hr a day, one bout, constant work rate, on the bicycle ergometer, then take test 2. After another week of training, they will take test 3. After another week, test 4. Tests 2, 3, and 4 will establish a plateau or a slope for extrapolation to the end of the experiment. A subsequent 5 weeks will be spent progressively training on the total-body ergometer, followed by test 5. After another week of training, they will take test 6, and after another week, test 7, which terminates the experiment (Fig. 5).

Measurements will include T-1824 for blood volume for tests 1, 4, and 7. The maximal oxygen consumption test will be done on the treadmill at 7 mph at discrete loads to confirmed maximum. The test will include monitoring phonoarteriographic blood pressures (1), electrocardiogram, respiratory rate, and oxygen consumption (Haldane and spirometer). Training exercise will be monitored. Phonoarteriographic blood pressures and heart rate will be measured from minute 20-25 and oxygen consumption from minute 26 to 27. Work rate will be measured from von Döbeln devices on the bicycle and total-body ergometers (2).

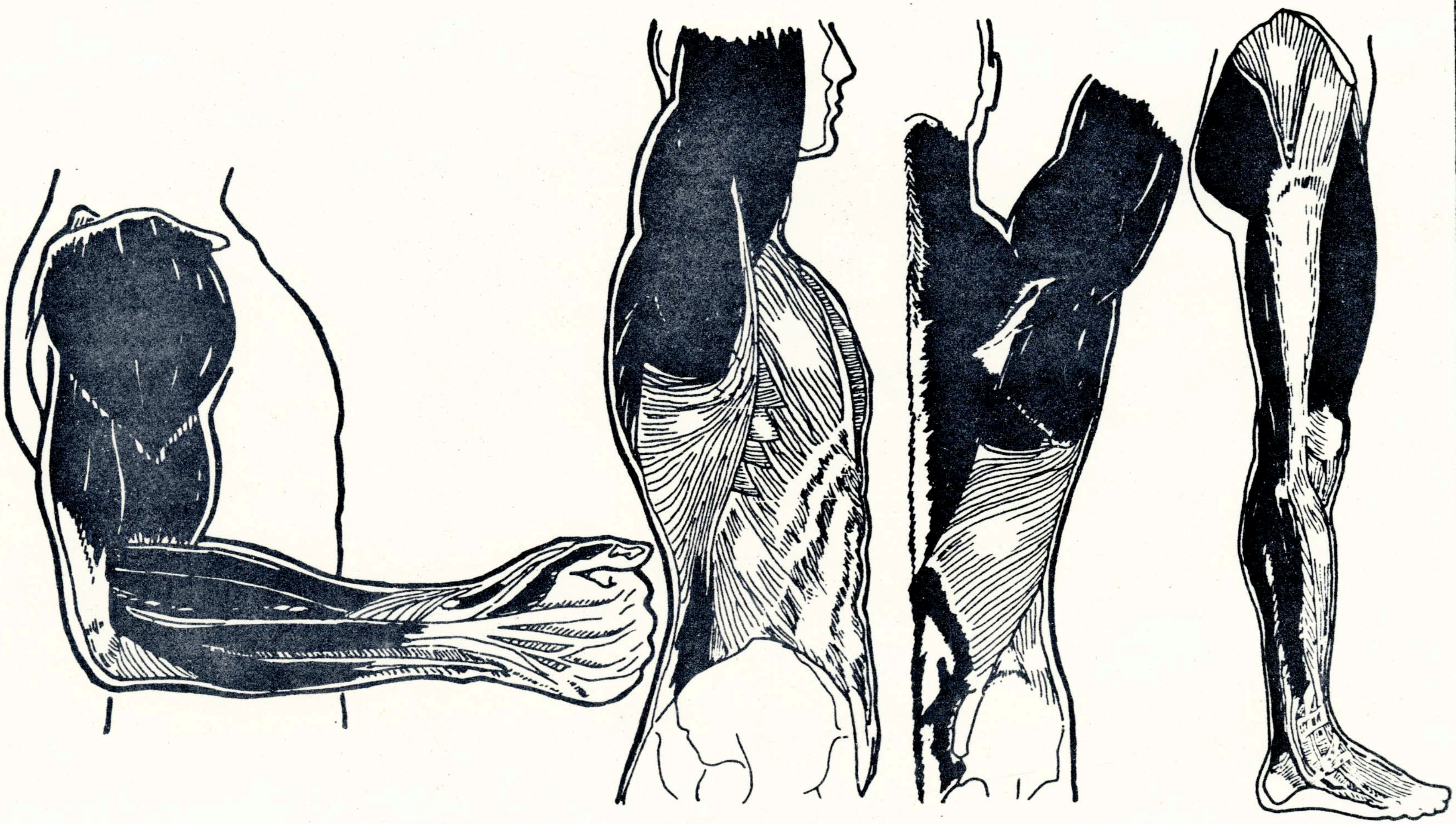


Figure ~~1-7~~ 2. Musculature Involved in ~~First Power~~ Extension Stroke for ~~Translating - Handle~~ Total-Body Ergometer

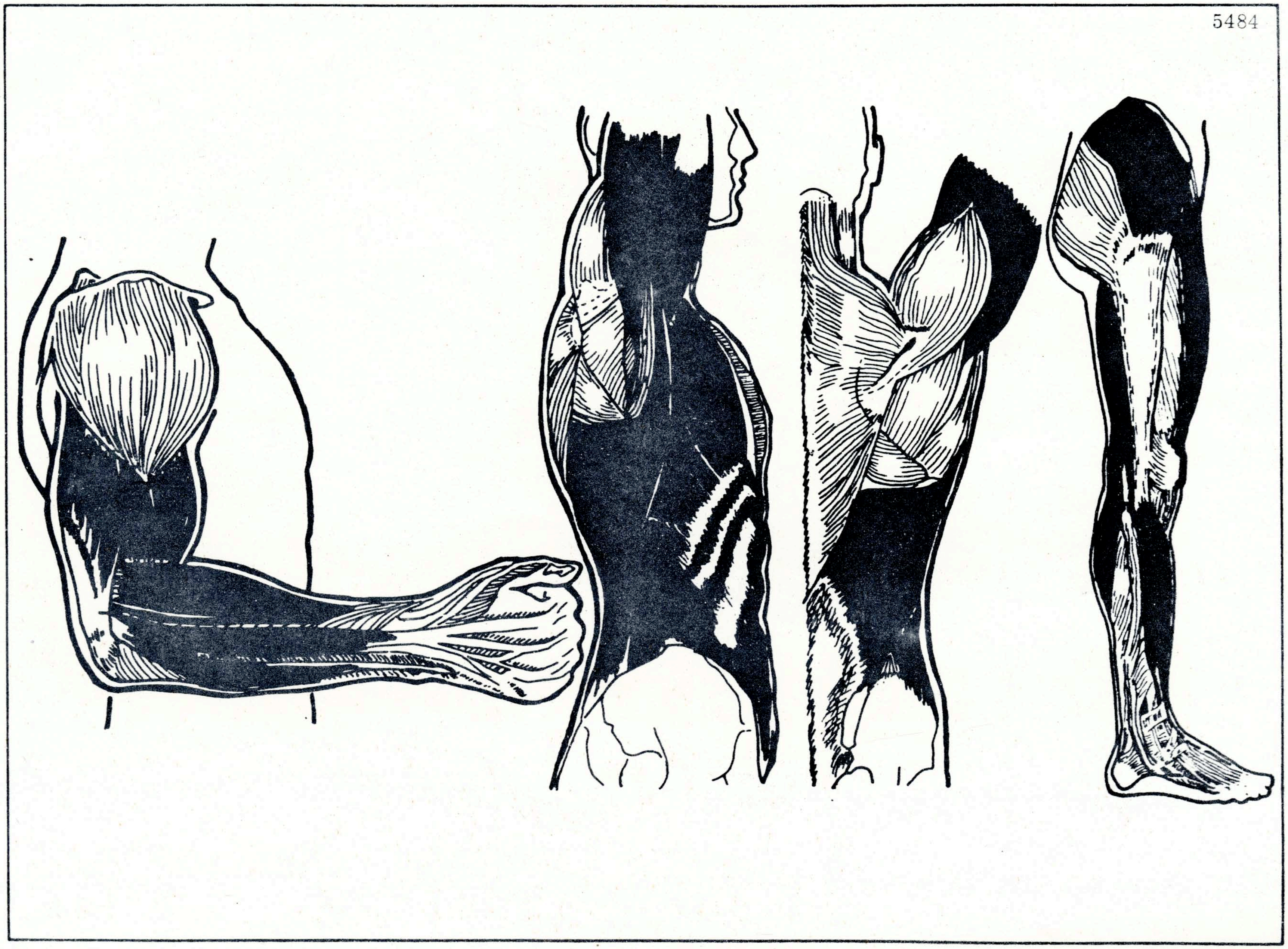


Figure ~~4-3~~ 3 Musculature Involved in ~~Second Power~~ Flexion Stroke for ~~Translating a Handle~~ Total-Body Ergometer

