ABSTRACT


The Precor C544 Transport (Transport) (Precor Inc., Bothell, WA) is a motorized cardiovascular exercise machine designed to glide feet in a forward (F) or backward (B) circular pattern. Twenty female Ss (18-37 yrs) performed 2, 10 min submaximal tests consisting of the F and B motion on the Transport at equivalent work settings. The Ss were placed into 2 categories based on their experience level of exercising on the Transport. Physiological responses (VE, VO2, METs, RER, kcal, HR, and RPE) for F and B exercise were analyzed and compared. A 3-way ANOVA with repeated measures determined no significant (p > .05) differences between responses based on experience levels. With data combined regardless of experience level, 2-way ANOVA with repeated measures indicated no significant (p > .05) interaction between F and B exercise in all physiological variables. Significant (p < .05) main effects were found between workloads for all physiological variables except RER. As the intensity increased, physiological variables significantly increased. A significant (p < .05) main effect was found for HR and RPE during the first workload which resulted in higher values during B exercise. It was concluded that the Transport elicits similar physiological responses in the F and B direction possibly due to the control for stride length and frequency. Exercising on the Transport should provide an adequate stimulus to improve aerobic capacity.
A COMPARISON OF ENERGY COST DURING
FORWARD AND BACKWARD EXERCISE
ON THE PRECOR C544 TRANSPORT

A THESIS PRESENTED
TO
THE GRADUATE FACULTY
UNIVERSITY OF WISCONSIN-LA CROSSE

IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE
MASTER OF SCIENCE DEGREE

BY
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DECEMBER 1997
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We recommend acceptance of this thesis in partial fulfillment of this candidate's requirements for the degree:

Master of Science in Adult Fitness/Cardiac Rehabilitation

The candidate has successfully completed her final oral defense.

Thesis Committee Chairperson Signature

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This thesis is approved by the College of Health, Physical Education, and Recreation.

Date

Date

Date

Date
ACKNOWLEDGEMENTS

A special recognition is extended to all who devoted their time and patience throughout the development of this thesis. I would like to express my appreciation to Dr. Nancy Butts, my thesis chairperson, for her guidance and expertise. I would also like to thank the other members of my committee, Dr. Marilyn Miller and Dr. Glenn Brice, for their time and assistance. Thank you to Mr. Kevin Ward for providing the Precor C544 Transport for this study and Mr. Chris Dodge for all his help in the Human Performance Laboratory. Also, thanks to all who volunteered to be part of this study, without you, this study could not have taken place. A sincere thank you to all my classmates. I will cherish the memories and friendship.

Thank you Mom, Dad, and family for your love and support. A special thanks to Amy and Brad Stanislawski for providing the use of their computer and printer at all hours. Tricia Schindler deserves a great deal of appreciation for assisting me though all the ups and downs encountered during this year. Finally, I would like to thank Todd Hammond for his patience and unending support.
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CHAPTER I
INTRODUCTION

Background

Equipment companies are continuously finding new ways to motivate the public to exercise. The more traditional cardiovascular machines, such as the treadmill and the bicycle, are being challenged with recent innovations that offer variability and decreased risk of injury (Murphy, 1997). Recently, equipment companies have focused on combining the traditional cardiovascular machines into one by designing machines that simulate several exercises. One of the latest innovations to reach the fitness market is the Precor C544 Transport (Transport) (Precor Incorporated, Bothell, WA) which has been designed to glide the feet in a forward or backward circular pattern simulating a combination of biking, walking, running, and stair climbing. According to the American College of Sports Medicine (ACSM, 1995), any activity that uses large muscle groups, can be maintained continuously, and is rhythmical and aerobic in nature may be used to develop and maintain cardiorespiratory fitness. The Transport meets these requirements. The unique nature of this machine is its capability to provide nonimpact exercise with a backward motion option.

Backward exercise, particularly backward running, has been part of training for sports such as football, basketball, and tennis for many years (Flynn, Connery, Smutok, Zeballos, & Weisman, 1994) and has been used primarily for short duration exercises to
increase coordination and endurance. More recently, backward running has gained acceptance as a form of training and as a treatment technique among athletes and researchers (Threlkeld, Horn, Wojtowicz, Rooney, & Shapiro, 1989). Marathon runners have supplemented their training regimens with backward running to improve the strength and balance of different muscle groups (Morton, 1986). In addition, several researchers have investigated the muscle action and joint compressive forces employed during backward running. Threlkeld et al. (1989) reported that backward running increased the strength of the quadriceps muscle group after an eight week backward running program. In 1995, Flynn and Soutas-Little found that backward running reduced patellofemoral joint compressive forces. Studies such as these have led to the use of backward running in the rehabilitation setting for increasing knee extensor strength and reducing stress to injured joints (Flynn & Soutas-Little, 1995).

Need for the Study

The knowledge and understanding of the physiological responses to backward exercise is necessary for the continued use of backward exercise in the rehabilitation setting, as well as for athletes wanting to maintain cardiovascular conditioning levels using this technique. The use of the backward exercise motion on the Transport may enable certain individuals to exercise at an intensity that may elicit cardiovascular benefits while recovering from an injury. Presently, there are no data available regarding the energy costs of forward and backward exercise on the Transport. Therefore, the purpose of this study was to determine if there are significant differences in the following
physiological responses between forward and backward exercise on the Transport: minute ventilation (Ve), oxygen consumption (VO2) expressed in L·min⁻¹, ml·kg⁻¹·min⁻¹, METs, kcal expressed in kcal·min⁻¹, respiratory exchange ratio (RER), heart rate (HR) expressed in beats·min⁻¹, and rating of perceived exertion (RPE).

**Null Hypotheses**

1. There will be no significant differences in physiological responses between exercising forward and backward on the Transport during submaximal exercise at equivalent work settings.

2. There will be no significant differences in physiological responses between the forward and backward exercise when experienced subjects are compared inexperienced subjects.

**Assumptions**

The following were assumptions of the study:

1. Each subject truthfully answered the questions on the written consent form.

2. All subjects were in good health and free of any physical limitations that would prevent exercising on the Transport.

3. All subjects adhered to preconditions outlined prior to testing.

4. One instructional practice session was sufficient to teach the subjects proper techniques while exercising both forward and backward on the Transport, to familiarize the subjects with the headgear used in measuring oxygen consumption and other test procedures, and to relieve test anxiety.
5. The Polar Vantage XL (Polar Inc., Stamford, CT) heart rate monitor accurately measured the subjects' heart rates.

