

THE ENERGY COST  
OF  
SIMULATED ROWING

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## CHAPTER I

### INTRODUCTION

Testing and training of the upper extremities has become an important concept in the rehabilitation of cardiac patients. Arm exercise provides an alternative to leg exercise as a means of testing and training individuals whose occupations and recreational activities are dominated by arm activity. Standard exercise testing and training modalities such as the treadmill, bench-step, and bicycle ergometer, require the use of the legs and are not applicable for individuals unable to perform work with the lower extremities. Numerous investigators have reported the importance of arm exercise for individuals who experience angina primarily by arm exertion, persons with intermittent claudication or orthopedic limitations, paraplegics, amputees, and others with lower extremity disabilities (Fardy, Webb, & Hellerstein, 1977; Franklin, Scherf, Pamatmat, & Rubenfire, 1982; Schwade, Blomquist, & Shapiro, 1977; Shaw, Crawford, Karliner, DiDonna, Carleton, Ross, & O'Rourke, 1974; Wahren, & Bygdeman, 1971). Therefore, alternative methods involving arm work are needed for those individuals who cannot perform work on the treadmill and standard bicycle ergometer.

The effectiveness and safety of arm exercise has also been documented in several studies. Magel, McArdle, Toner, &

Delio, (1978), Pollock, Miller, & Linnerud, (1974) and Wahren & Bygdeman, (1971) reported that the benefits derived from arm exercise were comparable to those obtained from lower extremity exercise, such as treadmill and bicycle ergometry. DeBusk, Valdez, Houston, & Haskell (1978) demonstrated that performing arm exercise was a safe and effective means of eliciting cardiac abnormalities several weeks following a myocardial infarction.

### Purpose

The purpose of this study was to determine the energy cost of three selected work loads completed on the Dyna Row-100 rowing machine. The determination of the energy cost of these work loads could then be used to establish a basis for the use of the Dyna Row-100 as an upper extremity ergometer in health as well as rehabilitation training.

### Need for Study

The increased concern for incorporating arm exercise in cardiac rehabilitation has given rise to the implementation of multi-modal or circuit-interval programs in phase II (Meyer, 1983; Porter, 1983). These types of programs had the patient exercise on six different exercise modalities. Upper extremity exercise included work on the arm ergometer, rowing machine, shoulder wheel, and wall pulley. Lower extremity exercises were done on the treadmill, bicycle



ergometer, and bench step. The stations were designed to alternate an upper extremity exercise with a lower extremity exercise in a circuit-like fashion. Each station consisted of a four minute exercise period followed by a predetermined rest period.

The most difficult problem in designing an exercise program was the prescription of the appropriate exercise intensity. Knowing the energy cost of an exercise makes the determination of the appropriate exercise intensity possible. The American College of Sports Medicine (1980) established equations for calculating the energy cost for walking, running, stepping and cycling. In 1981, Boles established the energy cost of arm cranking on the Monarch Rehab Trainer.

Most of the work in the area of simulated rowing examined the energy cost of experienced and Olympic caliber oarsmen at maximal levels (Carey, Stensland, & Hartley, 1974; Hagerman, McKirnan, & Pompet, 1975; Hagerman, Connors, Gault, Hagerman, & Polinski, 1978; Jackson, & Secher, 1976; Szogy, & Cherebetiu, 1974). With the increased use of the rowing machine in cardiac rehabilitation programs, there was a need to determine the energy cost at submaximal levels.

#### Assumptions

The following assumptions were made in this study:

1. All subjects were apparently healthy individuals.

2. Subjects were not involved in any form of competitive rowing.

#### Delimitations

1. All subjects were male college students 20 to 35 years of age attending the University of Wisconsin-La Crosse.

2. Three work loads were used for testing with all tests consisting of identical increments.

3. Subjects were tested only once.

4. Subjects were not experienced oarsmen.

#### Limitations

1. The upper extremity training that the subjects may have been doing was not controlled in this study.

#### Definition of Terms

Beckman Metabolic Measurement Cart (Beckman MMC) - a self-contained unit which includes an OM-11 oxygen analyzer sensitive to .01%, a LB-2 carbon dioxide analyzer sensitive to .01%, a flow meter sensitive to one milliliter, and a programmable calculator.

Dyna Row-100 - a hydraulic resistant rowing machine with eight possible increments in exercise intensity (see Appendix A).

Energy Cost - the amount of oxygen necessary to perform a specific rowing stage. In this study, energy costs are expressed in liters per minute, milliliters of oxygen utilized per minute per kilogram of body weight, and/or MET level (Berger, 1982).

Metabolic Equivalent (MET) - a relationship between work and resting metabolic rate of an individual. A resting metabolic unit is equal to approximately 3.5 ml  $O_2$ /kg/min (DeVries, 1980).

Rate Pressure Product (RPP) - an indirect index of myocardial oxygen consumption. The RPP is the product of heart rate multiplied by the attained systolic blood pressure.

## CHAPTER II

### REVIEW OF RELATED LITERATURE

#### Introduction

The purpose of this study was to determine the energy cost of three selected work loads completed on the Dyna Row-100 rowing machine. The determination of the energy cost provided a basis for the use of the Dyna Row-100 as an upper extremity exercise in health and rehabilitation training.

A review of the related literature revealed numerous studies pertaining to maximal oxygen consumption of experienced and Olympic caliber oarsmen. However, there was a limited amount of research in the area of submaximal rowing.

The literature reviewed was related to submaximal rowing and has been divided into five sections. The first section discussed the metabolic and cardiorespiratory responses of arm exercise compared to leg exercise at maximal and submaximal exercise intensities. The implications for the use of arm exercise as a testing and training modality in cardiac rehabilitation were discussed in the second section. The third section discussed the physiological parameters studied during simulated rowing. In the fourth section, the MET concept was discussed. Finally, the prescription of arm exercise was discussed in the fifth section.

