To the Graduate Council:

I am submitting herewith a thesis written by Jason Patrick Crum entitled "Energy Cost of using Hydroforce Equipment and a comparison of heart rate and subjective responses to land cycling." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Human Performance and Sport Studies.

David R. Bassett, Jr.

David R. Bassett, Jr., Major Professor

We have read this thesis
and recommend its acceptance:

Edward T. Howley

Accepted for the Council:

Associate Vice Chancellor
and Dean of the Graduate School

Energy cost of using Hydroforce Equipment and a comparison of heart rate and subjective responses to land cycling

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Jason Patrick Crum
May 1997

DEDICATION

This thesis is dedicated to my girlfriend,

Trina Topper,

and to my beloved daugther,

Hayley Alyssa Crum,

who have given me love, support, and the will to succeed when

things were always going in the right direction.

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ABSTRACT

This study determined the energy cost of exercising on the Hydroforce Cycle and Slider and compared heart rate (HR) and subjective ratings of perceived exertion (RPE) during stationary cycling in water and on land at the same oxygen consumption (VO_2). Ten trained cyclists ($VO_2max \geq 50$ ml/kg/min) participated in this study. Eight of the ten subjects participated in the energy cost of the Hydroforce Cycle, Slider, and comparison portion of the study. To determine the energy cost of each piece of equipment, 2 subjects rode at each of the selected cadences and throughout the range of selected levels. Open circuit spirometry was used to determine caloric cost. The physiological and subjective parameters measured included: HR, respiratory exchange ratio (RER), minute ventilation (VE), VO_2, and RPE. The VO_2 elicited by the available range of levels on the Hydroforce Cycle and Slider were 0.87 L/min - 2.38 L/min and 0.82 L/min - 2.09 L/min, respectively. Eight subjects were then asked to ride at 65 rpm on level 3 of the Hydroforce Cycle. On a separate day they rode a Monark cycle ergometer on land at 65 rpm and at a resistance that would elicit the same VO_2 again using the open circuit spirometry technique for gas collection and analysis. HR and RPE responses measured during stationary cycling in water were compared to those on land and showed no significant difference for either variable. It was concluded that exercise on the Hydroforce Equipment elicits an energy expenditure between 235-700 kcals/hr and may be performed by people of both high and low fitness levels. It was also concluded that

stationary cycling in water and on land elicit similar physiological and subjective responses.

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CHAPTER 1

INTRODUCTION

Recently, the American Heart Association named physical inactivity as one of the top four risk factors for development of cardiovascular disease. There is no question that regular physical activity is an important factor in reducing the incidence of cardiovascular disease, obesity, and other diseases that impair a healthy and happy lifestyle. Since regular exercise is such an important part of daily life, the American College of Sports Medicine (ACSM), in their Guidelines for Exercise Testing and Prescription (1995), devised a list of established benefits of regular physical activity which includes; improved cardiorespiratory function and reduced risk factors for coronary artery disease (Arroll and Beaglehole, 1992; Heath et al., 1983; Saris, 1993; Armstrong, 1991), peripheral vascular disease (Ernst and Matrai, 1987), and cancer (Frisch et al., 1987; Severson et al., 1989), decreased mortality and morbidity (Paffenbarger et al., 1986), decreased anxiety and depression (Martinsen at al., 1989), improved immunity (Nehlsen-Cannarella et al., 1991), enhanced feelings of well-being and confidence (Stevenson et al., 1988), and improved work, recreational, and sport performance (Minor et al., 1989; Rikli and Edwards, 1991). In order to attain these benefits, ACSM (1995) states that exercise must be performed according to established exercise guidelines. For the general population, ACSM recommends exercise be performed at 60-90% of HR max, or 50-85% of HR reserve, for 20-60 minutes per exercise session, and for 3-5 days per week. For sedentary or older populations, ACSM recommends exercise be prescribed at 50-70% of HR reserve, for 2-3 10 minute bouts, 3 days per week. Health benefits have also been reported for those exercising at intensities as low as 40-60% of HR max.

As more and more people become aware of the importance of exercise, the demand for new equipment also grows. Considerable research has been conducted to compare oxygen uptake and other physiological responses, such as heart rate and perception of effort, of individuals during exercise on different types of aerobic exercise equipment. As companies develop new types of exercise equipment, they frequently claim that their users will gain the benefits of regular aerobic exercise, lose more weight, and feel better than with any other device. Therefore, there is a need to evaluate new equipment on the market in order to present reliable data to the consumer concerning safety, benefits, and possible risks with its use. The majority of studies evaluating different pieces of equipment concentrate on energy expenditure, physiological responses, and perception of effort. The Hydroforce Corporation has taken two traditional land-based exercises, stationary cycling and simulated cross country skiing, and adapted them to the water in an effort to accommodate the population who is unable to perform weight-bearing activities. This company contends that because water has different properties than air, populations who are unable to exercise effectively on land may be able to benefit from the bouyancy, resistance, and cooling effect that water provides. Because this equipment is new and not yet on the market, the engineers of Hydroforce requested physiological data be collected so that comparisons could be made to other pieces of exercise equipment. This lead us to the purposes of this study which were: 1) to determine the metabolic cost of exercising on the Hydroforce Slider and Cycle; and 2) to compare the heart rate and perceived exertion responses on land and in water while riding a stationary cycle at the same VO_2.

Definition of Terms and Abbreviations

ATPS - the ambient temperature, pressure, and humidity of the testing environment.

Carbon dioxide production (VCO_2) - volume of expired carbon dioxide expressed in L/min under STPD conditions.

Cardiovascular Fitness - ability of the cardiorespiratory system to take in, and deliver adequate amounts of oxygen to the working muscles, allowing them to perform activity over time.

Energy - the capacity to do work, typically expressed in kilocalories.

Heart Rate (HR) - number of ventricular contractions per minute expressed in beats/min.

Kilocalorie (kcal) - amount of heat required to raise one kilogram of water one degree Celsius.

Peak Heart Rate (peak HR) - the maximum number of heart beats per minute attained during a maximal effort exercise test.

Peak Oxygen Consumption (VO_2 peak) - Maximal amount of oxygen that one can take in and deliver to working muscles during dynamic exercise involving a large muscle mass; expressed in either absolute terms (L/min) or relative to the subject's body mass (ml/kg/min).

Metabolic Equivalent (MET) - a systematic method of expressing the rate of energy expenditure in reference to resting conditions, where 1 MET = 3.5 ml/kg/min.

Minute Ventilation (VE) - the volume of expired air expressed in liters per minute under BTPS conditions.

Oxygen Consumption (VO_2) - amount of oxygen consumed per minute expressed in absolute terms (L/min) or relative to body weight (ml/kg/min) under STPD conditions.

Power - product of force and velocity - frequently referred to as "work rate" and typically expressed in watts.

Rating of Perceived Exertion (RPE) - subjective rating determined by the subject's perception of effort while performing work and relating that to the Borg's 6-20 scale of Perceived Exertion.

Respiratory Exchange Ratio (RER) - the ratio of carbon dioxide produced to oxygen consumed (VCO_2/VO_2). Considered an indicator of maximal effort when this reaches 1.1 or greater.

Steady State - when physiological responses to a constant work rate reach equilibrium allowing the body to perform that work over time.

Standard Temperature Pressure Dry (STPD) - The value used to standardize a volume of air using a barometric pressure of 760 mmHg, a temperature of 0 degrees Celsius, and 0% relative humidity.

Hypotheses

1. There will be a significant rise in VO_2 over rest while riding the Hydroforce Cycle. This increase will be dependent on speed of pedaling and resistance setting.
2. There will be a significant rise in VO_2 over rest while exercising on the Hydroforce Slider. This increase will be dependent on frequency of sliding and resistance setting.
3. Exercise on the Hydroforce Cycle will elicit significantly lower HR and RPE responses than that on the Monark cycle ergometer on land at the same VO_2.

Significance

The results of this study may have practical applications for those people who choose to use the Hydroforce equipment in their exercise regimen. It is hypothesized that exercise on the Hydroforce Cycle in water will elicit lower HR and RPE responses than stationary cycling on land. If this is proven to be true, exercise target heart rates based on land exercise may overestimate the metabolic cost of using the Hydroforce cycle in water. This finding may also have a significant impact on exercise prescription for patients with cardiovascular disease.

CHAPTER 2

REVIEW OF LITERATURE

The review of related literature is divided into several parts including: studies involving simulated cross-country skiing, comparison of physiological responses to land and water exercise, water exercise and its beneficial effects on the health of special populations, and the use of ratings of perceived exertion. These topics and related issues are presented below.

Skiing Studies

Several researchers have evaluated the energy cost and physiological responses to simulated cross-country skiing machines, or similar devices, on land. Weiland (1990) looked at VO_2, HR, VE, energy expenditure, RER, and RPE during cross country skiing at 3 different speeds on a Nordic Track simulated skier. As expected, all responses increased significantly as speed increased. Goss et al. (1989) evaluated the aerobic metabolic requirements of simulated cross country skiing on the Nordic Track. Oxygen consumption ranged from 21.6 ml/kg/min at 40 cycles per minute to 44.4 ml/kg/min at 60 cycles per minute, therefore, VO_2 increased significantly as the frequency of limb movement increased. These values corresponded to an energy expenditure of 7.43 kcal/min for leisure skiing and 16.85 kcal/min for maximal resistive skiing for an individual weighing 75.7 kg, which was the mean body weight of these subjects. Bowes (1986) also assessed the metabolic cost of simulated cross-country skiing using the

Nordic Track and found that caloric expenditure was dependent on body weight. Based on a linear regression equation for combined activity using frequency of limb movement and leg resistance the energy cost increased by 0.09 kcal/kg of body weight. In summary, simulated cross-country skiing has been found to be an excellent form of exercise for cardiovascular training and weight loss.