6. All subjects were able to follow a cadence of 100 and 120 strides per minute (spm).

7. The workload settings (i.e., 100 spm, 120 spm, ramp level 10, and resistance level 5) in the forward motion on the Transport were equivalent to workload settings in the backward motion.

**Delimitations**

The following were delimitations of the study:

1. The study was delimited to females in the age group of 18-37 years old.

2. The practice and testing sessions were completed in a three week testing period.

3. The order of the tests were randomly assigned.

4. The use of hands was allowed only to regain a loss of balance.

**Limitations**

The following were limitations of the study:

1. The subjects were female volunteers from the University of Wisconsin-LaCrosse and the surrounding community.

2. At least one practice session was conducted to familiarize the subject with the equipment until the individual could perform sufficiently with tester's approval.
Definition of Terms

Energy Cost - the amount of energy required by the body to perform an activity. Energy costs were estimated in this study from the oxygen requirements of the exercises and expressed in L·min⁻¹, ml·kg⁻¹·min⁻¹, METs or kcal.

Heart Rate (HR) - the number of times the heart beats per minute as determined by Polar Vantage XL (Polar Inc., Stamford, CT) heart rate monitors.

Precor C544 Transport (Transport) (Precor Incorporated, Bothell, WA) - motorized cardiovascular exercise machine which allows the foot to glide in a forward or backward circular pattern simulating walking, running, bicycling, and stair climbing.

Quinton Metabolic Cart (QMC) (Quinton Instrument Company, Seattle, WA) - a programmable, automated, open circuit system used to determine $V_B$, $VO_2$ (L·min⁻¹, ml·kg⁻¹·min⁻¹, METs), kcal, and RER.

Rating of Perceived Exertion (RPE) - a categorical scale ranging from 6 to 20 constructed by Borg (1970) to quantify subject's exercise intensity which corresponds to linear increase in $VO_2$ and HR during exercise.

Respiratory Exchange Ratio (RER) - a ratio of the volume of carbon dioxide expired per minute to the volume of oxygen consumed during the same time interval determined by the QMC through subject's exhaled gases.

Steady State - reflects the balance between physiological responses. Steady state was determined during the fifth minute when the values were no more than one ml·kg⁻¹·min⁻¹
different from the fourth minute. If the physiological responses varied more than one ml·kg⁻¹·min⁻¹, the sixth minute values were used for analysis.

*Strides Per Minute (spm)* - the number of strides (controlled by foot pedals on the Transport) per minute. The spm in this study was established using a metronome.
CHAPTER II

REVIEW OF RELATED LITERATURE

Introduction

As fitness enthusiasts create new and effective ways to enhance aerobic exercise, research is needed to understand the physiological responses to the new equipment. Currently, there is no published research pertaining to the energy cost of forward and backward exercise on the Transport, therefore, the following review of literature will discuss modes of exercise, backward exercise, and low impact/nonimpact exercises.

Modes of Exercise

According to the American College of Sports Medicine (1995), the greatest improvement in maximal aerobic power occurs when the exercise involves the use of large muscle groups, is rhythmic and aerobic in nature, and is maintained continuously for 20 to 60 minutes. The intensity should be 60-90% of maximal HR or 50-85% of HR_{max} reserve. The training adaptations are independent of the mode of aerobic activity, thus the following variety of endurance activities produce the same training effect: "walking, hiking, running, machine-based stair climbing, swimming, cycling, rowing, combined arm and leg ergometry, dancing, skating, cross-country skiing, rope skipping, or endurance game activities" (ACSM, 1995 p. 156).
Training Responses

Numerous studies have been performed comparing the physiological responses to various modes of exercise. Training programs that meet the above ACSM guidelines show a minimum increase of 15% in maximal aerobic power (Davis, Frank, Whipp, & Wasserman, 1979; Gaesser & Rich, 1984; Golding, 1961; Hickson, Foster, Pollock, Galassi, & Rich; 1985; Liang et al., 1982; Santiago et al., 1987; Seals, Hagberg, Hurley, Ehsanl, & Holloszy, 1984; Wanger & Bell, 1986). One of the first studies to employ a variety of endurance activities to a training program was accomplished by Pollock, Dimmick, Miller, Kendrick, and Linnerud (1975). They compared training responses among running, walking, and bicycling of 26 sedentary men. Training was conducted for 30 minutes, 3 days/week for 20 weeks at HR between 85 and 90% maximum. They reported significant increases in cardiovascular function with running, walking, and bicycling training when frequency, duration, and intensity of the training were held constant. They concluded that improvements in cardiovascular function were independent of the mode of training.

Lieber, Lieber, and Adams (1989) found similar training responses in cardiovascular function when they compared the effects of training between swimming and running. The subjects exercised 3 times/week for 11 ½ weeks at HR 75% maximum. The two training groups did not differ significantly from each other in maximal oxygen consumption ($\text{VO}_{2\text{max}}$) and RER between tests. It was concluded that when
cardiovascular stresses were held constant, the improvements in VO2max were not mode specific.

In 1990, Rathnow and Mangum compared the effects of a ten-week single mode training program versus a multimode training program with equivalent energy expenditures. The single mode program consisted of walking/jogging three days per week, whereas the multimode program differed in that subjects exercised one day walking/jogging, one day cycling, and one day arm cranking. A control group was used for comparison. Surprisingly, the posttraining VO2max values from the three ergometry modes for the single mode group values were significantly higher than multimode and control groups. An important difference between the studies by Rathow and Mangum (1990) and Pollock et al. (1975) was that Rathow and Mangum (1990) employed substantially different muscle groups in the multimode training group. Rathow and Mangum (1990) used treadmill running, cycle ergometry, and arm crank ergometry while Pollock et al. (1975) utilized running, walking, and bicycling.