### Arm versus Leg Exercise

The contrast of metabolic and cardiorespiratory responses in arm versus leg exercise has been the subject of many investigations. Generally, maximal physiological responses have been found to be greater in leg work than arm work. However, at a given submaximal work load, the metabolic cost has been shown to be greater in arm work than leg work (Åstrand & Saltin, 1961; Åstrand, Ekblom, Messin, Saltin, & Stenberg, 1965; Bar-Or & Zwiren, 1975; Stenberg, Åstrand, Ekblom, Doyce, & Saltin, 1967; Vokac, Bell, Bautz-Holter, & Rodahl, 1975; Vrijens, Hoekstra, Bouckaert, & Van Dytvanck, 1975).

#### Maximal Work

Åstrand and Saltin (1961) studied the maximal oxygen consumption ( $\dot{V}O_2$  max) and heart rate (HR) response during 1) cycling on a bicycle ergometer in a sitting position and 2) supine position, 3) simultaneous arm and leg exercise on bicycle ergometers, 4) treadmill running, 5) skiing, 6) swimming, and 7) arm cranking. Seven well-trained subjects (six males and one female) performed maximal work on these various types of modalities. Maximal work with the arms produced a  $\dot{V}O_2$  max that was 70% (range 69-71%) of the  $\dot{V}O_2$  max when cycling. The  $\dot{V}O_2$  max of uphill treadmill running was slightly higher (5%) than in cycling, combined arm and leg exercise, and skiing. The  $\dot{V}O_2$  max of supine cycling and swimming were

15% lower than sitting cycling (Åstrand and Saltin, 1961).

In 1965, Åstrand and associates reported similar results regarding maximal arm work. In this study, thirteen subjects (12 males and 1 female) performed maximal work with the legs and arms. It was shown that the  $\dot{V}O_2$  max during arm work was 70% of that observed during leg exercise. HR was on an average seven beats per minute lower during arm exercise and intra-arterial blood pressures (BP), as measured by catheter, were on an average 20-25 millimeters of mercury higher during maximal arm exercise. The authors suggested that the reason for the observed responses may have been that the peripheral vascular resistance was different in the two types of exercise. Vasoconstriction in the legs during arm work brought about a more pronounced elevation of peripheral resistance than did vasoconstriction in the arms during leg work. The observed differences in blood pressure may have been due to the static work developed during arm exercise.

Stenberg and associates (1967) reported that maximal arm work performed by ten subjects (6 males and 4 females) resulted in a  $\dot{V}O_2$  and cardiac output ( $\dot{Q}$ ) that was 66% and 80%, respectively, of the maximum values attained during leg work in the sitting position. However, HR was found to be higher during arm work.

In 1975, Vokac and colleagues studied the  $\dot{V}O_2$  and cardio-respiratory responses of leg and arm exercise in the sitting

and standing positions. Seven male subjects performed work while cycling, and arm cranking in the sitting position and standing position. The maximum work load achieved during arm exercise was 50-60% of that in cycling.  $\dot{V}O_2$  max was on the average 78% of the  $\dot{V}O_2$  achieved with the legs. The differences between the HR responses were insignificant.

Fardy and investigators (1977) studied the physiological responses of twenty-two high school male athletes during cycling and arm cranking. The  $\dot{V}O_2$ ,  $\dot{V}E$ , HR, systolic blood pressure (SBP) and rate-pressure product (RPP) were higher during maximal leg exercise.  $\dot{V}O_2$  max for the arms was 69% of that measured for the legs. However, when the aerobic capacity was expressed relative to extremity volume, the researchers reported a higher  $\dot{V}O_2$  max for the arms than the legs. The researchers noted that the values obtained relative to extremity volume may be subject to some question because arm ergometry also recruits muscles of the back, shoulders and chest.

#### Submaximal Work

Considerable data has documented that at a given submaximal work load, HR,  $\dot{V}O_2$ ,  $\dot{V}E$ , RER, SBP, diastolic blood pressure (DBP), and lactate production are higher during arm exercise when compared to leg exercise. Stroke volume was lower, while  $\dot{Q}$  was nearly the same in both arm exercise and leg exercise (Åstrand et al., 1967; Bobbert, 1960; Fardy

et al., 1977; Stenberg et al., 1967; and Vokac et al., 1975).

Bevegård and associates (1966) supported these findings in their comparison of the circulatory adaptations to arm, leg, and combined arm and leg exercise in six male subjects.  $\dot{V}\dot{E}$  ( $P < 0.001$ ), HR ( $P < 0.01$ ), and lactate production ( $P < 0.02$ ) were found to be significantly higher during arm exercise compared to leg and combined arm and leg exercise at the same level of oxygen uptake. SV failed to increase and was significantly lower ( $P < 0.05$ ) during arm exercise than during leg or combined arm and leg exercise. No significant difference was found between  $\dot{Q}$  and oxygen uptake during arm exercise, leg exercise and combined arm and leg exercise.

#### Arm Exercise in Cardiac Rehabilitation

Arm exercise has offered an alternative means of testing and training patients particularly for those who cannot perform leg work. In this section, the use of arm exercise as a modality for testing and training of patients has been discussed.

#### Implications for Arm Testing

In 1975, Bar-Or and Zwiren investigated the reliability and validity of arm testing by assessment of  $\dot{V}\dot{O}_2$  max. Fifty-nine males were studied, forty-one were in the test-retest group and eighteen were in the validity group.

The test-retest group performed a maximal arm test on a



modified bicycle ergometer. The work load was increased every 2 minutes by 150 kilopond meters per minute until the subject could not go any longer. The test was repeated 2 weeks later.