Comparison of Responses to Different Land-Based Modes of Exercise

Howley (1990) compared heart rate and RPE responses to graded exercise on a Monark cycle ergometer, Nordic Track, StairMaster 4000, Concept II rower, and the treadmill. Results showed that by working at the same %VO_2 max, relative heart rate on each piece of equipment was the same. When adjusted for individual differences in relative VO_2 max the RPE increased at a significantly higher rate on the Nordic Track than on any other types of exercise, however, at a range of recommended exercise intensities, 60-70% of VO_2 max, RPE scores for the Nordic Track fell in line with the other pieces of equipment. Thomas et al. (1995) compared cardiovascular and perceived exertion responses to steady state exercise during treadmill jogging, stationary skiing, shuffle skiing, stepping, stationary cycling, and stationary rowing. Each subject performed 20-minutes of exercise at a constant RPE of 14, followed by a second exercise bout at 60% of mode specific VO_2 peak on each piece of equipment. Subjects were able to work at a higher intensity during jogging to achieve a 14-RPE. VO_2 and HR were both significantly higher during jogging to achieve a 14-RPE, however, RER means were not significantly different between exercise modes. On the basis of this finding, jogging may be interpreted as being more beneficial than the other exercise modes in terms of energy expenditure, however, it has been demonstrated that each of the modes tested in this study is capable of eliciting appropriate cardiovascular responses to exercise consistent with what is used for a training effect.

Thomas et al. (1989) compared energy expenditure and substrate utilization during 60 minutes of steady state exercise at 65% of maximal HR while stationary cycling, rowing, simulated cross country skiing, and treadmill walking. No statistical difference was observed in VO_2, RER, total energy expenditure, or fat energy expenditure between modes. Allen and Goldberg (1986) found that VO_2 was greater on the Nordic Track at two different submaximal heart rates and during maximal effort when compared to rowing and cycling. The simulated skiing elicited a higher VO_2 for a given HR; it was therefore concluded that the Nordic Track allowed for a greater cardiorespiratory workout than cycling or rowing. McMillan et al. (1992) compared perceived exertion and metabolic responses during treadmill walking, stepping, stationary cycling, and low sit cycling. No significant differences were found between these modes of exercise. Bryant et al. (1992) observed a similar VO_2 at a heart rate of 140 beats/min for rowing, cycling, cycling with combined arm and leg work, walking, jogging, and stepping. The VO_2 to HR relationship was significantly lower during arm cycling, therefore, it was concluded that for moderate intensities, exercises using a large muscle mass elicit a similar energy cost. Katz et al. (1986) looked at the incidence of angina pectoris during cycling and treadmill exercise performed at 70-85% of HR max based on max time to anginal onset. It was found that after 850 total sessions for each exercise, anginal incidence was significantly greater during treadmill exercise as compared to cycling, 90 versus 35 episodes, respectively.

Circulatory Responses to Water Immersion and Exercise

Water temperature and pressure affects the circulatory responses of the human body by redistributing blood flow and allowing for a greater venous return, thus allowing for a lower or similar HR because of a greater preload of the heart at the same intensity. Hanna et al. (1993) studied the effects of exercise during upright cycling in 31 °C water in men with an old myocardial infarction. It was found that at rest, cardiac output and stroke volume were elevated over that on land, however, during exercise, heart rate, cardiac output, and stroke volume were not significantly different between land and water. When subjects were given beta-blocking medications and subjects with exercise induced ST-segment depression were excluded from analysis, water immersion still did not significantly change exercise responses. The results suggest that those with a history of myocardial infarctions have an altered cardiac response to increased preload during exercise.

Gleim and Nicholas (1989) studied the effect of water depth and temperature on the linear HR and VO_2 relationship during treadmill walking/jogging. At speeds $\geq$ 53.6 m/min, VO_2 and HR were significantly higher in water at ankle depth, below knee, midthigh, and waist depth, however, at speeds ≥ 134.1 m/min, the oxygen cost of jogging at waist depth was not significantly different from that on land. The rate of increase of HR compared to VO_2 in waist depth water was significantly greater at 30.5°C than for treadmill walking, and greater at 36.1°C than 30.5°C. It was therefore concluded that the temperature of the water affects the HR versus VO_2 relationship in waist depth water, but not in the shallower depths tested. Choukroun and Varene (1990) looked at the effect of water temperature (25°C, 34°C, and 40°C) during head-out immersion on respiratory gas exchange. Several conclusions were made: (1) Immersion in 25°C had no significant effect on cardiac output compared to that of 34°C, however, cardiac output was significantly greater when immersed in 40°C over that of 34°C; (2) Only in 25°C water was VO_2 increased significantly over that measured at the other water temperature values; (3) Arterial blood gases were not affected by water temperature; and (4) Oxygen transport during water immersion was affected by hydrostatic pressure and water temperature as determined by cardiac output and oxygen extraction of the tissue.

Christie et al. (1990) assessed the effect of redistribution of blood volume with water immersion on cardiovascular responses to graded dynamic exercise on an upright cycle ergometer. Systolic blood pressure was not significantly different during exercise on land or in water, however, HR was significantly lower in water during the two highest work intensities. This suggests that the factors affecting cardiac preload are greater during water than on land. McMurrary et al. (1988a) looked at the cardiovascular responses of pregnant women during aerobic exercise in water at 60% of VO_2 max in

30 °C water during their 15th, 25th, and 35th week of pregnancy. Immersion lowered the resting HR by ~ 8 beats/min and exercise in water also resulted in a significantly lower HR at the same VO_2, none of which were affected by duration of pregnancy. The researchers suggested that due to the altered responses in water, land-derived exercise target HR should not be used to prescribe exercise intensity for pregnant women in water. Since the difference between HR in water and on land is known, it is possible to adjust the target HR based on this information.

Land versus Water Exercise

A number of researchers have attempted to compare the effects of land exercises with similar types of exercise in the water. Cassady and Nielsen (1992) compared acute cardiorespiratory responses (VO_2 and HR) during land and water calisthenics. Both forms of exercise showed linear increases in VO_2 and HR with increasing cadence. Exercise in the water elicited a higher VO_2, however, the relative exercise intensity, expressed as a percent of age-predicted maximal heart rate, was higher for the land exercise. It was also found that the water calisthenics elicited a lower average heart rate of approximately 20 beats per minute at a given submaximal VO_2. Coad et al. (1987) found similar results when comparing walking and running on land and in the water. Walking at 80.4 m/min elicited a VO_2 in water 110% higher than walking on land at the same speed, and only a 23% lower VO_2 than both running on land and water at 160.8 m/min. Water running versus land running, at the same speed (160.8 m/min), showed no statistical differences in VO_2 or HR. These researchers found that water walking uses the same mechanical movements against water resistance and provides an excellent cardiovascular stimulus.

Craig and Dvorak (1969) compared VO_2, VE, HR, and body temperature during exercise on a cycle ergometer in air (22°C) and in water of different temperatures (25°C, 30°C, and 35°C) using 1 lean and 1 obese subject. Heart rate for a given VO_2 averaged ~10 beats/min less in 25°C water than under the other environmental temperatures. Heberlein et al (1987) compared physiological and subjective responses of high impact aerobics and water aerobics in middle aged females. Using identical routines, VE, HR, RQ, and RPE were all significantly less in the water than on land. It was also found that contrary to the other studies cited, VO_2 was significantly less in water than on land while performing the same routine. These researchers suggested that despite a 13% lower HR during water aerobics, the metabolic cost of these exercises in the water was still sufficient to attain a cardiovascular training stimulus of approximately 80% of predicted VO_2 max. It was therefore concluded that water aerobics was an excellent training alternative for rehabilitating or obese individuals. Conflicting results were found by Johnson et al. (1977). While performing 2 exercises, one using the arms and one using the legs, both on land and in the water at identical rhythms and using the same movements these researchers found that both HR and VO_2 were greater while performing each exercise in the water for both males and females. The conflicting results found in these studies may be due to differences in water temperature, however, the general finding is that exercise in cool water elicits a comparable VO_2 and a lower HR than the same exercise on land. Testing procedures and depth of immersion may also be factors affecting HR in water.

Water Exercise and Weight Loss

There is no question that water exercise is beneficial in terms of rehabilitation, disease prevention, and as a means of cardiovascular conditioning for most populations, however, there appears to be some controversy in the literature involving exercise in water and its effects on body composition and weight loss. Sheldahl et al. (1982) looked at the effects of exercise in cool water (17-22°C) on weight loss in obese women performing exercise at 30-40% of VO_2 max for 90 minutes, 5 days per week, for 8 weeks. There was no change in body weight, body fat, fat free body weight, or caloric intake after 8 weeks, however, there were no exercise related injuries and there was a 93% rate of adherence. It was postulated that even though no weight was lost in these obese subjects under these test conditions, exercise in cool water may motivate obese people to exercise at higher intensities for thermal comfort. Gwinup (1987) found similar results when testing the effect of swimming, stationary cycling, and walking on weight loss without dietary restriction. After 6 months of training the walkers lost 10% and cyclers lost 12% of initial weight. The swimmers lost no weight. Smith (1987) compared the effects of water aerobics and dance aerobics programs on body weight, body composition, VO_2 max, treadmill run time, max VE, and HR after training 40 minutes per day, 4 days per week for 7 weeks. The aerobic dance and water aerobics groups worked at 78% and 71% of maximal HR, respectively, and training heart rates were significantly lower for the water aerobics group. The results showed no significant changes in any of the tested variables for either group. It was therefore concluded that neither of these exercise modes was effective for improving cardiovascular fitness or body composition over a 7 week period.

Benefits of Water Exercise for Special Populations

Ciske et al. (1987) compared 5 minutes of exercise using 4 different cadenced type exercises, both on land and in water in cardiac patients. Water exercises were performed in chest-deep 31°C water. Changes in HR and RPE were similar both on land and in water, however, 2 of the 4 exercises in water elicited a significantly lower change in systolic blood pressure suggesting that the hemodynamic responses were less in water than on land. Fernhall et al. (1992) investigated the appropriateness of prescribing upright water based exercise from treadmill and arm ergometry in patients with cardiovascular disease. Treadmill exercise consistently elicited a higher VO_2 than upright water-based exercise for the same heart rate and similar or lower RPE at 60% and 70% of HR max, respectively. At these lower intensities arm ergometry and water exercise elicited similar RPE and metabolic responses, therefore, arm ergometry may be more appropriate to use in the prescription of upright water-based exercise at these intensities. However, at 80% of HR max metabolic responses for arm ergometry and water exercise became dissimilar. Treadmill exercise consistently elicited a higher VO_2 than upright water exercise for the same heart rate, however, with increasing intensities these differences decreased but did not disappear. Based on the findings of this study, treadmill exercise prescriptions that use HR, may overestimate the metabolic load for upright exercise in water.