Energy Expenditure

In the past several years, new modes of exercise have become increasingly popular (i.e., walking with arm poles or weights, rowing, skiting, and in-line skating). Several researchers have investigated the physiological responses to the new modes of exercise. Butts, Knox, and Foley (1995) compared the physiological responses to normal walking and walking on a dual action treadmill that incorporates arm exercises. The arm conditions resulted in significantly higher responses for VE, VO2 (L·min⁻¹,
ml·kg⁻¹·min⁻¹, METs), RPE, and HR. It was concluded that using arms while walking on
a dual action treadmill increases energy costs an average of 55% above normal walking.

Thomas, Felock, and Araujo (1989) compared the energy cost during steady state
exercise using four exercise machines: stationary cycle, rower, ski simulator, and
treadmill. The subjects performed 60 minutes of continuous exercise at 65% HR_{max} on
each mode. Results showed no significant difference in RER and energy cost among
exercise modes. They concluded that energy cost was similar for each machine when
intensity of exercise, based on HR, was held constant.

In contrast, Zeni, Hoffman, and Clifford (1996) found different results when they
compared the energy expenditure at a given rating of perceived exertion levels among six
different indoor exercise machines: Airdyne bicycle, cross-country skiing simulator,
cycle ergometer, rowing ergometer, stair stepper, and treadmill. The 13 subjects
exercised at self-selected work rates corresponding to three RPE values of 11 (fairly
light), 13 (somewhat hard), and 15 (hard) for each exercise machine. It was reported that
the treadmill exercise resulted in significantly higher rates of energy expenditure at a
given RPE values than all other exercise machines. The cross-country skiing simulator,
rowing ergometer, and stair stepper resulted in significantly higher rates of energy
expenditure than the Airdyne bicycle and cycle ergometer. Exercising at a given RPE
resulted in substantial differences among exercise machines in rates of energy
expenditure. ACSM (1990) recommends using the RPE scale as an adjunct to heart rate
in monitoring exercise intensity. However, once the relationship between heart rate and RPE is known, RPE may be used in place of heart rate.

Physiological responses to in-line skating were compared to treadmill running (Wallick et al., 1995). Absolute and relative VO2max values were both approximately 5% lower for in-line skating compared to treadmill running. Mean maximal HR was five beats·min⁻¹ lower for in-line skating versus treadmill running. Regression analyses indicated a similar metabolic load at a given heart rate for both modes of exercise. It was concluded that in-line skating may be an alternative to traditional modes of exercise for improving aerobic capacity. Overall, these studies show that variety of endurance activities may be performed to produce cardiovascular benefit; therefore, exercise prescription should focus on the personal preference for the exercise mode. The versatile, nonimpact nature of the Transport makes this mode of exercise an attractive option.

**Backward Exercise**

**Kinematics**

Recently, researchers have investigated the question: “Is backward locomotion a simple reversal of forward locomotion?” Several arguments have been made for and against this simple reversal. Vilensky, Gankiewicz, and Gehlsen (1987) found that backward walking makes functional demands on the system that differ from those made during forward walking. Amplitude of hip movement during backward locomotion is less than during forward locomotion (Bates, Morrison, & Hamill, 1984; Vilensky et al., 1987). This indicates that backward walking at any specific speed is achieved by a faster
cadence but a smaller stride length than forward walking (Flynn et al., 1994; Vilensky et al., 1987). According to Conrad, Beneke, Carnehl, Hohne, and Meinck cited in Vilensky et al., 1987, a smaller stride length may be part of a protective strategy to stabilize balance by minimizing displacement of the center of gravity during backward walking.

In addition to hip movement, marked changes in ankle movements make forward and backward walking quite different (Winter, Pluck, & Yang, 1989). Plantarflexion was greater during forward walking than during backward walking. According to Winter (1983), the plantarflexor movement in forward walking at push-off provides 80% of the power necessary to walk. However during backward walking, the toe-on phase is associated with weight acceptance, rather than push-off which results in a significant change in foot posture. The anatomical asymmetry of the foot and ankle muscles suggests that backward walking is not a simple reversal of forward walking (Vilensky et al., 1987).

Backward locomotion has very different pressure distributions relative to forward locomotion (Kugler, Armstrong, & Moleski, 1990). Extreme values for pressure distribution, as well as the duration of these pressures were found in backward walking and backward jogging. In backward walking the lowest forefoot duration values were found when the greatest rearfoot values were found. Whereas in backward jogging, the forefoot values were high and rearfoot values were low. This increased duration of pressure, whether on the rearfoot in backward walking or on the forefoot in backward
jogging, could cause more compressive loading over time. This may lead to injuries of the boney and soft tissue (Kugler et al., 1990).

In contrast, Winter et al. (1989) concluded that backward walking was almost a simple reversal of forward walking. Their study revealed that joint angle patterns of forward walking were similar to backward walking reversed with an exception of the ankle. The simple muscle function reversal in walking was supported by DeVita and Stribling (1991) who reported opposite power curves were found throughout the stride. Except for the ankle, the muscle activation patterns were consistent with Grillner model (Grillner, 1985). Grillner suggested that the different rhythmic limb movements, such as forward and backward walking, could be controlled by the same group of central pattern generating neurons.

In addition to backward walking and running, backward cycling has gained interest among researchers. A case study on a suitably designed bicycle found that pedaling backwards produced 20% more power than pedaling forward on a traditional bicycle, at cadences from 70 to 100 revolutions per minute (Spinnetti, 1987). The rider exhibited more leverage on the pedals in the backward direction.

**Rehabilitation Setting**

For several years, backward running has been used primarily for short duration exercises to increase coordination and endurance as a part of sports training (Threlkeld et al., 1989). Recently, backward running has been used in the rehabilitation setting. Several studies support backward running as a form of rehabilitation. In 1995, Flynn and
Soutas-Little, recognizing that patellofemoral pain syndrome was a common injury among runners, investigated the differences in patellofemoral joint compressive forces during forward and backward running. According to them, the peak patellofemoral joint compressive forces at self-selective speeds were significantly reduced in backward running when compared to forward running.