The validity group performed an all out arm test exactly as the test-retest group as well as a maximal treadmill test. In the test-retest group, the arm  $\dot{V}O_2$  max and arm  $\dot{V}E$  max had a high reliability, 0.94 and 0.98 respectively. The HR max was considerably lower at 0.76.

The maximum values for arm  $\dot{V}O_2$ ,  $\dot{V}E$ , and oxygen pulse in the validity group were two-thirds of the respective leg values. The predictability of maximal leg values from arm data was fair. For aerobic capacity, a correlation coefficient of 0.74 was reported (Bar-Or & Zwiren, 1975).

Lazarus, Cullinane and Thompson (1981) studied eleven male subjects with angina pectoris that was induced by both arm and leg exercise. Subjects performed two days of arm and two days of leg testing over a two week period. The investigators found the within day and between day coefficients of variation to be similar for both arm and leg testing. These results were in agreement with Bar-Or and Zwiren (1975) and confirmed that arm testing is highly reproducible.

Wahren and Bygdeman (1971) studied ten patients with a history of angina pectoris while performing arm cranking and cycling. The leg exercise was performed in the upright position on a bicycle ergometer. The same ergometer was modified for arm cranking by replacing the pedals with hand grips.

Angina was produced in all patients by both types of exercise at similar myocardial oxygen demand as measured by RPP.  $\dot{V}O_2$  at angina was slightly but significantly lower during arm work. The researchers suggested that the lower  $\dot{V}O_2$  during arm work may have been due to the limited range of oxygen uptake tolerated by the subjects used in the study.

In 1977, Schwade and colleagues studied thirty-three male patients performing arm and leg exercise of the same type as used by Wahren and Bygdeman (1971). Seventy-nine percent of the patients had identical endpoints as measured by angina, abnormal electrocardiogram, fatigue or shortness of breath with both tests. The RPP during arm and leg exercise in this group was not significantly different, which was in agreement with the findings of Wahren and Bygdeman (1971).

Shaw and associates (1974) compared treadmill exercise and arm crank ergometry using a modified bicycle ergometer with two handles fitted on a single pedal. Forty-seven patients were studied. Twenty-one patients were able to perform both arm crank and treadmill exercise, and twenty-six patients were able to perform only the arm crank exercise. The twenty-one patients able to do both modalities included seventeen with a documented myocardial infarction.

Of the twenty-one patients able to perform both tests, ten demonstrated ischemic S-T segment changes during both tests and another ten patients had negative responses to both

tests. There were no statistically significant differences between the peak HR, SBP, and RPP responses of arm-crank exercise and treadmill exercise. In the twenty-six patients unable to perform leg exercise, a lower HR and a higher peak SBP were obtained when compared to the twenty-one patients able to perform both modalities. However, the differences were not significant. When the RPP response of the twenty-six patients was compared to the RPP response of the twenty-one patients, no significant difference was found ( $22.4 \pm 1.2$  vs  $22.0 \pm 1.4 \times 10^3$ ,  $P > 0.5$ ).

#### Implications for Arm Training

The metabolic and cardiovascular responses to arm training were studied by Magill and colleagues (1978). Sixteen male college students served as subjects with nine being assigned to the training group and seven in the non-training group. The training group underwent ten weeks of interval arm training, 20 minutes per day, 3 days per week, while the non-training controls did not participate in any form of organized activity.  $\dot{V}O_2$  max was measured prior to and following the ten weeks of arm training in both groups during arm ergometry and treadmill running. Trained subjects showed significant increases ( $P < 0.01$ ) in  $\dot{V}O_2$  max,  $\dot{V}E$  max, maximal arteriovenous oxygen difference (a-v  $O_2$  diff) and maximal work capacity following arm training. Maximal values for  $\dot{Q}$ , HR, SV and RER did not change significantly. The non-training

group did not show any significant changes in any of the above measurements. Following the ten weeks of training, values for  $\dot{V}O_2$  max and the other physiological measurements were unchanged during treadmill running in both groups. The results suggested an improved cardiac efficiency following arm training and confirmed the specificity of training.

Similar conclusions were drawn by Vrijens, Hoekstra, Bouckaert, & Van Dytvanck (1975). Five paddlers in training for a national kayak squad and a control group of nine trained subjects were used in the assessment of maximal oxygen uptake and circulatory adaptations to work using legs and arms. Each subject performed two maximal tests once with the bicycle ergometer and the second with an arm ergometer. The paddlers with specific training to arm work had scores on the arm test closer to the results of a bicycle ergometer test than did the control group. The researchers concluded that arm work must be preferred for evaluating the training status of athletes when the upper extremities are used in training.

A study by Pollock and associates (1974) investigated the effects of arm training in twenty-nine sedentary men. Eight disabled men (group 1) and eleven normal men (group 2) trained by arm pedaling thirty minutes, three times a week for twenty weeks. A control group of ten men (group 3) took all tests but did not participate in any activity.  $\dot{V}O_2$  max,  $\dot{V}E$  max, and  $O_2$  pulse increased while the HR max remained unchanged in both experimental groups. Resting HR and the HR

response to a standard work task showed a significant ( $P<0.05$ ) decrease. Systolic blood pressure at the one minute recovery stage also decreased significantly ( $P<0.01$ ) in both groups following training. The control group remained unchanged in all measurements.

ECG and hemodynamic responses were studied in forty men, seven weeks post myocardial infarction, by DeBusk and colleagues (1978). The subjects performed static and dynamic work using the arms and legs. It was found that ischemic S-T segment depression was absent during static effort, while ten patients demonstrated ischemic S-T segment depression during dynamic exercise. Ventricular ectopy was significantly ( $P<0.05$ ) more common during dynamic exercise. Only three patients demonstrated ectopy during static exercise, premature ventricular contractions (PVCs) were isolated and infrequent. The data suggested that arm exercise was an appropriate exercise to include in the conditioning programs of cardiac patients.