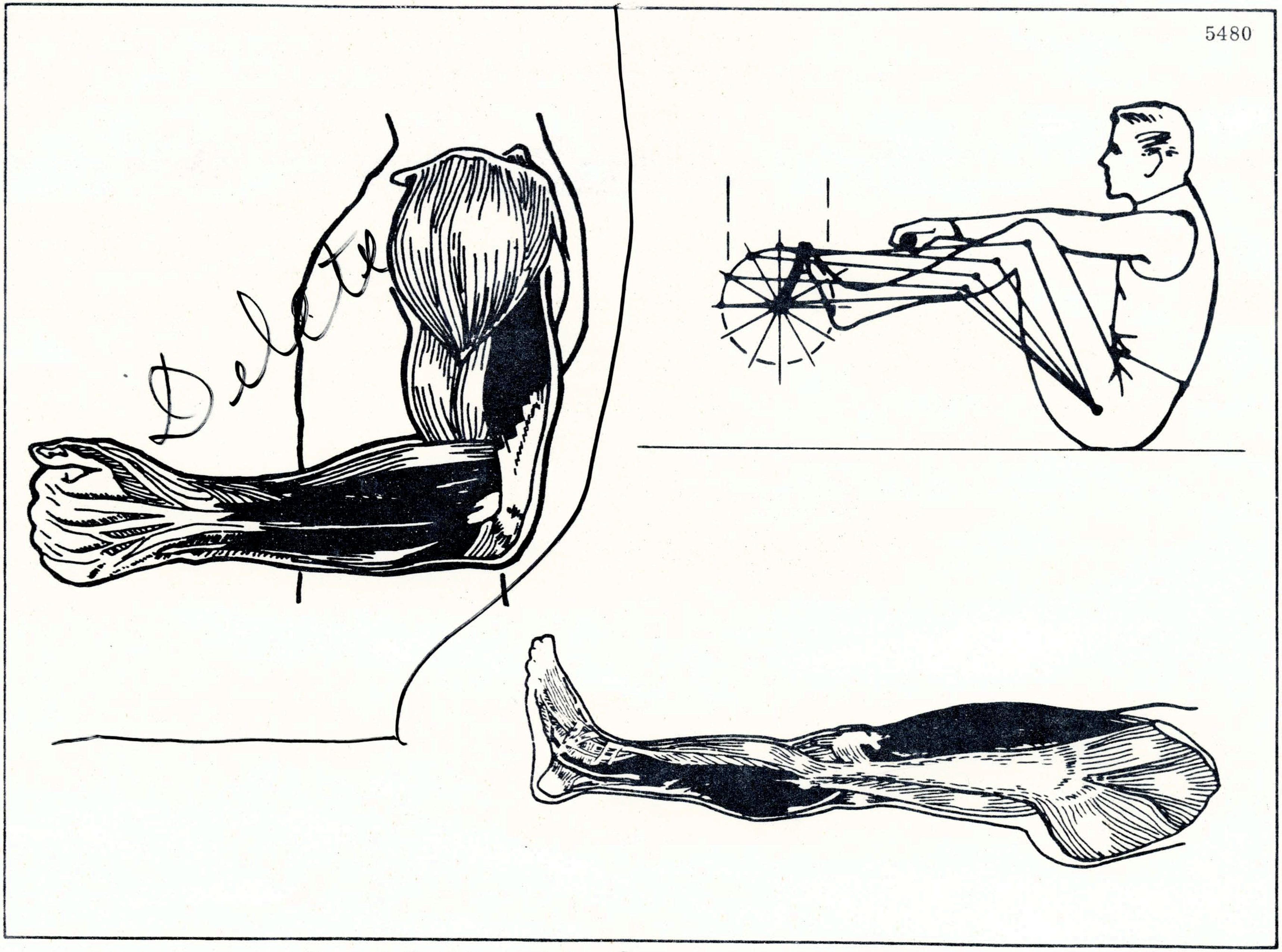