An earlier study by Flynn and Soutas-Little (1993) compared mechanical power and muscle action between forward and backward running. It was found that lower peak power occurred during backward running compared to forward running. In addition, significant differences in muscle activation patterns were found in the quadriceps muscle group. The muscle actions of the vastus lateralis and vastus medialis oblique were found to be largely eccentric and concentric during forward running. Whereas in backward running, the muscle actions were isometric and concentric. Miller (1986) reported that eccentric contraction, more commonly associated with muscle soreness, was nearly eliminated in backward running. In contrast, Gray cited in Kugler et al. (1990) reported delayed onset muscle soreness (DOMS) after prolonged backward jogging and suggested that DOMS may be accounted for by the eccentric control of the extreme pronation of the forefoot and the lowering of the calcaneous or heel. Despite the possibility of DOMS, backward running may be useful in the rehabilitation setting to increase knee extensor capabilities (Mackie & Dean, 1984; Threlkeld et al., 1989).

Threlkeld et al. (1989) noted quadriceps strength gains after an 8 week training program of backward running. Backward running produced lower ground reaction force
than forward running. In the rehabilitation setting, Mackie and Dean (1984) employed backward running on a treadmill for 3 months on 21 patients with ligamentous instability of the knee. They reported an increase in power but strength diminished in knee flexors and extensors. Research has shown that backward running appears to be an appropriate rehabilitation technique for people with patellofemoral pain syndrome.

**Physiological Responses**

Flynn et al. (1994) compared the physiological responses (i.e., $V_B$, $VO_2$, RER, HR, and blood lactate) of forward to backward walking and running at 4 mph, 6 mph, and maximum speed. All physiological values were found to be significantly higher during the backward walking and running conditions when compared to the forward walking and running. Blood lactate concentrations were significantly higher after backward exercises than after forward exercises. The results showed that backward walking at 4 mph was similar in physiological demands (approximately 60% $VO_2_{max}$) as forward walking at 6 mph.

An earlier study by Andrews cited in Morton (1986) measured seven subjects for 4 minutes at 4.5 mph in both directions. He reported that $VO_2$ was 28.8 ml·kg$^{-1}$·min$^{-1}$ in the forward direction, whereas the backward direction produced a $VO_2$ of 33.7 ml·kg$^{-1}$·min$^{-1}$. Running backward elicited a mean HR increase of 20.3 beats·min$^{-1}$ and a mean increase in RPE of 2.9 on the Borg's Scale compared to forward running. He concluded that backward walking and running requires greater physiological demands when compared with forward walking and running.
Another study on the physiological responses to backward exercise determined energy expenditure and perceived exertion for nine soccer players while running forwards, backwards, and sideways at three treadmill speeds (Reilly & Bowen, 1984). Results indicated that running sideways and backwards produced similar VO₂ values, but both were significantly higher than running forward at a given speed. A disproportionate rise in exertion was reported at higher speeds. Reilly and Bowen (1984) stated that differences in energy expenditure were likely to be a result of changes in stride frequency, mechanical efficiency, unique muscular demands, and level of individual skill in experimental modes.

Low Impact and Nonimpact Exercise

The type of aerobic activity performed can dramatically affect the load on the lower extremity joints. According to Pascale and Grana (1989), during running the force at the hip and ankle is twice as great as walking on a level surface and at the knee the force is six times as great. The trend toward nonimpact or low impact aerobic exercise has become increasingly popular due to its health and physical fitness benefits with a decreased risk of injury (Smith & Gilligan, 1987). Some activities that limit the amount of impact include cycling, stair stepping machines, swimming, and cross-country skiing. Grove and Londeree (1992) examined the effect of high impact and low impact activities on bone mineral density (BMD) at the lumbar vertebrae. They found that low impact exercise of moderate intensity performed for 20 minutes, three days per week for a year
was as effective as high impact exercise for maintaining BMD in early postmenopausal women.

In contrast, Smith and Gilligan (1987) reported weight bearing activities such as walking and running were more effective in maintaining integrity of the neck of the femur and spine than nonweight bearing activities such as bicycling and swimming. Dook, James, Henderson, and Price (1997) investigated females ranging in age from 42 to 50 years of age to determine if more than 20 years of consistent athletic training and competition in impact versus nonimpact sports had a positive effect on BMD compared to those with long-term abstinence from sport participation. Impact loading activities (i.e., netball, basketball, running, and field hockey) were associated with greater whole body and regional leg BMD than long-term abstinence from sport participation. Nonimpact sports such as swimming were associated with intermediate levels of BMD that did not differ significantly from those subjects with long-term abstinence from sport participation.

In addition, Fehling, Alekel, Clasey, Rector, and Stillman (1995) found that premenopausal athletes participating in the impact activities of gymnastics and volleyball had higher whole body BMD than swimmers and sedentary controls. These results suggest that nonweight bearing activities do not offer a sufficiently high level of strain to the skeleton to influence bone remodelling. However, individuals with low initial fitness levels or preexisting fractures may benefit from nonweight bearing or low impact
activities to strengthen or protect bone through increased muscle strength (Pascale & Grana, 1989).

**Summary**

Numerous studies have found that a variety of endurance exercise modes elicit the same training effect. Backward exercise, a rather unique mode of activity, has gained popularity in rehabilitation settings and as a form of conditioning for athletes to increase quadriceps strength and power. Research on the cardiopulmonary responses of backward walking and running indicates that backward exercise maintains cardiopulmonary fitness while increasing quadriceps strength and reducing compressive forces at the knee.

Impact or weight bearing exercises have been shown to provide mechanical stresses to maintain bone integrity, but with some risk to injury. Low impact and nonimpact exercises provide a decreased risk of injury with health and physical benefits. The Transport may incorporate the best of both conditions. The weight bearing design and nonimpact circular movement pattern of the Transport may allow for the maintenance of bone integrity and muscle strengthening with less stress on the lower body joints.
CHAPTER III

METHODS

Introduction

This study compared the energy cost of exercise on the Transport during forward and backward exercise at equivalent work settings. The methods addressed below include the following divisions: pilot testing, subject selection, practice sessions, testing procedures, and statistical treatment. The methods were approved by the University Human Subjects Institutional Review Board prior to any data collection.