Because of these studies and their findings, many cardiac rehabilitation programs have begun incorporating arm exercise in phase II programs (Meyer, 1983). An example of one such program was the phase II program at Gundersen Clinic, La Crosse, Wisconsin. In this program, patients exercised on six different modalities (treadmill, bicycle ergometer, stepping bench, arm ergometer, rowing machine, and shoulder wheel).

The stations were organized to alternate an upper extremity exercise with a lower extremity exercise (Porter, 1983).

### Physiological Responses to Rowing

The maximal oxygen consumption of competitive oarsmen has been studied by several investigators. Hagerman, McKirnan, and Pompert (1975) investigated the  $\dot{V}O_2$  max of five conditioned and four unconditioned former oarsmen. Maximal work was performed on a friction type rowing ergometer. The conditioned group obtained  $\dot{V}O_2$  max significantly higher ( $P < 0.01$ ) than the unconditioned group (66.2 ml/kg/min and 53.4 ml/kg/min respectively).

Hagerman and colleagues found similar results in 1978 when they measured  $\dot{V}O_2$  by open-circuit spirometry in 310 competitive oarsmen. Mean values of 67.6 ml/kg/min was reported with several outstanding oarsmen surpassing 70 ml/kg/min.

In 1974, Carey and associates compared  $\dot{V}O_2$  max of five male varsity crew members during maximal work on the treadmill and rowing ergometer. The  $\dot{V}O_2$  max of treadmill running (5.31 liters/min) was not significantly different ( $P > 0.05$ ) from rowing (5.32 liters/min). Maximal HR was significantly lower ( $P < 0.025$ ) during rowing. The authors suggested that the lower HR may have been due to a greater stroke volume secondary to a greater muscle pump utilizing both arms and legs.

### Metabolic Equivalent

Essentially all the energy expended by the body is derived from the reaction of oxygen with foods. The amount of oxygen used to perform specific work is a measure of both energy cost and heat produced from that work. The energy used for work is expressed in terms of rate of oxygen consumption or, more commonly, as metabolic rate (Berger, 1982).

Resting metabolic rate is approximately 3.5 ml O<sub>2</sub>/kg/min. The metabolic equivalent or MET is simply a number expressing the ratio of the exercise metabolic load to the resting metabolic rate (DeVries, 1980). The MET level for a given work load is calculated as follows:

$$\text{METs} = \frac{\text{ml O}_2 \text{ required for exercise} \div \text{kg body weight}}{\text{ml O}_2 \text{ required for rest} \div \text{kg body weight}}$$

Expressing the intensity of a work load in METs is a measure of oxygen consumption rather than a measure of power output (DeVries, 1980). Several researchers discussed the use of the MET as a means of prescribing the appropriate exercise intensity for healthy and diseased populations (ACSM, 1980; Amundsen, 1979; Cunningham & Rechnitzer, 1974; Pollock & Schmidt, 1979).

### Prescription of Arm Exercise

Ideally the exercise prescription should be determined from data obtained from an arm exercise test. Data should include: 1) MET level attained, 2) peak HR attained, 3) BP

response to progressive work increments, 4) rate of perceived exertion, and 5) subjective symptoms (Porter, 1983). The exercise intensity is then developed as a fraction of the  $\dot{V}O_2$  max, as described by the ACSM (1980), Amundsen (1979), and Cunningham and Rechnitzer (1974). The ACSM (1980) recommends that the exercise intensity be between 50-85% of  $\dot{V}O_2$  max. Healthy asymptomatic adults can work between 70-80% of  $\dot{V}O_2$  max, while cardiac patients may start conditioning at 40% to 60% of  $\dot{V}O_2$  max.

Obtaining data from an arm exercise test may not always be possible due to the limited number of programs that perform arm exercise testing. Therefore, data from leg tests may be used. Fardy and investigators (1977) show the relationship between percentage of HR max and percentage of  $\dot{V}O_2$  max for arms and legs at the same work loads to be nearly identical ( $r=0.96$  and  $r=0.97$  respectively). A given percentage of HR max during arm exercise results in a percentage of arm  $\dot{V}O_2$  max comparable to that of leg exercise. Because arm and leg exercise elicit differing physiological cost at a given submaximal level, a work load appropriate for leg exercise may need to be adjusted to be used for arm exercise. Franklin and associates (1982) suggest work loads 40% to 60% of those used for leg training are appropriate for arm training.

Amundsen, Takahashi, Carter, and Nielsen (1980) tested the significant difference between cardiorespiratory



responses to wall-pulley exercise and to exercise performed on the bicycle ergometer. Wall-pulley pushing, wall-pulley pulling, and cycling was performed by fifteen male subjects. Correlation coefficients and regression equations were calculated for HR, SBP, and  $\dot{V}O_2$  versus MET levels for each exercise. The comparison of mean regression lines and equations for HR versus MET levels of all three exercises revealed the slopes of the regression lines for cycling were significantly different from the slope of the line for wall-pulley exercise. There was no difference found in the slopes of the regression lines for SBP versus MET levels or  $\dot{V}O_2$  versus MET levels. The researchers concluded that MET levels provide a valuable index when prescribing exercise intensity for arm or leg work.

### Summary

Many researchers have investigated the physiological responses to arm and leg exercise and found maximal values to be greater during leg work. At a given submaximal work load, arm work required a greater physiological cost.