In two separate studies, McMurray et al. (1988a and 1988b) looked at the effect of advancing pregnancy on metabolic and cardiovascular responses during rest (on land), during immersion (at rest), and aerobic exercise at 60% of predicted VO_2 max in water of 30 °C. Resting VO_2 increased with advancing pregnancy and was higher in water than on land. Exercise VO_2 was similar for all trials, however, the workload required to elicit the VO_2 was decreased during the 35th week of pregnancy. These results suggest that pregnancy significantly alters metabolic responses to exercise in water. Immersion significantly lowered the resting HR by ~8 beats/min. Exercise in water also resulted in significantly lower HR as compared with the same level of exercise on land (132 ± 4 vs 149 ± 6 beats/min.). It was suggested that due to the combined effect of water, exercise, and pregnancy, cardiac output in water may be more elevated than on land, therefore, water based exercise should not be prescribed from a land-derived exercise target heart rate. In general, the water-based target HR may be adjusted to accommodate the lower HR observed in water, however, the amount with which the target HR percentage would be altered would only be a few beats/min.

Eyestone et al. (1993) compared different modes of aerobic training for maintaining VO_2 max and 2-mile run performance over a 6-week period. The subjects were trained runners who stopped their regular exercise routine and were randomly selected to train either using cycling, running on land, or running in the water. After 6 weeks of training, all groups had a small but significant decrease in VO_2 max, however, there was no difference between modes. It was suggested that runners who cannot run on land due to soft tissue injury can reduce losses in VO_2 max and 2-mile run performance during rehabilitation by using either cycling or water running as an alternative mode of training.

Stevenson et al. (1988) compared land and water exercise programs for older adults over a 10-week period and it was concluded that aquatic aerobic exercise elicits comparable physiological benefits to overground aerobic exercise. It was also found through use of the Depression and Anxiety Checklist (DACL) and the Profile of Mode States (POMS) psychological scales that older individuals gain confidence and composure over time when performing regular aquatic aerobic exercises. Ruoti et al. (1994) studied the effects of nonswimming exercises in water on muscular endurance, body composition, and aerobic work capacity of an older adult population over a 12-week period. The exercise group improved significantly on all tested variables, except body composition, whereas the control group showed no significant changes on any of the variables tested.

Studies Validating Ratings of Perceived Exertion

The subjective rating of perceived exertion during exercise is a key element in determining how hard one is working and is useful in prescribing exercise. There seems to be several different theories related to the physiological cues that are used by the individual to perceive effort. Perceptual cues are our primary source of information during work and these cues allow us to regulate work intensity. Ekblom and Goldbarg (1971) proposed that RPE was based on both local (peripheral) and central (respiratory-metabolic) perceptual signals. Borg and Noble (1974) described cues in the form of both general feelings of exertion and fatigue and also specific sensations varying in number and degree, such as muscular and joint pain, therefore, the overall perception of exertion may be regarded as a *gestalt* of many sensations and feelings. In the present study, Borg's 6-20 scale (Appendix A) for ratings of perceived exertion was used to verify attainment of VO_2 peak and to subjectively determine the subject's perception of effort during submaximal tests. Borg (1973) reported the results from two experiments comparing four different rating methods. Independent of which scale was used there was a good correlation between HR and RPE. Borg recommends the used of the 6-20 scale in most cases because it most often gives values that grow linearly with workload and HR. Skinner et al. (1973) compared the perceived effort of lean and obese subjects under different environmental conditions, 24°C and 32°C, while exercising on a treadmill and cycle ergometer to see if a difference in perception of effort existed for these different exercise modes. All subjects perceived the bicycle to be harder than the treadmill at the same VO_2. Obese subjects were not affected by the 32°C environment, however, at the same VO_2 the lean subjects perceived this work as being more difficult. It was concluded that RPE is most closely related to the proportion of maximal capacity required for a given workload. Henriksson et al. (1972) looked at RPE during eccentric and concentric exercises at varying intensities on a Krogh cycle ergometer. It was found that exercise performed at a lower rpm was perceived as being more difficult than exercise performed at the same VO_2 at a higher rpm. Hetzler et al. (1991) looked at the relationship between RPE and blood lactate at the lactate threshold, during fixed blood lactate concentrations, and at maximal exercise on different exercise modalities. There was a consistent relationship between RPE and blood lactate concentration, regardless of the exercise modality. To investigate intra- and intermodal regulation of exercise intensity through the use of RPE scales, Dunbar et al. (1992) compared VO_2 and HR responses between estimation (perception of effort response during a given workload) and production (exercising at a work rate which elicits a given RPE) trials at the same relative intensity. With one exception, RPE was found to be a valid means of regulating exercise intensity both intra- and intermodally at 50% and 70% of VO_2 max and, in general, Borg's 6-20 graded RPE scale provides a physiologically reliable method for regulating exercise intensity. These studies demonstrate the importance of input from peripheral variables (blood lactate and muscle strain) in determining the subjective "effort sense".

Summary

In summary, exercise has been shown to be effective in improving the quality of life and reducing the risk of disease. It has also been shown that exercise in water can be as effective as land based exercise and in most cases elicits similar cardiovascular and metabolic training responses to that on land (Eyestone et al., 1993; Stevenson et al., 1988). Researchers have found that training effects may be achieved while working at lower heart rates in water than on land at the same VO_2 (Cassady and Nielsen, 1992; Craig and Dvorak, 1969; Heberlein et al., 1987; Christie et al., 1990) and that one might be more efficient while training in water (Heberlein et al., 1987) which may be accentuated in lower water temperatures (Craig and Dvorak, 1969). Improved cooling and venous return are the two primary factors affecting the physiological responses during exercise in water. Studies concerning cardiac patients (Ciske et al., 1987; Fernhall et al., 1992) and pregnant women (McMurray et al. 1988a; McMurray et al., 1988b) provide evidence that water exercise provides sufficient stimulus for improving or maintaining cardiorespiratory fitness, however, due to altered physiological responses, exercise in the water should not be prescribed from a land-based exercise target heart rate for these populations.

The literature concerning water exercise and its effects on body composition and weight loss gives results that seem to be somewhat unexplainable. Training studies have shown that even though water exercise provides a stimulus inducing caloric expenditure, changes in body weight and composition have not been significant (Sheldahl et al., 1982;

Gwinup, 1987; Smith, 1987).

Studies have also found that hemodynamic responses are altered while immersed in water. The lower heart rates observed during water exercise may be due to greater venous return due to increased hydrostatic pressure and a shift in blood volume from the periphery to the core of the body because of the greater rate of heat dissipation in water than on land (Choukron and Varene, 1990). This results in an increased filling pressure of the heart, therefore, an increased stroke volume and lower heart rate at similar work rates.

Studies evaluating simulated cross-country skiing demonstrate that this type of exercise utilizes large muscle groups and results in increased energy expenditure with increased frequency of limb movement (Goss et al., 1989; Weiland, 1990). Body weight is another factor affecting the energy cost (Bowes, 1986). This form of exercise is weight-bearing, however, joint forces are minimal because of the sliding motion used, therefore, this may be a valuable form of exercise for the overweight and older populations.

CHAPTER 3

METHODS

Prior to data collection the testing protocol and procedures were reviewed in order to familiarize the investigator with the equipment to be tested and used during this investigation.

Subject Selection

The subjects in this study consisted of 10 university students all of whom were trained males cyclists ranging from the age of 20-34 (mean age 26.1 ± 4.3 years). Prior to participating in the study each subject was briefed on the testing procedures and protocol. Subsequently, subjects signed an informed consent form (Appendix B) approved by the University of Tennessee-Knoxville Institutional Review Board. To ensure that each subject would be able to attain an aerobic steady state at each intensity level, the subjects recruited qualified as being of an above-average fitness level, having a relative VO_2 max > 50 ml/kg/min. For each portion of the study, 8 of the 10 subjects were randomly selected for participation. Water temperature and laboratory room temperature remained relatively constant throughout the study at 30°C and 21.1°C, respectively. The subject's physical characteristics were determined to see if any correlation existed between VO_2 and any of these variables. These measurements are listed in Table 1.

Table 1. Physical characteristics of subjects (n=10)

	Age (yrs)	Height (m)	Weight (kg)	BMI	BSA* (m^2)	VO2max (ml/kg/min)
Mean	26.1	1.82	76	23	1.97	56.5
S.D.	4.3	0.05	7.9	2.04	0.12	3.1

*estimated from Consolazio et al. (1963).

Gas Collection and Analysis Procedure

Two open-circuit spirometry methods for collecting respiratory gases were used in this study. For each graded exercise test, an integrated computer system, Rayfield System (Rayfield Equipment, Waitsfield, VT), was used for measuring VO_2 peak. Inspired minute ventilation was determined using a dry gas meter (Rayfield Equipment, Waitsfield, VT) that was calibrated against a 120 L Tissot spirometer. Expired gas fractions were analyzed with Applied Electrochemistry S3-A O_2 and CD-3A CO_2 analyzers (Sunnyvale, CA). These devices were interfaced with an Apple microcomputer which calculated oxygen uptake using the respiratory Fick equation. The gas collection procedure used for Hydroforce testing was performed by directing expired air into Douglas bags which were then taken from the pool area to the laboratory for analysis. This procedure is described in more detail in the Hydroforce testing procedures section. Both techniques for measuring energy metabolism have been used in similar studies and provide convincing evidence for the validity of these procedures (McArdle et al., 1991). Prior to each test, the gas analyzers used were calibrated with gases of known O_2 and CO_2 concentrations that had been analyzed by the Scholander technique.

Graded Exercise Test

Prior to participating in the energy cost portion of this study each subject performed a graded, exercise test to volitional exhaustion on a Monark cycle ergometer which was calibrated on a level surface using known reference weights as described in the Monark Cycle Owner's Manual (Monark Exercise AB) before each test. The initial work rate was set at 40 W for the first minute, and it was then increased by 40 W at 1-minute intervals thereafter. Pedaling frequency (80 rpm) and resistance were closely monitored throughout each test. Each subject wore a Polar Vantage heart rate monitor and heart rate was recorded during the last 15 seconds of each 1-minute stage. Rating of Perceived Exertion (RPE) using the Borg 6-20 Scale (Borg, 1973) was also assessed during the last 15 seconds of each stage. End-point determination of the test was defined as volitional exhaustion and the test was discontinued when the subject could not maintain the required pedal cadence of 80 rpm. VO_2 peak was defined as the highest VO_2 attained for 30 seconds during the test. Physiological data for each subject during the graded maximal exercise test are shown in Appendix C.