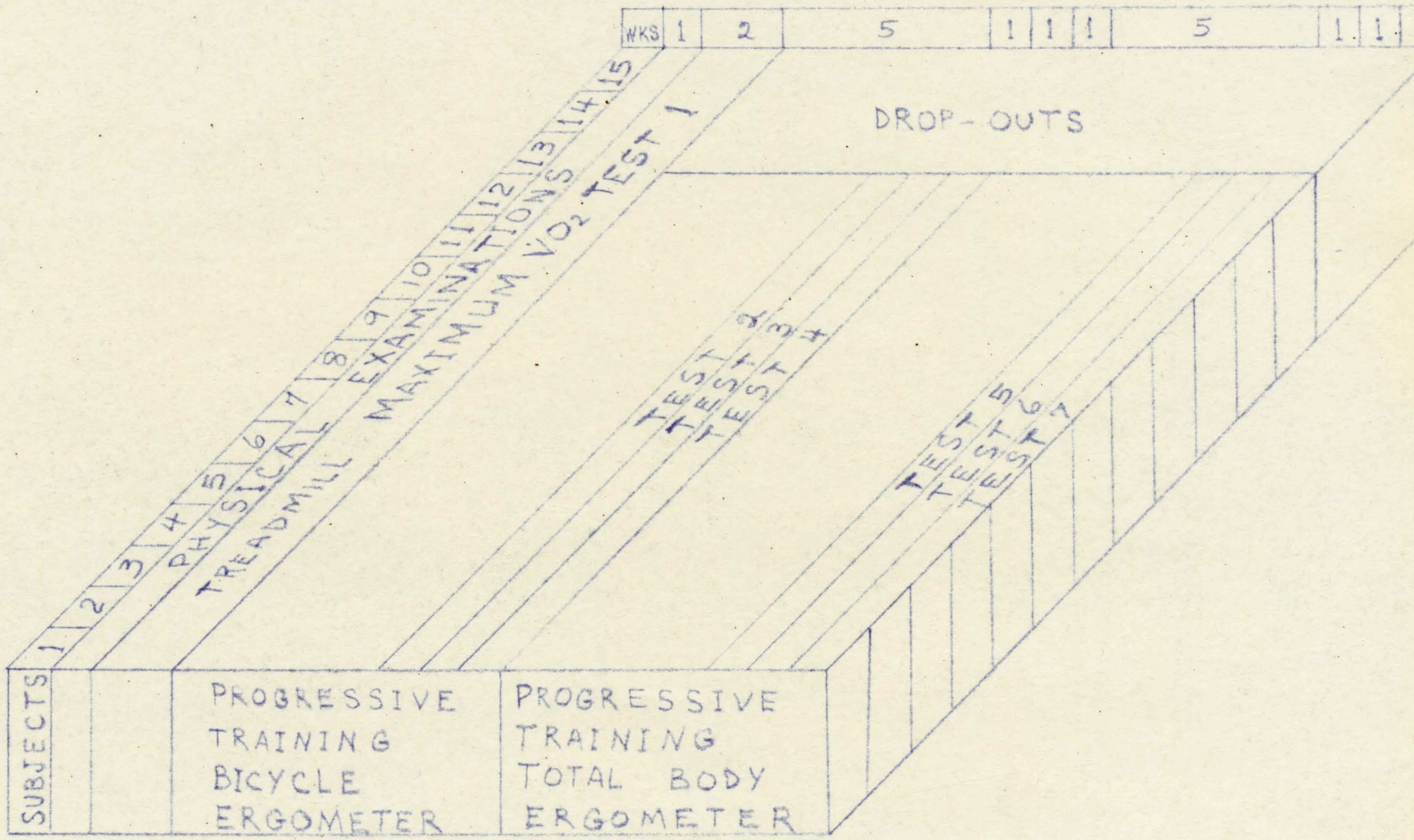