The use of arm ergometry as a testing modality has been shown to be highly reproducible and a satisfactory diagnostic test to detect myocardial ischemia, S-T segment displacement, and angina. As a training modality, the specificity of aerobic improvement was shown. Very little, if any, cross training occurred from arms to legs. ECG results showed no

greater prevalence of dysrhythmia during arm training than during leg training.

When prescribing exercise intensity for arm training, a fraction of max  $\dot{V}O_2$ , obtained from an arm exercise test has been used. However, when using data obtained from leg tests, it was important to note that arm and leg exercise elicit differing physiological cost at a given submaximal work load. Therefore, work loads appropriate for leg exercise may need to be adjusted by 40% to 60% for prescription of arm training.

Research regarding the physiological values for rowing at submaximal levels have not been reported while maximal values have been researched extensively. Studies have shown that highly trained and competitive oarsmen obtained maximum physiological values similar to those reported for other endurance athletes.

## CHAPTER III

### METHODS AND PROCEDURES

#### Subject Selection

Twenty male graduate and undergraduate students, 20 to 35 years old, from the University of Wisconsin-La Crosse, La Crosse, Wisconsin, volunteered for this study. All of the subjects were involved in some form of regular exercise, none were involved in competitive rowing.

#### Instrumentation

The Dyna Row-100 (M & R Industries, Inc., Redmond, WA.) rowing machine was used in this study. Calibration of the shocks was performed at the time of manufacture as shown in Appendix B. The seat was adjusted for each subject so that the legs remained in the out-stretched position throughout the entire exercise. This was done to concentrate on working the torso and upper extremities and to minimize any lower extremity involvement.

A stroke cadence of 20 strokes per minute was used. Instructions and cadence were maintained constant for each subject by use of a cassette recording telling when and how often to stroke. The tape began with the following instructions: "At the count of three, begin to stroke. One. Two.

Three. Stroke-one-two; stroke-one-two; stroke-one-two; etc.\*.

One inch increments were marked on the oar-extension bar to denote increases in work load. By raising or lowering the lever arm, which was attached to the oar-extension bar, the work load was increased or decreased respectively. The first three work loads were used in this study, work load-1 (WL-1) being the easiest, work load-2 (WL-2) more difficult, and work load-3 (WL-3) the most difficult.

The test consisted of a four minute discontinuous protocol with four minutes rest between work loads. The initial load was set at WL-1, and thereafter, increasing increments equal to WL-2 and WL-3 were applied.

#### Testing Procedures and Data Collection

On the day of the scheduled test, each subject reported to the Human Performance Laboratory at the University of Wisconsin-La Crosse, where each was given a complete explanation of the procedures of the study. The informed consent form was explained to each subject (see Appendix C). The subjects were then asked to sign and date the form. All of the subjects subsequently did so. Weight and height were recorded for each subject to the nearest pound and inch, respectively, and converted to the appropriate metric measurement. The subject was then given as much time as necessary to practice the stroke cadence before the actual testing was begun.

### Oxygen Consumption Determination

The Beckman Metabolic Measurement Cart (MMC) was used to measure the oxygen consumption during the testing. Readings were obtained every 30 seconds of the work period. A Beckman LB-2 Carbon Dioxide analyzer, sensitive to 0.01% and a Beckman OM-11 O<sub>2</sub> analyzer, sensitive to 0.01% was used to analyze the expired air. The Beckman MMC was calibrated before and after each test with a tank of known Scholandered gas and room air. Meteorological calibration of the Beckman MMC was done daily before testing using a mercury barometer and a calibrated thermometer. The barometric pressure was adjusted according to the laboratory conditions and the temperature readings were adjusted so as to be comparable with the in-unit thermometer of the MMC.

### Heart Rate

The subject was prepared for electrode placement by abrading and cleansing the skin with alcohol. A CM<sub>5</sub> bipolar lead system was used, with the electrodes being placed on the manubrium of the sternum and the right and left axillary line, along the fifth intercostal space.

Heart rates were continually monitored on the Quinton Electrocardiograph Model 621 bipolar tracing system. Minute heart rates were determined by counting the QRS complexes of a 15-second strip and multiplying by four. Electrocardiographic strips were taken prior to testing and during the

last 15-seconds of each work load.

#### Blood Pressure

Indirect arterial blood pressure (BP) recordings were measured by a standard cuff and sphygmomanometer using the brachial artery of the left upper arm. BP measurements were obtained on each subject prior to testing and immediately upon the conclusion of each work load. An attempt was made to acquire BP readings within the first twenty seconds of the rest period.

#### Ratings of Perceived Exertion (RPE)

The subject was asked to numerically rate the intensity of exertion perceived according to Borg's scale (1973) during the last thirty seconds of each work load (see Appendix D). Prior to testing, the subject was given a verbal explanation on how the scale would be used. It stated:

"As you can see, the number system ranges from 6 to 20; 6 being the way you would feel sitting in a chair doing nothing, and 20 would indicate absolute arm fatigue, that point at which you could not perform another stroke.

During the last thirty seconds of each work load, I will gradually lower my finger down the numbers. Once I reach the number that best describes the intensity of work you are experiencing, I want you to shake your head.

Because the work is being done by your arms and torso, it is important to indicate the number which best describes the intensity and fatigue of the arms and torso only.

Are there any questions before we get started?"

### Initiation of the Test

After the subject had been seated on the rowing machine, a headgear apparatus supporting a Rudolph valve (no. 2700) was placed on the subject. Corrugated tubing was used to connect the valve to the gas collection unit of the Beckman MMC (see Appendix E).

Each subject was asked to give his best effort and continue until the completion of each work load. However, the subject was instructed to stop immediately if at any time he felt it unsafe to continue. Any final questions the subject had were then answered by the researcher. At this time, the test was ready to begin.