Description of Hydroforce Equipment

Each piece of Hydroforce equipment was suspended from the deck of the pool and submerged into the deep end (10 feet) of the pool. This allowed the subject to exercise at waist to chest level in water, depending on the height of the user. Included in Appendix D (1 through 3) are photographs of the Hydroforce Slider and Cycle. Due to the construction of this equipment, their use as ergometers would not be appropriate because the resistance is not measureble; therefore, exact knowledge of the workload is unknown.

Slider. The Hydroforce slider is an aquatic version of a simulated cross-country skiing machine without the use of the upper body. Placement on the machine requires only that the subject adjust the pelvic pad to the level of the anterior superior iliac spine while standing in the upright position. Hand rails are available and are used for balance only, not support. The movement of the lower extremities ranges from approximately 20 degrees of both hip extension and hip flexion with slightly flexed knees. The subject's feet are secured to the skates and allow a limited range of motion at the ankle. Exercise on this piece of equipment primarily involves use of the hamstring, gluteal, and quadricep muscle groups. Resistance is adjusted by manipulating the size of the entrance for water passing through the system. By changing the level, up or down, the opening is either constricted or widened, thereby, increasing or decreasing the resistance, respectively. Due to mechanical malfunctions there were only 4 workable levels on the slider at the time of testing that were evaluated to determine metabolic cost.

Cycle. The Hydroforce cycle attempts to simulate stationary cycling in a water medium. Placement on the cycle requires only that the subject adjust the saddle height to allow for only approximately 5-10 degrees of knee flexion at the bottom of the pedal stroke. This piece of equipment, like conventional cycles, primarily relies on the force produced by the quadriceps muscle group. The Hydroforce cycle very accurately mimics the pedal stroke on a stationary cycle with the exception of a slightly wider space between pedals due to the turbine which allows for water to be the source of resistance. The cycle allows for 6 different resistance settings or levels, which is dependent on the amount of water flowing through the turbine. The more water that is allowed into the turbine the greater the resistance. The highest level (level 6) was immovable, therefore, only levels 1-5 were tested.

Hydroforce Testing Procedures

The Hydroforce slider and cycle were both evaluated to determine the energy cost while exercising through a range of intensities. Each piece of equipment was evaluated on separate days. To allow each subject to become familiar with the equipment, there was a 10 minute accommodation period before testing each piece of equipment. After becoming accustomed to the equipment, each subject performed 4 submaximal stages on the slider and 5 submaximal stages on the cycle, 4 minutes at each stage. The slider was tested at cadences of 25, 30, 35, and 40 cycles per minute (cpm). The cycle was tested at cadences of 50, 60, 65, and 70 revolutions per minute (rpm). Romijn et al. (1992) concluded that indirect calorimetry is a valid technique for determining substrate utilization during cycling up to 80-85% of VO_2 max in trained cyclists ($p<0.05$). At each cadence, 2 subjects were tested through the range of levels for each piece of equipment. Since failure to attain a metabolic steady state would invalidate the energy cost data, subjects rode at selected cadences based on their VO_2 max scores. For example, the 2 subjects with the highest VO_2 max scores exercised at 40 cpm on the slider and 70 rpm on the cycle. Expired air was collected through the use of a mouthpiece and directional breathing valve worn by each subject, and connected to a 1.5 inch-diameter flexible hose. Expired gas was collected over the last 2 minutes of each stage in 100 or 200 L Douglas bags. It has been found that there is no difference in VO_2 values at minutes 2 and 5 at low workloads, ranging from 4 to 10 METS, therefore, 2 minutes is sufficient time to reach steady state at submaximal workloads (Nagle et al., 1971). Expired gas fractions were analyzed as previously described and the volume of expired air was measured by pushing the air into a 120 Liter Tissot gasometer. Using a computer program, VO_2, VCO_2, VE, and caloric expenditure were computed using the Haldane transformation of the respiratory Fick equation. Each subject wore a Polar Vantage heart rate monitor and HR was recorded at minutes 3 and 4 of each stage and averaged. Perception of effort was recorded during the last 15 seconds of each stage using Borg's scale of Perceived Effort.

Comparison of HR and RPE Procedures

The second purpose of this study was to compare the heart rate and RPE responses of Hydroforce cycling in water to that of stationary cycling on a Monark cycle ergometer. On the basis of previous testing, it was found that each subject could elicit a VO_2 of ~ 2.0 L/min while riding at 65 RPM at Level 3 on the Hydroforce cycle. Having not participated in any vigorous or prolonged activity on the day of testing, each subject reported to the lab and rode for 6 minutes at 65 RPM and level 3 on the Hydroforce cycle.

Expired air was collected in Douglas bags during the last 2 minutes of the test and analyzed to determine VO_2 using the same procedures previously described. Heart rate was determined from the average HR response recorded at minutes 4, 5, and 6. RPE was recorded during the last 15 seconds of the test.

Using the measured value of VO_2 for each subject on the Hydroforce cycle, the ACSM equation for cycle ergometry was used to predict a work rate that would elicit the same approximate VO_2 on the Monark (land) cycle. After 15 minutes of rest, each subject then rode the Monark cycle ergometer at 65 RPM and at the individual's predicted resistance. Using the previously described integrated computer system, VO_2 was measured every 30 seconds throughout the 6 minute test on the land cycle. Resistance was adjusted to elicit a VO_2 as close as possible to that on the Hydroforce cycle, however, no changes were made after 3 minutes. The Rayfield system was used only to make sure that each subject was exercising at a VO_2 of ~2 L/min. To keep data collection procedures consistent throughout the study, expired air was collected in Douglas bags during the last 2 minutes of the stage. Values used for comparison came from the expired air that was collected and analyzed. Heart rate and RPE were recorded during the land cycle test in the same manner as that on the Hydroforce Cycle during this portion of the study.

Data Analysis

Descriptive data, means and standard errors, was computed for each of the measured variables during the maximal graded cycle test on land. For each cadence and level on the Hydroforce Cycle and Slider, means and standard deviations were calculated for each of the measured physiological variables to provide visual information and to construct graphs on the energy cost of using the Hydroforce equipment.

To compare the physiological responses during water and land cycling, means and standard deviations were calculated for each variable on land and in water. To determine if any statistical differences existed between land and water exercise, paired t-tests were computed. The significance level was set at $p=0.05$ for all comparisons.

CHAPTER 4

RESULTS

Descriptive results obtained during the energy cost portion of the study while riding the Hydroforce Cycle are shown in Table 2. Test results on the Hydroforce cycle show that VO_2, VCO_2, RER, and HR increased substantially with increasing pedal cadence (rpm), however, these variables were relatively independent of the resistance settings, or increasing levels. VO_2 increased from 0.87 L/min at the lowest workload to 2.38 L/min at the highest workload tested. Figure 1 shows the oxygen cost of riding the Hydroforce Cycle on levels 1-5 and at selected cadences and again shows that VO_2 is dependent on speed of pedaling and does not consistently increase with increased resistance.

Descriptive data obtained while studying the energy cost of the Hydroforce Slider are given in Table 3 and show VO_2, VCO_2, RER, and HR increased with increasing cadence (cycles/min.) and also with increasing resistance settings (Level 1-5). The ratings of perceived exertion also showed an increase with cadence and level. Figure 2 shows VO_2 increasing with both increasing cadence and with resistance from level 2-4. Individual data for the Hydroforce Cycle and Slider can be found in Appendices E-1 and E-2, respectively.

Table 4 shows the data comparing Hydroforce cycling versus Land cycling. No statistical differences were obtained for any of the tested physiological or subjective variables when VO_2 is controlled.

Table 2. Physiological and perceptual data obtained during the energy cost portion of this study while riding the Hydroforce Cycle.

Cadence (rpm)	**Level**	**VO_2** (L/min)	**VCO_2** (L/min)	**VE** (L/min)	**RER**	**HR** (b/min)	**RPE** (6-20)	**Energy** (kcal/min)
50 (n=2)	1	0.87±0.08	0.75±0.06	16.6±1.3	0.87±0.02	90±11	6.5±0.7	4.22±0.39
	2	0.91±0.14	0.80±0.12	18.3±2.5	0.88±0.01	92±12	8.0±2.8	4.40±0.65
	3	0.99±0.08	0.91±0.02	19.1±0.2	0.93±0.05	93±11	10.5±0.7	4.86±0.35
	4	1.04±0.06	0.96±0.02	19.7±0.3	0.92±0.04	93±10	11.0±0.0	5.12±0.23
	5	1.01±0.01	0.94±0.04	21.2±1.5	0.93±0.03	98±9	12.5±0.7	4.97±0.08
60 (n=2)	1	1.27±0.19	1.12±0.19	24.3±5.3	0.91±0.06	109±10	7.0±1.4	6.16±0.94
	2	1.22±0.09	1.07±0.06	22.2±1.9	0.88±0.01	109±13	7.0±1.4	5.92±0.43
	3	1.36±0.20	1.22±0.14	26.0±2.6	0.93±0.07	110±16	8.0±0.0	6.64±2.58
	4	1.47±0.18	1.31±0.16	27.9±4.0	0.89±0.00	114±14	10.0±1.4	7.19±0.87
	5	1.47±0.21	1.32±0.18	29.0±2.7	0.89±0.01	118±11	10.0±1.4	7.20±1.01
65 (n=2)	1	1.76±0.10	1.52±0.16	32.9±4.1	0.86±0.04	119±16	9.0±2.8	8.54±0.57
	2	1.91±0.02	1.74±0.03	36.2±0.5	0.91±0.01	122±16	9.5±2.1	9.37±0.40
	3	2.11±0.08	1.96±0.05	41.1±0.1	0.93±0.02	125±12	10.5±2.1	10.39±0.3
	4	2.30±0.16	1.91±0.15	41.2±3.1	0.91±0.02	126±13	11.0±2.8	10.32±0.5
	5	2.34±0.35	2.12±0.36	45.3±9.8	0.90±0.02	132±9	12.5±3.5	11.45±1.7
70 (n=2)	1	2.34±0.39	2.06±0.35	42.6±10.	0.89±0.01	114±1	10.5±2.1	11.37±1.8
	2	2.13±0.32	1.92±0.33	39.6±8.1	0.90±0.02	120±13	11.0±2.8	10.41±1.5
	3	2.22±0.13	2.02±0.17	43.2±4.2	0.91±0.02	127±19	10.5±3.5	10.86±0.7
	4	2.37±0.06	2.17±0.15	46.5±4.5	0.92±0.04	127±13	12.0±4.2	11.62±0.4
	5	2.38±0.05	2.14±0.03	44.6±0.4	0.90±0.00	131±13	12.0±4.2	11.65±0.2