Pilot Testing

Prior to actual collection of data, a pilot study was conducted to determine the exact testing protocol. After signing an informed consent, two female subjects were scheduled for one exercise session on the Transport during which they exercised at various combination of speeds (i.e., 80, 90, 100, 110, 120, and 130 spm), ramp levels (i.e., 1-10) and resistant levels (i.e., 1-10). Based on the reaction of the subjects, two workloads were selected from this pilot study: 100 and 120 spm. Speeds slower than 100 spm and faster than 120 spm posed difficulty balancing in the backward motion for both subjects. A resistance level of five and the highest ramp level of ten were selected since they also allowed for greater control over balance, allowing no use of hands. From this pilot study, the testing protocol was finalized and implemented.
Subject Selection

The subjects selected were 20 female volunteers, ages 18 to 37 years old, from the University of Wisconsin-LaCrosse and the surrounding community. The subjects needed to meet certain criteria before selection based on the Health History Form (see Appendix A). The subjects were in good health and free of any known cardiovascular, respiratory, or orthopedic problems. After the subjects were selected, testing time was established. Each subject was scheduled for one practice session and one testing session.

All subjects were given practice and testing guidelines (see Appendix B). They were instructed to refrain from caffeine, eating, smoking, and drinking alcoholic beverages for at least 4 hours prior to each test. Also, the subjects were advised on the appropriate exercise clothing to wear and asked to refrain from any strenuous exercise on the same day of the test. A consent form (see Appendix C) was given to each subject on the day of the practice session and signed prior to any exercise.

Practice Session

One practice session was required for each subject. During the practice session, subjects were asked if they had ever used the Transport and if so, how many times. Subjects who used the Transport less than 20 times were placed in one category for statistical analysis. Subjects with 20 or more experiences on the Transport were placed in the experienced group. All subjects regardless of experience level practiced at the appropriate stages in both directions until the tester believed the subject could perform adequately. The purposes of the practice session were to familiarize the subjects with
exercising on the Transport, to teach the subjects proper techniques, to familiarize the subjects with the headgear used in measuring oxygen consumption and other test procedures, and to relieve test anxiety.

A demonstration by the researcher included the following: an explanation of the proper way to get on and off the Transport, the correct stride movement patterns in both forward and backward motions, the correct alignment including the use of hands only to regain balance, the explanation of the Borg's Rating of Perceived Exertion (see Appendix D), and the description of the heart rate monitor. After the demonstration, each subject was allowed time to practice exercising both in forward and backward motion at a selected stride rate and resistance. When the subjects felt comfortable with the exercise, they were scheduled for the testing session.

**Testing Procedures**

One testing day was required for each subject. The test day consisted of exercising on the Transport in the forward and backward motion at each of the two different work settings of 100 and 120 spm. The order of forward and backward motion exercises were randomly assigned by a coin toss. On the day of the test, each subject had her height and weight measured while wearing exercise clothing. The height was measured to the nearest centimeter and the weight was measured to the nearest .25 kilogram. The subjects were instructed during the exercise testing session to do warm up stretches prior to the actual test.
The expired air was analyzed by open circuit spirometry using the Quinton Metabolic Cart (QMC, Quinton Instrument Company, Seattle, WA). The QMC determined $V_E$, $VO_2$ (ml·kg$^{-1}$·min$^{-1}$, L·min$^{-1}$, METs), kcal, and RER from exhaled air. The QMC was calibrated prior to each test and current room temperature, relative humidity, and barometric pressure were entered into the program. The calibration procedure for volumes included the use of a 3,000 Liter syringe at various flow rates. The oxygen and carbon dioxide analyzers were calibrated using gases of a known percentage previously determined by the Scholander technique. Heart rates were recorded using the Polar Vantage XL (Polar Inc., Stamford, CT) heart rate monitors. The RPE was recorded using the Borg 6 to 20 point scale. The physiological data ($V_E$, $VO_2$, kcal, and RER) were recorded each minute of the test, and RPE was recorded during the last minute of each workload for both the forward and backward directions.

The testing session consisted of steady state exercises lasting 5 to 6 minutes each for workloads of 100 and 120 spm in both forward and backward directions. Steady state was determined during the fifth minute of each workload. If the $VO_2$ values varied more than one ml·kg$^{-1}$·min$^{-1}$, a sixth minute values were used for analysis. The subject's heart rate was required to return to the preexercise rate before continuing on with either the forward and backward motion. A metronome was used to determine a cadence of 100 spm for the first workload and 120 spm for the second workload. The panel on the Transport was covered so the subjects would not be distracted by information given such as the time clock and spm.
Statistical Treatment

Data were analyzed using the Statistical Program of Social Science (SPSS) software. A three-way analysis of variance (ANOVA) with repeated measures was conducted to determine if a significant difference at the .05 level of confidence existed among direction, workload, and experience level. A two-way ANOVA with repeated measures was used to determine if a significant difference at the .05 level of confidence existed between the forward and backward motion on the Transport. Means, standard deviations, and ranges were calculated for age, height, weight, and steady state variables of $V_e$, $VO_2$ (L·min$^{-1}$, ml·kg$^{-1}$·min$^{-1}$, METs), kcal, RER, HR, and RPE. The HR and respiratory gas values were determined from the last minute of each steady state period. The $VO_2$ values were converted to METs by dividing $VO_2$ ml·kg$^{-1}$·min$^{-1}$ by 3.5 ml·kg$^{-1}$·min$^{-1}$, which is equal to one MET.
CHAPTER IV

RESULTS AND DISCUSSION

Introduction

The purpose of this investigation was to determine if there were significant differences in the physiological responses of exercising forward and backward on the Transport. The 20 subjects were female volunteers between the ages of 18-37 years from the University of Wisconsin-LaCrosse and surrounding area. To determine if exercise experience on the Transport influenced the results, the subjects were placed into two categories based on their experience level of exercising on the Transport (i.e., greater or less than 20 times). The physical characteristics of subjects are presented in Table 1.

Table 1. Physical Characteristics of Subjects (N = 20)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>24.3</td>
<td>4.0</td>
<td>18 - 37</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>164.0</td>
<td>2.4</td>
<td>152.4 - 175.3</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>58.5</td>
<td>7.1</td>
<td>45.0 - 71.0</td>
</tr>
</tbody>
</table>
Results

The steady state variables $V_{E}$, $VO_2$ (ml·kg$^{-1}$·min$^{-1}$, L·min$^{-1}$, METs), kcal, RER, HR, and RPE obtained during the final minute of each stage were analyzed and compared. These values were obtained for workloads at 100 and 120 spm for both the forward and backward directions. A three-way ANOVA (direction $\times$ workload $\times$ experience) with repeated measures was conducted in order to determine significant difference among responses by experience level. No significant ($p > 0.05$) interaction occurred indicating similar changes in all responses between the experienced and the inexperienced subjects, therefore data were pooled for further analysis.