### Data Analysis

During each work load, oxygen consumption expressed as L/min and ml/kg/min was measured every 30 seconds directly from the Beckman MMC and recorded onto the data sheet (see Appendix F). Means and standard deviations were calculated for all the subjects at each work load. The means were then converted to MET values.

## CHAPTER IV

### RESULTS AND DISCUSSION

#### Introduction

Using the Dyna Row-100, the energy cost ( $\dot{V}O_2$ ) of three selected work loads was determined. Means and standard deviations were calculated for all the subjects at each work load. Means were then converted to MET values. The purpose of this chapter was to present the results and to discuss the pertinent findings regarding work performed on the Dyna Row-100.

#### Results

##### Subjects

Twenty male graduate and undergraduate college students from the University of Wisconsin-La Crosse participated in this study. The physical characteristics of the subjects were presented in Table I. Appendix G contained the individual data of all subjects.

Each subject performed a four minute discontinuous protocol with four minutes rest between work loads on the Dyna Row-100 rowing machine. The protocol contained three work loads of increasing intensity, WL-1, WL-2, and WL-3.



### Oxygen Uptake (ml/kg/min)

Mean oxygen uptake (ml/kg/min) values for each work load were presented in Table 2. Individual subject's data were listed in Appendix H. The results indicated a gradual, progressive increase in  $\dot{V}O_2$  with increasing work loads. Mean  $\dot{V}O_2$  values in this study were 10.4, 14.5, and 20.0 ml/kg/min, respectively, for the three selected work loads.

Table 1

Subject Characteristics for Age, Weight, and Height (n=20)

Variable	Mean	SD	Range
Age (yr)	27.7	3.8	23 - 35
Weight (kg)	74.7	9.1	63.5 - 93.4
Height (cm)	176.5	6.7	167.6 - 185.4

Table 2

Means and Standard Deviations of  
 $\dot{V}O_2$  (ml/kg/min) and MET Levels

Workload	ml/kg/min	SD	MET	SD
WL-1	10.4	2.1	3.0	.6
WL-2	14.5	3.0	4.1	.9
WL-3	20.0	3.8	5.7	1.0

### MET Level

MET level values for each work load were presented in Table 2. Individual subject's data were listed in Appendix H. As noted in Table 2, there was approximately a 1.0 MET increase per increasing work load. The work loads in the present study indicated a suitable testing and training protocol for individuals in rehabilitation programs because of the gradual increase from one work load to another.

### Discussion

Fardy and associates (1977) reported the relationship between percentage of HR max and percentage of  $\dot{V}O_2$  max for both arm and leg exercise compared at the same energy cost to be almost identical, .96 and .97, respectively. In a study by Amundsen and colleagues (1980), the brachial SBP and myocardial oxygen cost ( $M\dot{V}O_2$ ), as calculated by RPP, were reported to be greater at a given external work load but not at comparable oxygen uptake levels. The regression lines for SBP versus MET levels and  $M\dot{V}O_2$  versus MET levels were not significantly different.

The high correlations between energy cost, or MET level, and HR, SBP, or  $M\dot{V}O_2$  indicate that MET levels provide a valuable index for measuring the intensity of arm or leg work. The MET values obtained in this study for rowing exercise should be beneficial in the planning of arm endurance exercise for patients with ischemic heart disease.

The MET values obtained in the present study may indicate a suitable testing and training protocol for individuals in rehabilitation programs because of the gradual increase from one work load to the next. The American College of Sports Medicine (1980) supports this type of progression and recommends increases of approximately 1.0 MET during a graded exercise test (GXT).

In 1982 Bennett studied the relationship between RPE and MET levels during four graded exercise tests (GXTs) in early outpatient (phase II) cardiac rehabilitation. A low level GXT ( $T_1$ ) was given on the day prior to patient discharge from the hospital. Functional GXTs were conducted two ( $T_2$ ) and four ( $T_3$ ) weeks post-discharge. At eight weeks post-discharge, or at completion of the phase II program, a symptom-limited maximum GXT ( $T_4$ ) was completed. Bennett (1982) reported mean MET values of 2.77 for  $T_1$ , 3.67 for  $T_2$ , 4.75 for  $T_3$  and 7.25 for  $T_4$ . These results indicated that the MET levels obtained in this study were appropriate for phase II rehabilitation.

Porter (1983) describes in detail the MET method used for exercise prescription by the phase II program at Gundersen Clinic, La Crosse, Wisconsin. In this program, the patient begins phase II at the same intensity level attained during the final stage of phase I. The exercise intensity is increased in a stair step fashion with a 1.0 MET increase

occurring every two weeks over the subsequent eight to twelve week period. Ideally the goal of the program is to have the patient at an exercise intensity between 60% and 70% of the subsequently determined symptom-limited maximal MET capacity. The advantage of having the patient attain that level of intensity at the end of phase II is that the patient can then begin phase III at an exercise intensity capable of eliciting the conditioning response as described by the ACSM (1980).

Boles (1981) determined the energy cost of five selected work loads using the Monarch Rehab Trainer. The MET increments obtained in this study compared favorably with those established by Boles (1981) using a four minute discontinuous protocol. The MET value for WL-1 was similar to 90 kpm, WL-2 was similar to 180 kpm, and WL-3 was similar to 360 kpm. MET values were 3.0 compared to 3.09, 4.1 compared to 3.93, and 5.7 compared to 5.76 respectively.

## CHAPTER V

### SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

#### Summary

The purpose of this study was to determine the energy cost of three selected work loads performed on the Dyna Row-100. The determination of the energy cost of these work loads could be used to establish a basis for the use of the Dyna Row-100 as an upper extremity ergometer in health as well as rehabilitation training. Variables studied included ml/kg/min and MET level.