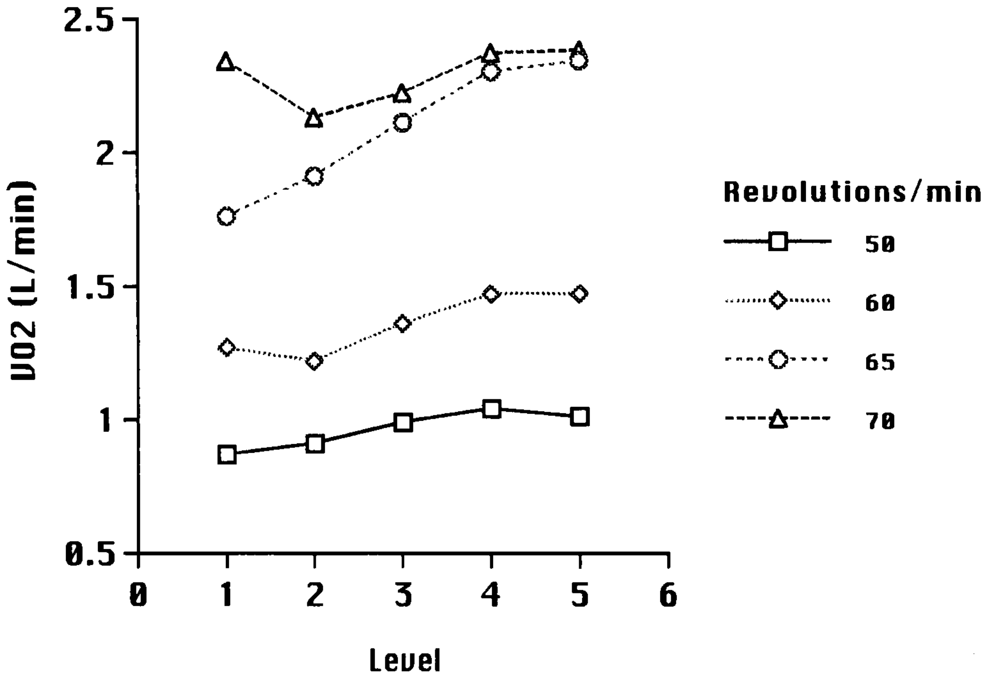

Figure 1. This graph shows the VO_2 while riding the Hydroforce Cycle on levels 1-5 and at selected cadences.

Table 3. Physiological and perceptual data obtained during the energy cost portion of this study while exercising on the Hydroforce Slider.

Cadence (cpm)	Level	VO_2 (L/min)	VCO_2 (L/min)	VE (L/min)	RER	HR (b/min)	RPE (6-20)	Energy (kcal/min)
25 (n=2)	1	0.82±0.13	0.68±0.24	14.8±4.1	0.82±0.16	83±4	7.0±1.4	3.92±0.81
	2	0.82±0.12	0.70±0.15	16.8±4.4	0.85±0.06	87±4	9.5±3.5	3.95±0.64
	3	0.91±0.15	0.78±0.14	17.1±2.6	0.86±0.00	92±8	10.5±3.	4.39±0.76
	4	1.20±0.13	1.03±0.16	21.2±4.0	0.85±0.04	100±6	12.5±2.	5.79±0.69
30 (n=2)	1	1.01±0.02	0.86±0.05	20.3±1.7	0.85±0.03	93±7	8.0±0.0	4.91±0.16
	2	0.95±0.00	0.80±0.03	18.9±0.3	0.84±0.03	94±2	9.5±0.7	4.58±0.06
	3	1.28±0.11	1.11±0.01	22.5±1.8	0.83±0.02	103±1	12.0±1.	6.13±0.50
	4	1.53±0.31	1.39±0.26	31.9±5.4	0.91±0.02	121±1	14.5±0.	7.51±1.51
35 (n=2)	1	1.34±0.35	1.10±0.28	26.3±6.4	0.82±0.01	92±9	6.0±0.0	6.42±1.68
	2	1.42±0.45	1.20±0.38	27.9±8.5	0.84±0.00	95±10	8.0±1.4	6.86±2.18
	3	1.59±0.39	1.37±0.31	30.6±6.3	0.86±0.02	104±0	10.5±3.	7.71±1.86
	4	1.87±0.09	1.65±0.02	37.6±0.0	0.88±0.05	112±9	12.5±3.	9.11±0.32
40 (n=2)	1	1.35±0.01	1.19±0.01	27.0±1.9	0.88±0.00	100±13	9.0±2.8	6.58±0.08
	2	1.29±0.09	1.15±0.04	27.2±2.1	0.90±0.03	104±14	10.0±2.	6.28±0.40
	3	1.72±0.03	1.54±0.01	34.4±1.2	0.90±0.04	116±7	11.5±3.	8.38±0.26
	4	2.09±0.5	1.95±0.37	49.1±12.	0.96±0.03	148±8	15.5±2.	10.34±2.4

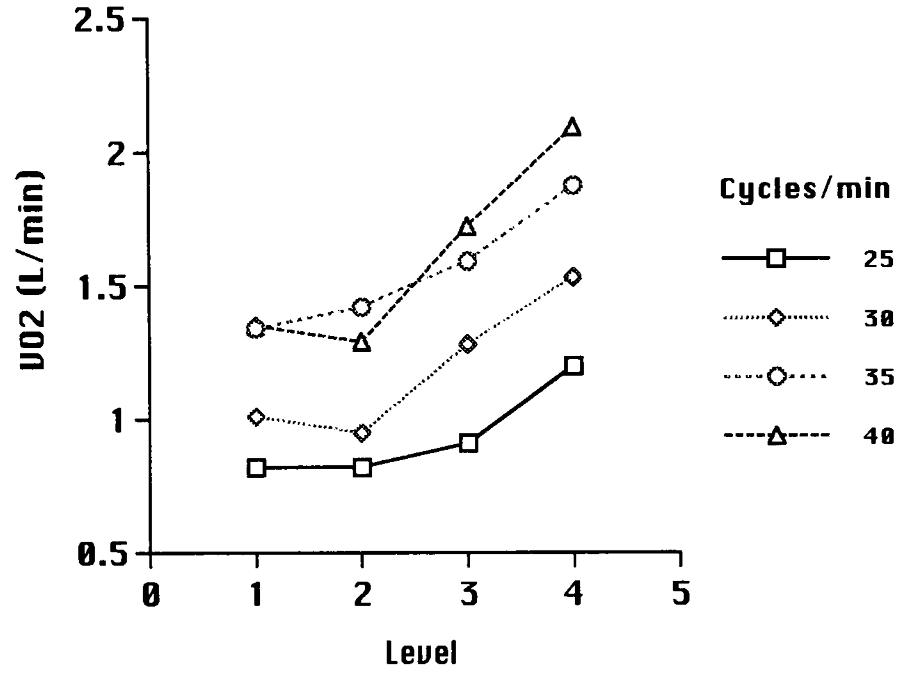

Figure 2. This graph shows the VO_2 while using the Hydroforce Slider on levels 1-4 and at selected cadences.

Table 4. Statistical data obtained during submaximal exercise on the Hydroforce Cycle in water versus the Monark cycle ergometer on land.

Variable	**Monark Cycle** (Land)	**Hydroforce** (Water)	**Significance** (p-value)
VO_2 (L/min)	2.04±0.13	2.04±0.21	0.965
HR (beats/min)	123±16	126±15	0.315
RPE (Borg 6-20)	11.1±1.7	10.6±2.3	0.45
RER	0.91±0.09	0.92±0.07	0.81
VE	36.3±5.0	36.2±3.3	0.989
VE/VO_2	17.8±2.33	17.8±1.69	1.0

CHAPTER 5

DISCUSSION

With increasing emphasis being placed on weight loss/control and cardiovascular training for disease prevention and a longer, healthier life, it is helpful to know how much energy is actually being used while exercising. Determining the energy cost of using the Hydroforce Cycle and Slider was the primary focus of this study. The data collected gives the caloric cost of using this equipment at various cadences and resistance settings which will enable the engineers of Hydroforce to design a control panel displaying estimated rates of energy expenditure, expressed in either Calories/minute and Calories/hour. Similar work has been done to develop feedback on the displays of other pieces of exercise equipment such as stair climbers, treadmills, rowers, simulated cross-country skiers, and stationary cycles. This information is also useful for those needing special attention during exercise, such as cardiac and respiratory patients, who need to be constantly monitored, however, ergometers which can be calibrated may be more suitable for these groups.

Because of viscosity and drag forces, water, as a medium for exercise, provides resistance that is proportional to the effort exerted (Wilder et al., 1993). Water also provides a buoyant effect on a submerged body which causes the body to lose weight equal to the weight of water displaced while submerged, thus resulting in less stress and pressure on bone, muscle, and connective tissue. Therefore, water allows overweight individuals or injured athletes to exercise or maintain cardiovascular fitness without being full weight-bearing. Water also has a much greater specific heat than that of air, which allows an increased rate of heat loss for a given temperature (Wilder et al., 1993), provided the water temperature is lower than skin temperature, making water an excellent medium for exercise for the obese population.

When exercise is performed in the water, the energy cost of the activity is altered. Water provides resistance to movement and the resistance is a function of the speed of movement and the size of the object being moved through the water. The dominant forces against which movement through water is resisted are buoyancy, turbulence, and viscosity friction (Kolb, 1957). Kolb also states that superimposed on the viscosity of friction is the effect of length and girth of the limbs moving through the water. The longer and larger the limb the more this will increase the resistance to movement.

Energy Cost of Riding the Hydroforce Cycle

On the Hydroforce Cycle, VO_2 increased with increasing pedal cadence. However, the same did not hold true for increasing resistance settings, or levels. Failure of VO_2 to consistently increase with increasing levels may be explained by an error in mechanical design of the turbine built into the prototype we used, however, adjustments have been made to correct this problem by the manufacturers of the equipment. Due to the physiological and verbal responses of the subjects obtained during this portion of the study, the engineers of Hydroforce discovered that there was not enough of a change in the size of the openings which allow water to flow into the turbine to increase or decrease resistance significantly with changing of levels (settings). Throughout the range of intensities studied energy cost varied between 250 to 700 Calories per hour while riding the Hydroforce Cycle, corresponding to 45 and 72% of HR max attained during the maximal Monark cycle test, respectively.