The steady state variables for workloads of 100 and 120 spm for both the forward and backward directions are presented in Table 2. The two-way ANOVA (direction $\times$ workload) with repeated measures revealed no significant ($p > 0.05$) interaction between direction and workload. These results indicate that the forward and backward exercise on the Transport elicit similar results for all of the physiological variables at each workload (100 and 120 spm) regardless of direction.

A significant ($p < 0.05$) main effect was found between workloads for $V_{E}$, $VO_2$ (ml·kg$^{-1}$·min$^{-1}$, L·min$^{-1}$, METs), kcal, HR, and RPE with the 120 spm values being significantly ($p < 0.05$) higher compared to 100 spm regardless of direction. These differences were expected due to increasing workloads from 100 to 120 spm. However, no significant ($p > 0.05$) differences were found for RER between the 100 and 120 spm
Table 2. Means and Standard Deviations of the Physiological Responses to Exercising on the Transport at Workloads of 100 and 120 spm in the Forward and Backward Direction (N = 20).

<table>
<thead>
<tr>
<th>Variables</th>
<th>100 spm</th>
<th>120 spm**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Forward</td>
<td>Backward</td>
</tr>
<tr>
<td>$V_E$</td>
<td>36.3$^a$</td>
<td>37.5</td>
</tr>
<tr>
<td>(L·min$^{-1}$)</td>
<td>5.8$^b$</td>
<td>6.6</td>
</tr>
<tr>
<td>$VO_2$</td>
<td>22.1</td>
<td>22.0</td>
</tr>
<tr>
<td>(ml·kg$^{-1}$·min$^{-1}$)</td>
<td>1.8</td>
<td>2.2</td>
</tr>
<tr>
<td>$VO_2$</td>
<td>1.27</td>
<td>1.26</td>
</tr>
<tr>
<td>(L·min$^{-1}$)</td>
<td>0.12</td>
<td>0.11</td>
</tr>
<tr>
<td>HR</td>
<td>141.1$^*$</td>
<td>145.1</td>
</tr>
<tr>
<td>(beats·min$^{-1}$)</td>
<td>19.1</td>
<td>19.8</td>
</tr>
<tr>
<td>METS</td>
<td>6.3</td>
<td>6.3</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>0.6</td>
</tr>
<tr>
<td>kcal</td>
<td>6.4</td>
<td>6.4</td>
</tr>
<tr>
<td>(kcal·min$^{-1}$)</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>RER</td>
<td>0.95</td>
<td>0.97</td>
</tr>
<tr>
<td></td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>RPE</td>
<td>10.5$^*$</td>
<td>11.1</td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Note. *significantly (p < .05) different between forward and backward at 100 spm  
**significantly (p < .05) different between 100 and 120 spm for all variables except RER.  
a = mean  
b = standard deviation
workloads during the backward exercise protocol. A significant (p < .05) main effect was found between directions for HR and RPE only during the first workload (100 spm) with values being higher during the backward exercise compared to the forward. No significant (p > .05) differences were found for VO₂ (ml·kg⁻¹·min⁻¹, L·min⁻¹, METs), Vₕ, kcal, and RER between exercising in the forward motion compared to the backward motion at each workload.

Discussion

Experience Level

The 20 female subjects were placed into two different groups based on their experience levels of exercise on the Transport. Twelve subjects were considered inexperienced with less than 20 workouts on the Transport and the remaining eight were considered experienced with 20 or more workouts. The present investigation found that when the overall values were compared there were no differences in responses between the experienced and the inexperienced which suggests that using the Transport does not require much skill. This may possibly be due to the design of the Transport which simulates familiar exercises in the forward direction such as cycling, running, walking, and stair climbing.

Although experience levels did not influence the overall results, it should be noted that most of the subjects who indicated that they used the Transport regularly stated that they used it predominately in the forward direction. Thus, the forward direction may have been most comfortable for both the experienced and inexperienced subjects since it most
clearly simulated normal activities. In contrast, using the backward motion may have been as unfamiliar to the experienced group as it was for the less experienced. However, since there were no significant differences in responses between experience levels, the data were combined for all other comparisons.

**100 versus 120 spm**

As expected significantly higher values for $V_E$, $VO_2$ (ml·kg$^{-1}$·min$^{-1}$, L·min$^{-1}$, METs), kcal, HR, and RPE were found at the higher workload of 120 spm compared to 100 spm. Heart rate rises in a linear fashion as a function of increased oxygen uptake and oxygen uptake increases progressively as a function of exercise intensity (ASCM, 1995). However, there was no significant difference in RER between 100 and 120 spm. The reason why there were no differences in RER between workloads is not clear since both RPE and energy costs significantly increased at the higher workload of 120 spm.

**Forward versus Backward Direction**

In the present investigation, $V_E$, $VO_2$ (ml·kg$^{-1}$·min$^{-1}$, L·min$^{-1}$, METs), kcal, and RER were not significantly different between the forward and backward exercise protocols at similar workloads. In contrast, several authors (Flynn et al., 1994; Andrews cited in Miller, 1986; Reilly & Bowen, 1984) reported significantly higher values for oxygen consumption, $V_E$, RER, and HR during backward walking and running conditions compared to similar forward walking and running conditions on a motorized treadmill. They also reported that backward walking and backward running on a motorized treadmill resulted in significantly shorter stride length and significantly greater stride
frequency than the forward walking and forward running counterparts. The control of the
stride length and frequency on the Transport may account for the differences reported by
others (Flynn et al., 1994; Andrews cited in Miller, 1986; Reilly & Bowen, 1984). The
design of the Transport does not permit the subject to alter either their stride length or
frequency at will since their feet always remain in contact with the pedals. Furthermore,
the frequency of the strides were controlled at 100 and 120 spm. Therefore, the similar
responses in $V_E$, $VO_2$ (ml·kg$^{-1}$·min$^{-1}$, L·min$^{-1}$, METs), kcal, and RER between the
forward and backward exercise protocols may be attributed to the control of stride length
and frequency.