Twenty male graduate and undergraduate college students from the University of Wisconsin-La Crosse volunteered to participate in the study. The subjects performed a four minute discontinuous protocol with four minutes rest between work loads on the rowing machine. The protocol contained three work loads of increasing intensities, WL-1, WL-2, and WL-3.

Determination of oxygen consumption was made with a Beckman Metabolic Measurement Cart. Expired air was analyzed by a Beckman LB-2 carbon dioxide analyzer and a Beckman OM-11 oxygen analyzer. Heart rate was recorded during the last fifteen seconds of each work load. Indirect blood pressure was obtained by a standard cuff and sphygmomanometer

immediately upon the conclusion of each work. The Borg scale (1973) was used to rate perceived exertion. The HR, BP, and RPE data obtained was used in a separate study by another researcher. Means and standard deviations were calculated for each subject at each work load. Means were then converted to METS.

### Conclusions

The determination of the energy cost ( $\dot{V}O_2$ ) of the three selected work loads was completed in this study using the Dyna Row-100. The results revealed a gradual and progressive increase in  $\dot{V}O_2$  with increasing work loads. MET values for the male subjects were calculated for each work load with approximately a 1.0 MET increase reported per work load increase.

### Practical Implications of the Results

The MET values obtained in this study should be valuable in the planning of arm endurance exercise for patients with ischemic heart disease. The MET values indicated a suitable testing and training protocol for male individuals in rehabilitation programs using the Dyna Row-100 because of the moderate levels and gradual increase in intensity. These MET values were appropriate for phase II cardiac rehabilitation.

### Recommendations for Further Study

The following are recommended as areas needing further investigation:

1. Conduct a similar investigation using a higher stroke cadence.
2. Conduct a similar investigation using a cardiac population.
3. Determine the energy cost ( $\dot{V}O_2$ ) of rowing on the Dyna Row-100 with the legs involved in the exercise.
4. Conduct a similar study using a discontinuous protocol until  $\dot{V}O_2$  max has been attained.
5. Conduct a similar investigation comparing  $\dot{V}O_2$  and hemodynamic responses to lower extremity exercise.
6. Conduct a similar investigation comparing the energy cost ( $\dot{V}O_2$ ) of males and females.
7. Conduct a similar investigation and establish the reliability and validity of the Dyna Row-100 as a testing and training modality.

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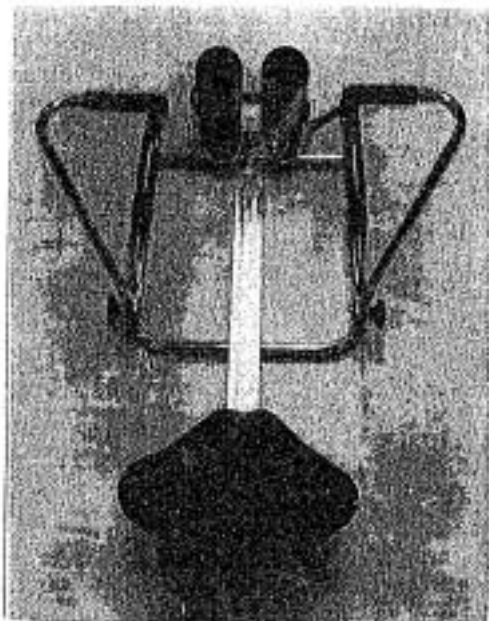


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APPENDIX A  
DYNA ROW-100



DYNA ROW-100\*

\* (M&R Industries, Inc., Redmond, WA.)

APPENDIX B

CALIBRATION OF THE DYNA ROW-100

# Procedure for Calibrating the Dyna Row-100

Viscous Damping -  $F = C\dot{X}$

$F$  = Force ( $\text{lb}_f$ )

$\dot{X}$  = Velocity ( $\text{in/sec}$ )

$C$  = Damping coefficient ( $\text{lb}_f\text{-sec/in}$ )

Step 1: Shocks were hung vertically with a known weight attached to the piston arm.

Step 2: The weight was released to allow the shock to extend to its full length (stroke = 13.00"). The elapsed time for the full stroke was measured and recorded.

Step 3: Velocity was then computed ( $13 \text{ in}/\Delta T$ )

Step 4: Once data was collected the damping coefficient was calculated.  $C_{\text{ave.}} = \frac{\Delta F}{\Delta V}$

Example:

Shock	37 lb	50 lb	70 lb
#1	38.5 s (.34 in/sec)	23 s (.57 in/sec)	15 s (.87 in/sec)
#2	42 s (.31 in/sec)	23 s (.57 in/sec)	16 s (.81 in/sec)

APPENDIX C  
INFORMED CONSENT FORM



## INFORMED CONSENT

Project Titles: Energy costs of simulated rowing with college women.

Energy costs of simulated rowing with college men.

Relationship of the psychophysiological responses to MET levels for prescriptive purposes while rowing in college-aged students.

Principal Investigators: Joseph Roethle  
Mary Danken  
Cathy Walentiny

I, \_\_\_\_\_, being of sound mind and \_\_\_\_\_ years of age, do hereby consent to authorize and request the persons named above to administer to me a rowing test. I understand that this test is designed to measure heart rate, blood pressure, amount of oxygen intake, and perceived exertion while I perform the exercise on a rowing device. Throughout the test I will have on head gear supporting a mouth piece in my mouth, and three (3) adhesive electrodes on my chest. There will be three different workloads at which I will perform. In the case that abnormal EKG responses or adverse subjective responses are observed by the investigators, the test will be terminated. I am also aware that I may withdraw from this study at any time.

I understand that I will have my heart rate measured by means of an electrocardiogram and that no other use of this reading will be made. I have no cardiovascular problems or limitations that I am aware of that would limit my participation in this study.