Energy Cost of Using the Hydroforce Slider

While exercising on the Hydroforce Slider at cadences ranging from 25 to 40 complete cycles/min and levels 1 through 4 energy cost varied from 235 to 620 Calories/hour and correspond to 41 and 89% of HRmax attained during the maximal Monark cycle test, respectively. Figure 2 shows that VO_2 increased consistently from levels 2 through 4. It should also be noted that at the highest cadence, 40 cpm, VO_2 increased at a greater rate than that at 35 cpm because of a lower VO_2 response on level 2. In comparison to the study by Goss et al. (1989) who found that VO_2 on the Nordic Track was more dependent on frequency of limb movements than on resistance, the present study found that the increasing VO_2 was a function of both cadence and resistance.

Comparison of HR and RPE in Water to that on Land during stationary cycling

The second purpose of this study was to compare the HR and RPE responses while riding stationary cycles in water and on land. It is frequently reported in the literature that exercise in the water elicits a greater VO_2 than on land while performing the same exercise at the same cadence (Johnson et al., 1977; McMurray et al., 1988b; Coad et al., 1987). This is not surprising given the fact that movement through water is resisted to a greater extent than the same movements in air, therefore, these studies reported a VO_2 that was significantly higher in water because of the added resistance of water.

Appendix F gives the physical characteristics that may have had an effect on VO_2 for each subject participating in this portion of the study while riding the Hydroforce Cycle in water. BMI had the highest correlation with VO_2 ($r = 0.624$) and may have accounted for approximately 38% of the variation in VO_2. Body weight and BSA had correlations of $r = 0.43$ and $r = 0.259$, respectively.

Researchers have also controlled VO_2 in an attempt to compare HR and RPE (Cassady and Nielsen, 1992; Heberlein et al., 1987). It was concluded in these studies that at the same submaximal VO_2, HR and RPE were significantly lower in the water. The results of our study show no significant difference in HR or RPE during water and land cycling at the same VO_2. We found that HR was approximately 3 beats/min higher during cycling in water as compared to that of cycling on land, however, this was not a significant finding. To discuss the discrepancies found in this study the factors affecting HR must first be addressed. Cardiac output (Q) is the amount of blood pumped out of the heart and distributed to the rest of the body to supply adequate oxygen to working muscles and to maintain nutrition. In other words, Q is the product of HR and stroke volume (SV). At rest, Q is approximately 5-6 L/min; however, during high intensity exercise, Q can be elevated to as high as 20-25 L/min. SV and HR must adjust to accommodate the increased demand for oxygen. SV can be increased by a greater preload leading to a more forceful contraction of the heart and greater cardiac emptying (McArdle et al., 1991). Some of the factors affecting the preload of the heart include body position, muscle pump, gravity, and body temperature. McArdle, Katch, and Katch (1991) state that Q and SV are highest and most stable in the horizontal position, which is demonstrated in supine versus upright cycling. During exercise the contracting musculature helps to increase venous return by pushing the blood back towards the heart increasing cardiac filling. Johnson et al. (1977) also state that the hydrostatic pressure against the body may compress the vascular beds and force the blood up into the torso. Body position and the active muscle "pump" probably had the least effect on the discrepancies found in this study as compared to the other studies comparing HR during water and land exercise because each of these studies tested upright exercise.

Gravity, body temperature, and the added hydrostatic pressure of water may have been the major contributing factors and the depth of submersion may have had a significant effect on these factors. The studies which have reported lower HR for a given submaximal VO_2 (Cassady and Nielsen, 1992; Heberlein et al., 1987) submerged their subjects into the water up to chest level. Due to the construction of the Hydroforce Equipment, our subjects could only be submerged up to 2-4 cm above the umbilicus. The taller the subject, the more the seat on the Hydroforce Cycle was raised to get proper range of motion throughout the pedal stroke.

During upright exercise on land, blood is pumped back to the heart against gravity via the active muscle "pump". With the cessation of exercise there is a venous pooling of blood in the lower limbs because of gravity. Submersion in water has been shown to increase Q and SV by 32-79% (Christie et al., 1990) while HR has been reported to remain unchanged or slightly decrease (Ciske et al., 1987; McMurray et al., 1988a; Johnson et al., 1977). A body that is submerged in water becomes more bouyant and therefore an antigravity effect is applied to the body. This may also assist in venous return to the heart and prevent pooling of the blood to the lower body in the upright position.

These researchers also attempt to explain the lower HR in water by describing a reflex response of the cardiovascular system to the cold receptors in the skin. It is said that blood flow to the skin can account for as much as 30% of the total Q and this shunting of skin blood volume, to conserve body heat, increases cardiac preload via greater venous return. Heat transfer in air is accomplished via evaporation of sweat, convection, and radiation. When completely immersed in water the body relies solely on convection to transfer heat. Water has a specific heat per unit volume that is about 4000 times greater than that of air and a thermal conductivity that is 25 times greater than that of air (Nadel, 1977). Nadel suggests that even though we are limited in the number of pathways for transferring heat in water, the rate of heat transfer is much greater in water than on land. This is true, however, there must be a significant temperature gradient between the water and skin for this to be a major factor in altering the cardiovascular response.

One possible explanation for the finding in the present study that HR is not lower in water than in air at the same VO_2 is because of the depth of immersion. If water aides in an increased venous return because of weightlessness/antigravity, hydrostatic pressure, and redistribution of blood flow then the amount of surface area or depth of immersion in water could have a large impact on these factors. Therefore, the HR obtained in the present study may not have been significantly different than those on land because our subjects were not submerged to the same level as in previous studies (Cassady and Nielsen, 1992; Heberlein et al., 1987).

Another possible explanation for obtaining similar HRs in the present study may have been that the environmental conditions were thermoneutral, as described by Denison et al. (1972). These researchers agree that water immersion exposes the body to hydrostatic, viscous, inertial, and thermal conditions which could alter the physiological responses to water exercise. These researchers also believe that water temperature and intrathoracic pressure may further effect these changes. However, Denison et al. (1972) found no significant differences in HR during supine cycling in water (35.0 to 35.5°C) and on land (18 to 22°C) at the same VO_2. Similar results were found by Craig and Dvorak (1969) who compared stationary cycling on land to that in water of temperatures 25, 30, and 35°C in one lean and one moderately obese subjects. Most importantly, these researchers found that HR for a given VO_2 was 10 beats/min lower in 25°C water than in warmer water and in air. These studies were all done with the head out of the water, therefore, "cold face immersion" was not a factor. Ear temperature was monitored throughout each test condition and was found to be directly related to water temperature in the lean subject but not in the obese subject. It was therefore concluded that except for differences related to thermal regulation and mechanics of breathing, responses to exercise in water are the same as those in air. McArdle et al. (1976) compared the circulatory responses to exercise in water (18, 25, and 33°C) and in air while riding a stationary cycle. These investigators found that for a given VO_2, HR was significantly lower in water of 18°C and 25°C. It was hypothesized that the lower HR in cooler water would be compensated for by a proportional increase in stroke volume. With reference to these studies, we conclude that the environmental conditions on land and in water in the present study were not significantly different, and stationary cycling in water of 30°C does not sufficiently increase cardiac preload, therefore, it had no affect on HR.

We had hypothesized that, due to a greater rate of heat dissipation in water, riding the Hydroforce Cycle in water would elicit lower subjective ratings of perceived exertion than those seen while riding a stationary cycle on land at the same VO_2. Table 4 shows that there was no significant difference in RPE between land and water cycling in our study. Very few studies have been done on this subject. Bishop et al. (1989) found that at comparable levels of RPE, aqua running was associated with lower VO_2, respiratory quotients, and ventilation than running on a treadmill. Coad et al. (1987) found that while walking and running in water and on land at the same speed RPE was significantly higher for both forms of exercise in water. VO_2 was significantly higher for water walking compared with land walking, however, there was no difference in VO_2 between running trials. Ciske et al. (1987) found that when comparing 4 different activities in water versus on land in cardiac patients that 3 of the exercises elicited similar RPE responses while the other exercise elicited a greater RPE on land than in the water.

The mechanism by which man perceives intensity of exertion is unknown (Skinner et al., 1973). Borg and Noble (1974) contend that perception of effort is dependent on many different kinds of body sensations, including both central (HR, VO_2, and VE) and peripheral factors (lactic acid, muscle tension or "strain", and proprioception in the joints). Borg (1973) reviewed the history of his rating of perceived exertion scale and stated that based upon previous studies a good correlation exists between HR and RPE independent of the scale used. There is also a high correlation between HR and VO_2 (Borg and Noble, 1974), therefore, given the similarity in the physiological responses observed in the present study in land versus water, it is not surprising that RPEs were also similar.

Borg and Noble (1974) state that under certain conditions, such as the influence of autonomic nervous system blocking agents and increased environmental heat, the relationship between RPE and these physiological variables can be disrupted. In our study, laboratory room temperature (21.1°C) and water temperature (30°C) were considered thermoneutral temperatures to the body, therefore, there was no excessive environmental load placed on the subjects. Because both of the environmental test conditions were thermoneutral, it may be that the cooling effect of the water was apparently no greater then the conditions in the lab. Pandolf et al. (1972) found that RPE was not affected by environmental heat at equal work loads even though HR significantly increased with increasing heat stress. These researchers suggest that the RPE-HR relationship may be independent of environmental conditions. The results of the present study supports this contention.

Summary

In summary, it was found that the Hydroforce Cycle and Slider can be used by people of varying fitness levels because of the wide range of work settings, which elicit a caloric cost ranging from 250 to 700 kcal/hr.

It was hypothesized that work on the Hydroforce Cycle in water would elicit lower HR and RPE responses than that during stationary cycling on land at the same VO_2. We found no significant difference in HR or RPE at the same VO_2 when land and water cycling were compared. The research available on comparing HR and RPE responses on land and in water during exercise is controversial. Some researchers suggest that due to the physical properties of water, HR is lower during exercise in water than on land, however, this was not the case in our study. It is apparent that only in cold water temperatures are HRs significantly lower during exercise in water, however, altered HR might also be dependent on the depth of immersion in the water.

RPE is a subjective response which may be dependent on central or local factors.