In contrast to the actual energy costs, both HR and RPE were found to be
significantly higher during the backward direction at 100 spm compared with the forward
motion at 100 spm. However, no significant differences were found for HR and RPE at
120 spm. It is not clear as to why higher values for HR and RPE were found in the
backward direction for the first workload (100 spm) and not the second workload (120
spm). Although, the increase in HR during the backward exercise during the first
workload may be explained, in part, by the subjects' unfamiliarity of exercising in the
backward direction (Flynn et al., 1994). Schwane, Johnson, Vandenakker, and
Armstrong (1983) suggested that the novelty of the task may contribute to an increase in
metabolic cost because novel tasks require the recruitment of a larger number of motor
units. As stated previously, the experienced subjects in this study indicated that they were
most familiar with the forward direction on the Transport. Therefore, it seems reasonable
to have higher HR values in the backward direction for all subjects regardless of the amount of general experience they may or may not have had on the Transport. Another possible reason for the higher HR with backward exercise may be due the different actions of the quadriceps femoris muscle group during backward movement compared to the forward motion. Flynn and Soutas-Little (1993) found that backward walking and running requires isometric and concentric activity of the quadriceps femoris muscle group, whereas forward walking and running was largely eccentric and concentric.

The comparison of forward and backward exercise also resulted in significantly higher rating on the Borg’s RPE scale in the backward direction compared to the forward direction at 100 spm. This suggests that forward exercise on the Transport is perceived to be easier. Reilly and Bowen (1984) and Andrews cited in Miller (1986) reported similar results in RPE during backward exercise. It was found that backward running on a motorized treadmill at three speeds (5, 7, and 9 km·h⁻¹) elevated perceived exertion 2, 3, and 4 units higher, respectively, when compared to forward running on the Borg’s RPE scale with increasing speeds (Reilly & Bowen, 1984). The novelty of the backward exercise and an increase in HR may have contributed to the individual perceiving the backward exercise to be more difficult (Andrews cited in Miller, 1986).

**Intensity Level**

A concern with the uniqueness of the design of the Transport was whether or not this machine could provide a training stimulus sufficient to increase cardiopulmonary endurance. According to the ACSM position stand (1990), a minimal training intensity
threshold for improvements in VO_{2\text{max}} is approximately 60% of HR_{\text{max}} and 50% of VO_{2\text{max}} or HR_{\text{max}} reserve. The 50% of HR_{\text{max}} reserve represents a HR of approximately 130-135 beat·min^{-1} for young persons similar to those in the present study. In the present investigation, the mean HR for the two directions combined was 143.1 beats·min^{-1} for 100 spm and 160 beats·min^{-1} for 120 spm, which should be sufficient to attain a training threshold in most subjects. Accordingly, the HR levels corresponded to values of 10.8 and 13.2 on the Borg RPE scale which fell within the ACSM’s recommended range (11-13) for maximum cardiorespiratory training. Furthermore, the MET levels achieved in this investigation for 100 and 120 spm were 6.3 and 7.7 METs, respectively. According to the ACSM (1991) metabolic formula, this would correspond to walking at approximately 100.5 m·min^{-1} (3.75 mph) at 4% and 7.5 % grade, respectively. A study by Butts et al. (1995) on energy cost of walking found similar results for MET levels. These results indicate that the Transport would be an alternative mode to walking which could provide a sufficient intensity to improve an individual’s aerobic capacity.

The caloric expenditures on the Transport with both directions combined were found to be 6.4 and 7.8 kcal per minute at 100 and 120 spm, respectively. ACSM (1990) recommends a minimal caloric expenditure of 300 kcal per exercise session performed three days per week, or 200 kcal per session performed four days per week. Thus it appears reasonable to attain that goal by exercising on the Transport a minimum of 30 minutes per session. Although the console on the Transport produces a kcal summary for each workout, its accuracy was not determined in the present study.
Summary

Analysis of the data revealed no significant differences in physiological response to direction and workload between experience levels. However, it should be noted that the majority of the experience in the experienced group was in the forward direction. No significant interaction was found between workloads and directions indicating that forward and backward exercise at similar spm on the Transport elicit similar results for all the physiological variables. As the intensity increased, all physiological variables increased with the exception of RER. Similar values were found for all physiological variables between the forward and backward exercises with exception of higher HR and RPE during the backward exercise for only the first workload. Similar results between the forward and backward exercises for $V_e$, $VO_2$ (ml·kg$^{-1}$·min$^{-1}$, L·min$^{-1}$, METs), kcal, and RER may be a result of mechanics of the Transport which control for stride length and frequency. A significant increase in HR and RPE in the backward direction may be explained by subjects' unfamiliarity of training in the backward direction (Flynn et al., 1994) or due to the different action of the quadriceps muscle group (DeVita & Stribling, 1991). The results suggest that exercising in either the forward or backward motion would elicit similar physiological responses, and thus may provide similar cardiorespiratory benefits in both directions. In addition, the data also show that exercising on the Transport should provide an adequate stimulus to improve aerobic capacity.
CHAPTER V
SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

Twenty female volunteers from the University of Wisconsin-La Crosse and surrounding community performed an exercise test on the Transport in the forward and backward motion at two different work settings. The QMC was used to determine $V_{E}$, $VO_2$ (ml·kg$^{-1}$·min$^{-1}$, L·min$^{-1}$, & METs), kcal, and RER each minute. Both RPE and HR were recorded at the end of each stage. The subjects were placed into two categories for statistical analysis based on their experience level of exercising on the Transport.

A SPSS program was used to determine if a significant difference existed in the physiological variables between the forward and backward exercises using .05 level of confidence. No significant ($p > .05$) differences in the variables of $V_E$, $VO_2$ (ml·kg$^{-1}$·min$^{-1}$, L·min$^{-1}$, & METs), kcal, RER, HR, and RPE were found between the forward/backward exercises or between the two workloads when experience levels were compared. Therefore regardless of experience levels, data were combined for all other comparisons. No significant ($p > .05$) interaction was found in the variables between forward/backward exercises at either workloads. However, a significant main effect ($p < .05$) was found between workloads in all physiological variables with exception of RER. A significant main effect ($p < .05$) between the forward and the backward exercises was found for HR and RPE. These values were significantly higher in the backward
direction when compared to the forward direction only during the first workload (100 spm).