I hereby acknowledge that no guarantees or assurances of any kind pertaining to the test have been made to me. The information obtained from this test will be used for Masters theses; all data will be reported without reference to my identity. I have read the foregoing and understand it. All questions that I have asked have been answered to my satisfaction.

Signed: \_\_\_\_\_ on this date \_\_\_\_\_.

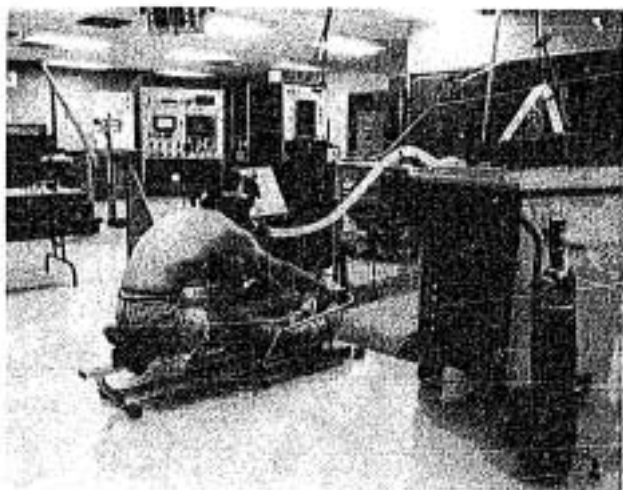
Witnessed by: \_\_\_\_\_ on this date \_\_\_\_\_.

APPENDIX D  
RATINGS OF PERCEIVED EXERTION

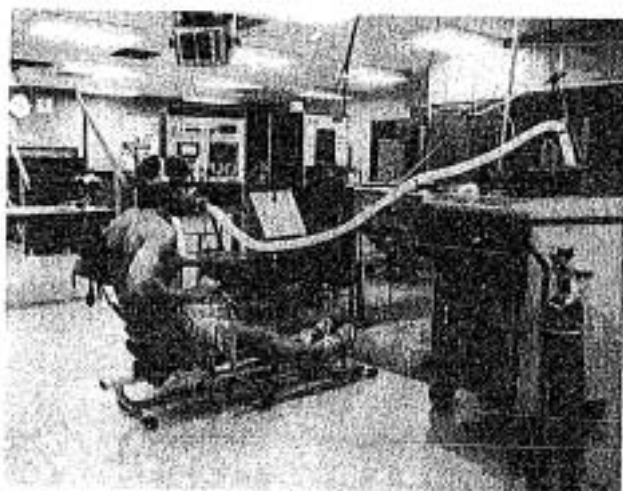
The BORG Scale for Ratings of  
Perceived Exertion

- 6
- 7 Very, very light
- 8
- 9 Very light
- 10
- 11 Fairly light
- 12
- 13 Somewhat hard
- 14
- 15 Hard
- 16
- 17 Very hard
- 18
- 19 Very, very hard
- 20

APPENDIX E  
EQUIPMENT SET-UP



Beginning of Stroke



Completion of Stroke

APPENDIX F  
DATA SHEET

[illegible]

APPENDIX G  
SUBJECT CHARACTERISTICS



## Individual Data for 20 Male Subjects

Subjects	Age (yrs)	Weight (kg)	Height (cm)
1	28	68.9	172.7
2	24	78.9	182.9
3	27	81.1	182.9
4	28	68.5	172.7
5	23	70.3	167.6
6	24	88.9	180.3
7	29	70.7	180.3
8	35	73.4	170.2
9	23	63.5	167.6
10	24	87.1	185.4
11	28	72.6	167.6
12	31	76.2	180.3
13	28	76.2	182.9
14	32	74.4	180.3
15	30	65.7	167.6
16	31	63.9	172.7
17	35	63.9	172.7
18	24	88.8	185.4
19	23	66.6	172.7
20	26	93.4	185.4
Mean	27.7	74.7	176.5
$\pm$ SD	3.8	9.1	6.7

APPENDIX H  
SUBJECT DATA

## Oxygen Uptake for 20 Male Subjects

Expressed in ml/kg/min

Subjects	WL-1	WL-2	WL-3
1	11.7	15.8	25.2
2	10.9	13.2	17.9
3	10.1	14.4	20.8
4	9.8	12.2	17.2
5	13.7	18.1	24.2
6	11.5	15.1	18.6
7	12.5	17.1	20.0
8	8.5	12.6	18.3
9	9.5	17.2	24.8
10	9.2	11.1	14.5
11	7.7	10.8	17.3
12	7.7	12.3	17.1
13	9.6	15.0	20.8
14	12.1	16.8	24.2
15	11.4	14.9	23.0
16	14.5	19.9	25.7
17	13.0	20.1	23.4
18	8.1	11.0	15.0
19	9.0	11.3	17.2
20	7.6	10.5	14.2
Mean	10.4	14.5	20.0
$\pm$ SD	2.0	3.0	3.8

Oxygen Uptake for 20 Male Subjects  
Expressed in METs

Subjects	WL-1	WL-2	WL-3
1	3.0	4.5	7.2
2	3.1	3.8	5.1
3	2.9	4.1	5.9
4	2.8	3.5	4.9
5	3.9	5.2	6.9
6	3.3	4.3	5.3
7	3.6	4.9	5.7
8	2.4	3.6	5.2
9	2.7	4.9	7.1
10	2.6	3.2	4.1
11	2.2	3.1	4.9
12	2.2	3.6	4.9
13	2.8	4.3	5.9
14	3.5	4.8	7.0
15	3.3	4.2	6.6
16	4.1	5.7	7.4
17	3.7	5.8	6.7
18	2.3	3.1	4.3
19	2.6	3.2	4.9
20	2.2	3.0	4.1
Mean	3.0	4.1	5.7
$\pm$ SD	.6	.9	1.0