It was hypothesized that because of the greater thermal conductivity of water to that of air that stationary cycling at the same VO_2 would elicit lower ratings of perceived exertion in water than on land. Our results showed that this was not the case. We found that at the same VO_2, RPE was not significantly different in water as compared to that on land. This may have been because RPE is so closely related to HR, therefore, if HR was not altered in water then RPE would also not be affected. This may suggest that the environmental conditions in our study did not disrupt the HR-RPE relationship. It was also concluded that stationary cycling in water and on land at thermoneutral temperatures does not significantly affect RPE.

Future research is needed to determine if the physiological and subjective responses of other populations are different on this equipment in the water compared to similar exercise on land. Investigation of this equipment in different water temperatures would also be done to see if HR and RPE are affected. Studies have also reported that exercise in water does not alter body composition or weight, therefore, a training study involving the Hydroforce equipment is indicated to see if body composition and weight are improved with these types of exercise. Lastly, due to the proposed alterations being made to the turbine of the Hydroforce Cycle another energy cost study should be performed on this piece of equipment.

CHAPTER 6

CONCLUSIONS

The Hydroforce Cycle and Slider provide ample stimulation of the large muscles of the legs for cardiovascular training. VO_2 ranged from 0.87 L/min to 2.38 L/min and from 0.82 L/min to 2.09 L/min on the Hydroforce Cycle and Slider, respectively. This equipment would provide the majority of the population with an appropriate modality for improving health through exercise or for maintaining cardiovascular fitness for injured athletes.

It can also be concluded from the results of this study that there is no significant difference in HR and RPE of cycling at the same VO_2 in water and on land under thermoneutral conditions.

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APPENDICES

APPENDIX A

Borg's RPE-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 B

INFORMED CONSENT FORM

Title: ENERGY COST OF USING HYDROFORCE AQUATIC EXERCISE EQUIPMENT

Investigator: David R. Bassett, Jr.

Address:
Exercise Science Unit
College of Education
University of Tennessee-Knoxville
1914 Andy Holt Ave./ Knoxville, TN. 37996

Phone: (423) 974-8766

You are invited to participate in a research study, the purpose of which is to determine the caloric cost of using two new pieces of exercise equipment, the Hydroforce aquatic cycle and cross-country ski machine.

You will be asked to undergo a graded, maximal cycle test on land. This will involve pedaling a cycle ergometer at a constant speed, while the work rate is gradually increased. You will be asked to wear a mouthpiece and noseclip to allow us to collect your exhaled air for determination of maximal oxygen consumption. A 3-lead electrocardiogram will be used to monitor your heart rate. On another day, you will exercise on two pieces of equipment in the swimming pool at the HPER building. You will be submerged in water a little deeper than waist level while you exercise on an underwater cycle and cross-country ski machine, at five different intensities (4 minutes at each level). You will then ride a conventional land-based cycle ergometer at 5 submaximal intensities, so that we can compare the heart rate and perceived effort of the Hydroforce aquatic cycle versus a traditional exercise cycle. The total time involvement for the study is about 3 hours.

Risks and Benefits: There are risks associated with maximal exercise testing, which include abnormal blood pressure responses, musculoskeletal injuries, heart rhythm disturbances, and in rare instances, heart attack or even death. However, to reduce the likelihood of these events, only subjects who perform regular exercise and who have no history of cardiovascular complications will be permitted to be in the study.

Confidentiality: The information obtained from these tests will be treated as privileged and confidential and will consequently not be released to any person other than the project director without your consent. However, the information will be used in research reports or presentations but your name and other identity will not be disclosed. The consent forms and data will be stored in a secure location at the university.

You are free to decide whether or not to participate in this study and are free to withdraw from the study at any time without penalty.

Before you sign this form please ask questions about any aspects of the study which are unclear to you.

AUTHORIZATION:

I, ________________________, have read the above and decided to participate in the research project described above. My signature also indicates that I have received a copy of this consent form.

______________________________ ______________

Participant's signature Date

I hereby certify that I have given to the above individual an explanation of the contemplated study and its risks and potential complications.

______________________________ ______________

Witness Date

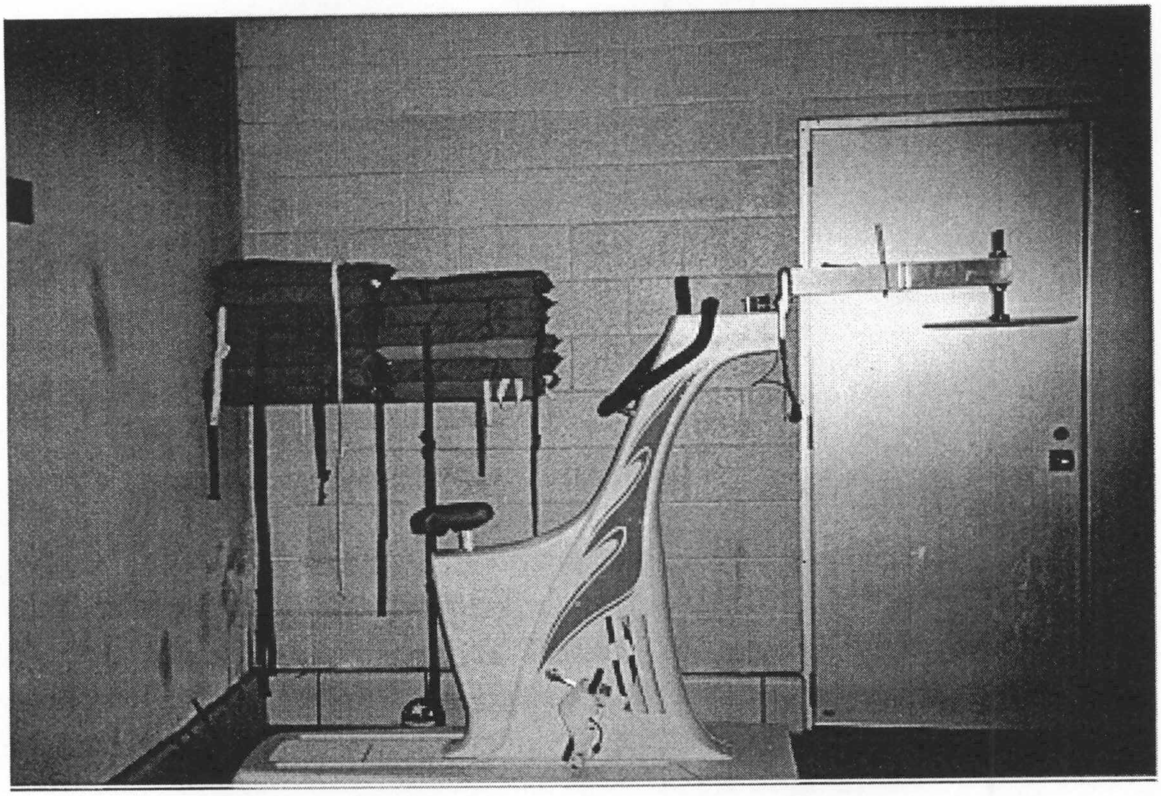
APPENDIX C

This table contains descriptive data for each subject obtained during the maximal graded cycle test.

Subject	VO_2 max (ml/kg/min)	VO_2 max (L/min)	Workrate (watts)	HR max (beats/min)	RER	RPE (6-20)
A	60.07	4.58	360	194	1.10	20
B	57.31	3.83	320	197	1.24	20
C	59.91	5.11	360	194	1.25	20
D	53.43	4.98	440	176	1.20	20
E	56.58	3.91	360	196	1.32	20
F	51.89	3.89	345	189	1.25	20
G	53.09	4.19	320	199	1.19	20
H	54.33	4.13	345	179	1.25	20
I	58.82	4.18	345	195	1.24	20
J	59.52	4.22	360	202	1.29	20
Means	56.5	4.3	355.5	192.1	1.21	20
S.D.	3.1	0.5	33.5	8.4	0.1	0

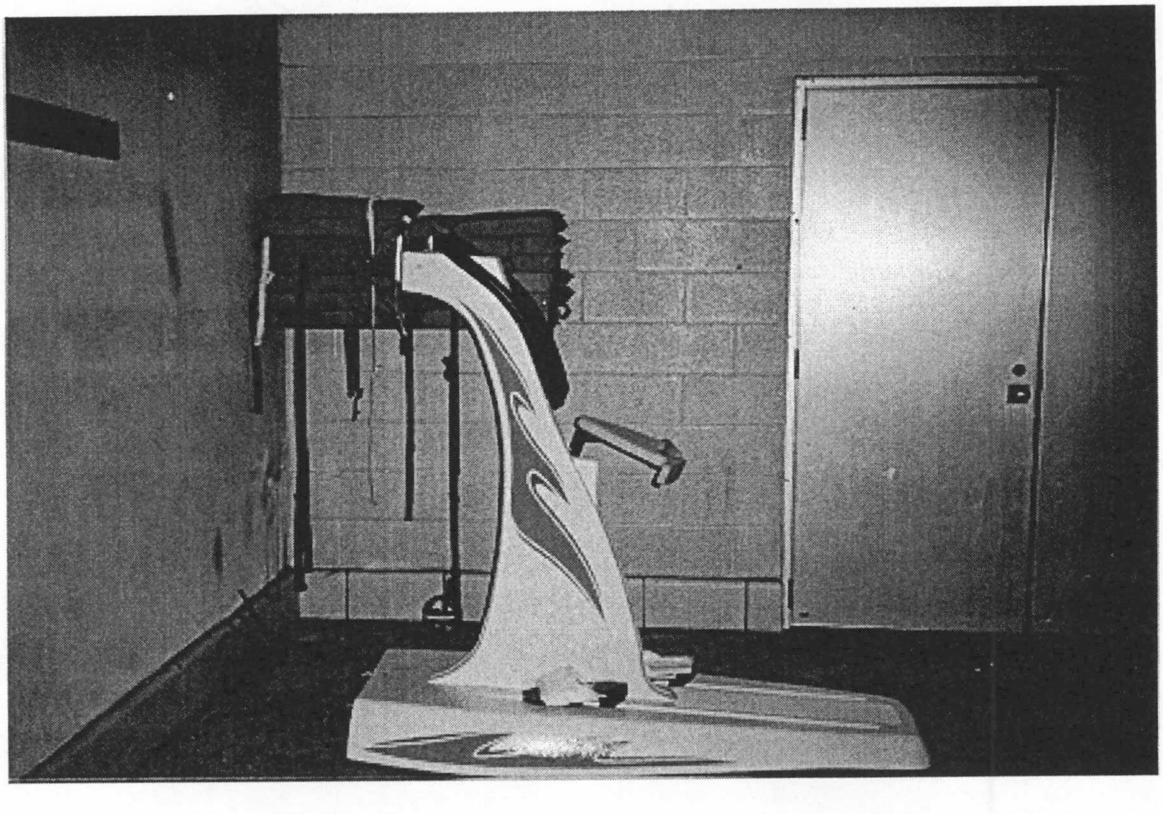
APPENDIX D-1

This is a photograph of the Hydroforce Cycle prototype that was used for testing. The hood and display panel were not intact. To show the entire piece of equipment the picture was taken with the piece out of the water.