**Conclusions**

The Transport elicited similar physiological responses in the forward and backward direction possibly due to the control for stride length and frequency. Use of the Transport without the use of hands may be limited to 100 and 120 spm because of the issue of balance in the backward direction. In this study, the HR levels ranged from 143.1 to 160.0 beats-min$^{-1}$ which meets the ACSM guidelines for a minimal training intensity of 50% of HR$_{max}$ reserve (ACSM, 1990). Based on the results of this study, the Transport should provide an adequate stimulus to improve aerobic capacity.

**Recommendations for Future Study**

1. A Transport training study is recommended to determine if cardiovascular responses are maintained during backward exercise in both healthy and injured populations.

2. A kinematics study is recommended to determine muscle actions during forward and backward exercise on the Transport.

3. A comparison study could be done to determine the relationship between the actual and predicted caloric expenditure on the Transport.
REFERENCES


APPENDIX A

HEALTH HISTORY FORM
HEALTH HISTORY FORM
for testing on Precor Transport

Name: ___________________________ Date: __________

Address: __________________________ Age: __________

Phone: Home __________________________ Height: __________

Work __________________________ Weight: __________

Medications: __________________________

Please check if you have or have had any of the following:

___ Blood Pressure ≥ 160/90
___ High Cholesterol ≥ 240 mg/dl
___ Diabetes Mellitus
___ Chest Pain with Exercise
___ Shortness of Breath
___ Dizziness or Fainting
___ Claudication with Exercise
___ Orthopedic Problems Explain:
___ Recent Illness Explain:

Do you currently smoke?  ___ Yes  ___ No

Physical Activity
Check all the activities in which you currently participate:

___ None  ___ Walking  ___ Running  ___ Bicycling  ___ Swimming

___ Aerobic Dance  ___ X-C Sking  ___ Stair Climbing

___ Strength Training  ___ Other ________________________

How many days of the week do you exercise? Circle one: 0 1 2 3 4 5 6 7

How long do you exercise?

___ None  ___ Less than 15 minutes  ___ 15-30 minutes

___ 31-45 minutes  ___ 46-60 minutes  ___ > 60 minutes

Do you experience any discomforts such as shortness of breath, chest or leg pain or dizziness when exercising?

___ Yes  ___ No  If Yes, please explain:

Signature ___________________________________________ Date ______________________

Witness ___________________________________________ Date ______________________
APPENDIX B

PRACTICE AND TESTING GUIDELINES
THESIS STUDY: A COMPARISON OF ENERGY COST DURING FORWARD AND BACKWARD EXERCISE ON THE PRECOR TRANSPORT

Name__________________________________________________________

YOUR SCHEDULED PRACTICE SESSION(S)    YOUR SCHEDULED TESTING SESSION

__________________________________________    ______________________________

PRACTICE/TESTING GUIDELINES

Participation in this study will include a minimum of one practice session and one testing session. The practice session(s) will be a minimum of 30 minutes in duration. During the practice session(s), you will become accustomed with the nature of the Precor Transport and given instructions about the testing day. The testing day will be 45 minutes in duration. The location for the practice session will be either in the Strength and Conditioning Center in Mitchell Hall or the Human Performance Laboratory, 225 Mitchell Hall as assigned by Angela Bakken. The testing session will be located in the Human Performance Laboratory.

Prior to the practice session(s) and testing session, the following guidelines must be followed:

1. Please refrain from consuming alcohol or caffeine, using tobacco, or eating food for at least 3 hours before practice or testing session.

2. Please bring and/or wear comfortable shorts, T-shirt, socks, and gym shoes.

3. Please report on time to the Human Performance Laboratory well rested, and having not performed heavy exercise for 24 hours prior to the practice or testing sessions.

PLEASE KEEP THESE APPOINTMENTS. IF FOR ANY REASON YOU CAN NOT MAKE YOUR ARRANGED SESSION, PLEASE CALL:

Angela Bakken........... 782-2691    Human Performance Lab........... 785-8681

I would like to thank you in advance for your participation in my thesis study. Your time and efforts are greatly appreciated.
APPENDIX C

INFORMED CONSENT FORM
THESIS STUDY: A COMPARISON OF ENERGY COST DURING FORWARD AND BACKWARD EXERCISE ON THE PRECOR TRANSPORT

INFORMED CONSENT

I ___________________________ willingly volunteer to participate in a research study to investigate the energy cost of exercising on the Precor Transport, an aerobic cross-training machine. I understand that I will exercise at two submaximal workloads for five to six minutes each in both forward and backward directions. I am aware that the test sequence will be randomly assigned. I understand that the testing session will involve two different cadence speeds of 100 and 120 strides per minute in each direction. After completing one directional test, I will not start the next test until my heart rate returns to pre-exercise rate. Throughout the test, I realize that a headgear with mouthpiece and nose clip will be used during the test so that expired air may be analyzed. My heart rate will be recorded throughout the test with a heart rate monitor strapped to the chest.

I understand that my participation in this research study will require a minimum of one, 30 minute practice session and one, 45 minute exercise session. All sessions will be scheduled at my convenience and conducted by Angela Bakken (782-2691) in the Human Performance Laboratory or the Strength and Conditioning Center in Mitchell Hall on the campus of University of Wisconsin-La Crosse under the direction of Nancy Butts, Ph.D. (785-8586, 221 Mitchell Hall).

As with any exercise, there exists the possibility of adverse changes occurring (i.e., dizziness, falling, difficulty in breathing, etc.) during the test. In addition, I may feel tired at the end of the test. If any abnormal observations are noted, I understand that the test will be immediately terminated.

I understand that any information that I provide will be kept confidential. In addition, I understand that I will not be identified by name in any published material. To my knowledge, I consider myself to be in good health and have no limiting physical conditions or disabilities, especially with regard to my heart, that would preclude my participation in the exercise test as described above. I have been fully advised of the nature of the procedure and the possible risks and complications involved in it. I have read the foregoing information and understand it. Any questions which may have occurred to me have been answered to my complete satisfaction. I, therefore, voluntarily consent to be tested. Furthermore, I know I may withdraw from these exercise sessions at any time without penalty.

Signed: ___________________________ Date: ________________

Witness: ___________________________ Date: ________________
APPENDIX D

BORG'S RATING OF PERCEIVED EXERTION
Borg's Rating 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