Figure 4[redacted] Cycling [redacted] with Musculature Exercised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PHYSICAL EXAMINATIONS
TREADMILL MAXIMUM VO2 TEST 1
TEST 2
TEST 3
TEST 4
TEST 5
TEST 6
TEST 7
SUBJECTS
PROGRESSIVE TRAINING BICYCLE ERGOMETER
PROGRESSIVE TRAINING TOTAL BODY ERGOMETER

Fig. 5

Mean differences will be tested by a simple analysis of variance after a Bartlett test for equal variability. If sets of data are significantly different, then specific differences will be tested. For all tests, probability will be set at less than 0.05. The central tendency and variability statistics will be the mean, the range, and the standard deviation.

Controls

The comparability of the cardiovascular and respiratory responses to exercise would be compromised without adequate environmental control. The facility for testing and training will have temperature controlled at 22 ± 0.5°C (mean and standard deviation) relative humidity controlled at 40 ± 5%, and air controlled at 0.03 ± 0.03% CO_2 and 20.93 ± 0.03% O_2.

The test for any hypothesis about oxygen consumption changes with training requires fine control over the work rate, and the volume and composition of expired air. The von Döbeln sinus balance (2) is unexcelled for accuracy, precision, calibration certainty, and constancy of torque force determinations over a wide range of angular velocities. By means of a mechanical counter, and a pacing device (like a metronome), mean work rate can be measured exactly and steady work rates can be maintained and reproduced. This permits an exact test of an hypothesis if metabolic rate also is measured exactly. In this regard, electronic analyzers are not reliable enough. In a study (Oxygen Consumption Continuously Measured During Exercise, in preparation for publication) of more than 100 experiments over a range of 900 to 3700 ml/min oxygen consumption on 21 men, the coefficient of variation from the Haldane and spirometer was 3%, yet differences in excess of 1 liter/min were found occasionally.

In more than 13 months of intensive work, several areas of systematic errors were uncovered and data reduction time still exceeded that for the Haldane and spirometer. To our knowledge, no one to date has achieved electronically the accuracy, the precision, and the data reduction time of the Haldane and spirometer although there is promise for the future. For these reasons, the Haldane, spirometer, and von Döbeln sinus balances in conjunction with an rpm counter and a pacing device are recommended.

The validity and reliability of the fitness test are critical to the experimental design. Substantial evidence indicates that treadmill running, at 7 mph at grade levels graduated in 300 ml/min $\dot{V}O_2$ steps, results in a higher (therefore more valid) crest oxygen consumption than that attained on a bicycle ergometer. The max $\dot{V}O_2$ criterion is achieved if a plateau ($P < 0.01$) or decrement in $\dot{V}O_2$ results from a subsequent work load. The procedure also requires at least 10 min of rest between work loads and no more than 4 loads per session. Under these conditions, and again assuming Haldane-spirometer analysis, the maximal oxygen consumption is considered the most reproducible metabolic rate measurement (within 5%). In addition, a test device different from each training device supports the analytical structure of the experiment which must be prepared to distinguish between neuromuscular (skill) and cardiopulmonary causes for changes in oxygen consumption as a result of training.

An increase in maximal oxygen consumption of 18.3% was found in men 44-61 years old by 12 min. of supervised bicycle ergometry 3 times a week for 11 weeks. The expectation is that max $\dot{V}O_2$ will increase a comparable amount in this study. If it does, then the initial crest loads and crest oxygen consumptions will become submaximal as the experiment goes on. Repetition of these test loads will provide the test of the major and ancillary hypotheses on oxygen consumption. Repetition, during testing periods, of the initial near maximum training loads will provide data specific to the training device, as well as data for comparisons between the training devices, and between the training devices and the test device. From prior experience on the magnitude of variance and mean differences for these parameters, the number of subjects and tests are calculated to uncover true differences with statistical significance.

Protocol Schedule

The protocol work schedule is given in Table 1.

Table I

Protocol Work Schedule

Protocol	Hours: Subjects	Prin. Invest.	Co-Invest.	Technician	Medical Superv.	Total
Physical examinations	45					45
Test 1	90	80	80	80	80	410
Bicycle ergometry training	600	200	200	200		1200
Test 2 and training	120	40	40	40	40	280
Test 3 and training	120	40	40	40	40	280
Test 4 and training	120	40	40	40	40	280
Total-body ergometry training	600	200	200	200		1200
Test 5 and training	120	40	40	40	40	280
Test 6 and training	120	40	40	40	40	280
Test 7 and training	120	40	40	40	40	280
Data analysis and writing		320	320			640
Total	2055	1040	1040	720	320	5170

References

1. Mastropaolo, J.A., et al. Validity of Phonoarteriographic Blood Pressures During Rest and Exercise. J. Appl. Physiol. 19(6): 1219-1233, 1964.

2. von Döbeln, W. A simple Bicycle Ergometer. J. Appl. Physiol. 7:222-224, 1954.