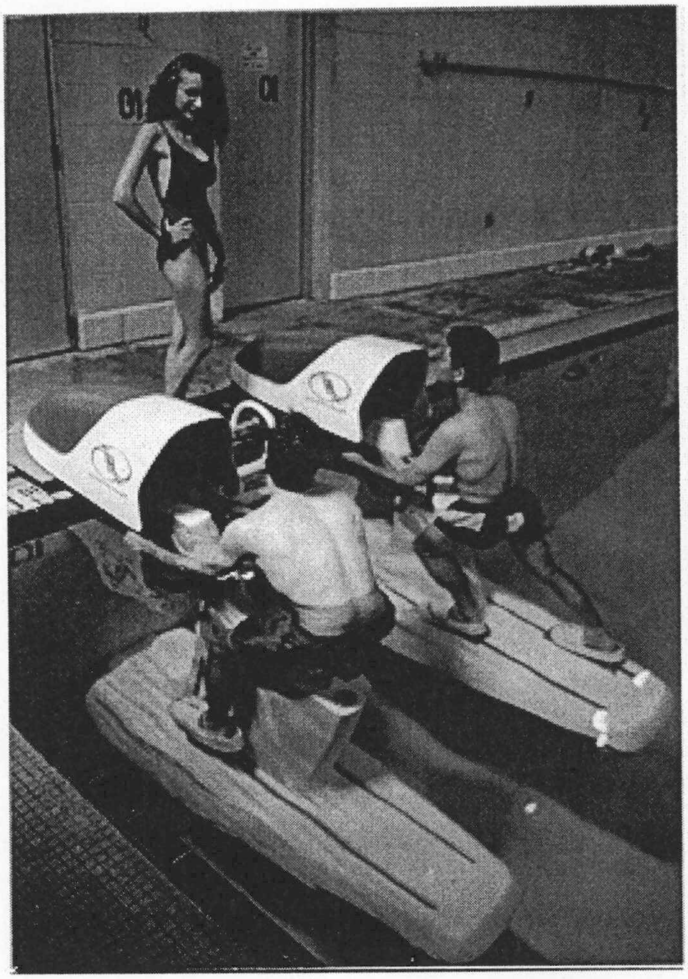
APPENDIX D-2

This is a photograph of the Hydroforce Slider prototype that was used for testing. The hood and display panel were not intact. To show the entire piece of equipment the picture was taken with the piece out of the water.



APPENDIX D-3

This is a photograph of the Hydroforce Cycle and Slider in the water and mounted to the deck of the pool.



APPENDIX E-1

This table contains the individual data obtained during the energy cost portion of the study while riding the Hydroforce Cycle.

Subject	Cadence (rpm)	Level	VO_2 (L/min)	VCO_2 (L/min)	VE (L/min)	RER	HR (b/min)	RPE (6-20)	Energy Cost (kcal/min)
E	50	1	0.93	0.79	17.5	0.85	97	6	4.49
		2	1.01	0.88	20.1	0.88	100	6	4.86
		3	1.05	0.93	19.0	0.89	101	10	5.11
		4	1.08	0.97	19.5	0.90	100	11	5.28
		5	1.01	0.91	20.1	0.91	104	12	4.91
H	50	1	0.81	0.71	15.7	0.88	82	7	3.95
		2	0.81	0.72	16.6	0.89	83	10	3.94
		3	0.93	0.90	19.2	0.96	85	11	4.62
		4	1.00	0.95	20.0	0.95	86	11	5.00
		5	1.02	0.96	22.2	0.95	91	13	5.03
B	60	1	1.40	1.24	28.1	0.88	116	6	6.82
		2	1.28	1.11	23.5	0.87	118	6	6.22
		3	1.50	1.32	27.9	0.88	121	8	7.29
		4	1.60	1.42	30.7	0.88	124	11	7.80
		5	1.62	1.44	30.9	0.89	125	11	7.91
I	60	1	1.13	0.98	20.6	0.86	102	8	5.49
		2	1.15	1.02	20.9	0.89	100	8	5.61
		3	1.22	1.12	24.1	0.97	98	8	5.98
		4	1.35	1.20	25.1	0.89	104	9	6.58
		5	1.33	1.19	27.1	0.90	110	9	6.48

APPENDIX E-1 (cont.)

Subject	Cadence (rpm)	Level	VO_2 (L/min)	VCO_2 (L/min)	VE (L/min)	RER	HR (b/min)	RPE (6-20)	Energy Cost (kcal/min)
J	65	1	1.83	1.63	35.8	0.89	130	11	8.94
		2	1.90	1.72	36.5	0.91	133	11	9.30
		3	2.05	1.93	41.1	0.94	133	12	10.13
		4	2.03	1.81	39.5	0.89	135	13	9.90
		5	2.09	1.86	38.4	0.89	138	15	10.20
D	65	1	1.69	1.40	30.0	0.83	107	7	8.14
		2	1.92	1.76	35.8	0.92	111	8	9.44
		3	2.17	1.99	41.0	0.92	116	9	10.65
		4	2.18	2.02	43.9	0.92	117	9	10.73
		5	2.59	2.37	52.2	0.92	125	10	12.70
A	70	1	2.61	2.30	49.9	0.89	115	12	12.70
		2	2.35	2.15	45.4	0.91	129	13	11.53
		3	2.31	2.14	46.1	0.92	140	13	11.36
		4	2.41	2.27	49.6	0.94	136	15	11.91
		5	2.35	2.12	44.4	0.90	140	15	11.50
C	70	1	2.06	1.81	35.3	0.88	113	9	10.03
		2	1.90	1.69	33.9	0.89	110	9	9.28
		3	2.12	1.90	40.2	0.90	113	8	10.35
		4	2.32	2.06	43.3	0.89	117	9	11.33
		5	2.41	2.16	44.9	0.90	122	9	11.79

APPENDIX E-2

This table provides individual data obtained during the energy cost portion of the study while exercising on the Hydroforce Slider.

Subject	Cadence (cpm)	Level	VO_2 (L/min)	VCO_2 (L/min)	VE (L/min)	RER	HR (b/min)	RPE (6-20)	Energy Cost (kcal/min)
E	25	1	0.72	0.51	11.9	0.71	80	8	3.35
		2	0.73	0.59	13.7	0.81	84	12	3.50
		3	0.80	0.68	15.3	0.86	86	13	3.85
		4	1.10	0.91	18.3	0.83	96	14	5.3
F	25	1	0.91	0.85	17.6	0.93	86	6	4.49
		2	0.90	0.80	19.9	0.90	90	7	4.40
		3	1.01	0.88	18.9	0.86	97	8	4.92
		4	1.29	1.14	24.0	0.88	104	11	6.27
H	30	1	1.03	0.90	19.1	0.87	88	8	5.02
		2	0.95	0.82	18.7	0.86	92	10	4.62
		3	1.20	1.10	21.3	0.85	102	13	5.78
		4	1.31	1.21	28.1	0.92	120	15	6.44
J	30	1	1.00	0.83	21.5	0.83	98	8	4.79
		2	0.94	0.77	19.0	0.82	95	9	4.53
		3	1.35	1.11	23.8	0.82	104	11	6.48
		4	1.75	1.57	35.7	0.90	118	14	8.57
I	35	1	1.09	0.90	21.7	0.83	86	6	5.23
		2	1.10	0.93	22.0	0.85	88	9	5.32
		3	1.32	1.15	26.2	0.87	104	13	6.39
		4	1.81	1.66	37.5	0.92	118	15	8.88
D	35	1	1.58	1.29	30.8	0.82	98	6	7.60
		2	1.74	1.47	33.9	0.84	102	7	8.40
		3	1.86	1.59	35.1	0.85	104	8	9.02
		4	1.93	1.63	37.6	0.85	105	10	9.33

APPENDIX E-2 (cont.)

Subject	Cadence (cpm)	Level	VO_2 (L/min)	VCO_2 (L/min)	VE (L/min)	RER	HR (b/min)	RPE (6-20)	Energy Cost (kcal/min)
A	40	1	1.36	1.20	28.3	0.88	109	11	6.63
		2	1.35	1.18	28.7	0.88	114	12	6.56
		3	1.76	1.53	35.3	0.87	121	14	8.56
		4	2.44	2.21	58.1	0.94	153	17	12.03
C	40	1	1.34	1.18	25.6	0.88	91	7	6.52
		2	1.22	1.12	25.8	0.92	94	8	5.99
		3	1.67	1.55	33.6	0.93	111	9	8.20
		4	1.74	1.69	40.1	0.97	142	14	8.64

APPENDIX F

This table gives the physical characteristics of each subject participating in this portion of the study which may have had an effect on oxygen consumption of cycling in water.

Subject	Height (cm)	Weight (kg)	BSA* (square meters)	BMI
A	185	76	2.00	22.2
B	175	67	1.80	21.9
C	185	85	2.10	24.8
D	185	93	2.18	27.2
E	175	69	1.82	22.5
F	178	74	1.92	23.4
G	180	79	1.99	24.4
J	188	71	1.98	20.1
Means	182	76	1.97	23.0
S.D.	4.6	7.9	0.12	2.0

* Obtained from Consolazio et al. (1963).

VITA

Jason Patrick Crum was born in Frederick, Maryland on July 23, 1972. He attended the public schools of Frederick County and graduated from Walkersville High School in June 1990. In August 1990 he attended Frostburg State University, Maryland where he received his Bachelor of Science degree in Health and Physical Education in December 1994.

In August of 1995 he entered the Graduate School of the University of Tennessee, Knoxville to begin his studies in exercise physiology while employed by the University as a graduate teaching associate in the Physical Education and Activities Program.