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Upper Versus Lower Body Contribution to the Rowing Stroke

Davon I. Jones
Cleveland State University

UPPER VERSUS LOWER BODY CONTRIBUTION TO THE ROWING STROKE

DAVON I. JONES

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Thesis Committee Chairperson, Dr. Kenneth Sparks

Department/Date

Dr. Sheila Patterson

Department/Date

Dr. Kathleen Little

Department/Date

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Psalm 19:14- Let the words of my mouth and the meditation of my heart, be acceptable in thy sight, O LORD, my strength, and my redeemer.

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ABSTRACT

Purpose: This study examined energy expenditure and power output by the upper and lower body, as well as gender, and training differences, using the Concept II Model E rowing ergometer. It was hypothesized that (1) there will be greater energy expenditure and power output with the lower body as compared to the upper body, (2) there will be a significantly greater upper and lower body energy expenditure and power output for males in the rowing stroke, and (3) there will be a significantly greater lower body energy expenditure and power output for trained rowers. **Methods:** Subjects included 14 males (7 trained, 7 untrained) and 14 females (7 trained, 7 untrained). Test 1 had participants rowing using the full body; a 1000 meter all out row was performed. Test 2 had the pull-chain from the row handle directly attached to the seat of the Concept II to isolate only lower body rowing input. Rowers then completed a 1000m row using the lower body at the same cadence of the full body row. To determine the contribution of the upper body, the results of test 2 were subtracted from test 1. Power output, energy expenditure, row time, distance per stroke, blood lactate, heart rate, and rate of perceived exertion were recorded. A repeated measures ANOVA was used to compare upper vs lower body, and independent t-tests were used to analyze gender and training effects. **Results:** Upper body power output (188.6 ± 60.5) was significantly greater than lower body (60.2 ± 28.5) power output (p=.001). Lower body energy expenditure (5.5 ± 4.5) was significantly greater than upper body (8.5 ± 3.8) energy expenditure (p=.043). There was a significant upper/lower by gender interaction for power, with upper body power output significantly greater in males ($p=.018$). There was a significant upper/lower by training interaction for both power and energy expenditure, with lower body power output ($p=.008$) and lower body energy expenditure ($p=.021$) significantly greater for trained. **Conclusion:** Upper versus lower body differences show the lower body to be more important in determining better rowing performance. Minor gender differences assume that technique, body composition (i.e. height, lean body mass, etc.), or other factors may be more influential in the rowing stroke. Results also suggest that training is more important than gender in rowing performance.

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CHAPTER I

INTRODUCTION

1.1 Background Information

There has been little research on rowing exercise performed with either the arms or legs separately (Jurimae, Perez-Turpin, Cortell-Tormo, Chinchilla-Mira, & Cejuela-Anta, 2009). Additionally, Jurimae et al. (2009) noted that there was limited examination of the upper and lower body influences on ergometer rowing. To attain better results in various exercises, it is important for athletes and other active individuals to be mindful of physiological and mechanical areas that may need improvement.

The fundamental rowing action requires the application of force in a repetitive, maximal, and smooth manner, through which every large muscle group contributes in a synchronized approach (Mazzone, 1988). The rowing sequence is comprised of the catch, the drive, the finish, and the recovery in that order, respectively (Appendix A). Though mechanical efficiency requires coordinated movement of all major muscles, Cosgrove, Wilson, Watt, and Grant (1999) noted that elite rowers produce approximately 75-80% of their power with their legs, and 20-25% with their arms during the rowing stroke. It is necessary that training is in accordance with this to produce the best results in competition. Physiological factors such as maximal oxygen uptake (VO_{2max}) and delayed lactate accumulation serve as two main purposes of rowing training (Maestu, Jurimae, & Jurimae, 2005). Although some studies have provided a physiological and mechanical understanding of rowing, there still remains little information about the contribution to energy and power output between the upper and lower body in the rowing stroke. There is also a lack of evidence of gender and training differences in the upper and lower body contribution to the rowing stroke.

To simulate the rowing sequence, the rowing ergometer is used by most rowers to reproduce the basic biomechanical and physiological demands of on-water rowing (Hagerman & Korzeniowski, 1989). Simulation of rowing exercise in its proper form and motion is necessary to provide valid and reliable results when compared to rowing on water. Lamb (1989) acknowledges that rowing ergometers are designed to replicate the movements performed during rowing on water, with a high level of performance success when used for training.

1.2 Statement of the Problem

Based on the literature, rowing ergometers are valid in simulating rowing on water. There is a need to determine the contribution to energy expenditure and power output of the upper and lower body, as well as compare males and females, trained and untrained, using an indoor rowing machine.

1.3 Purpose of Study

The purpose of this study was to examine the contribution to energy expenditure and power output by the upper and lower body, assess gender differences, and compare trained and untrained rowers using an indoor rowing machine.

1.4 Hypotheses

1. There will be greater energy expenditure and power output with the lower body as compared to the upper body in the rowing stroke.

2. There will be a significantly greater upper and lower body energy expenditure and power output for males in the rowing stroke.

3. There will be a significantly greater lower body energy expenditure and power output for trained rowers.

CHAPTER II

LITERATURE REVIEW

This study examined the contribution to energy expenditure and power output by the upper and lower body and assessed gender and training differences with an indoor rowing machine. A summary of the literature relevant to this study is discussed in the following sections: Physiological Differences, Energy Expenditure, Power Output, Blood Lactate Concentration, Mechanical Efficiency, and Gender Differences.

2.1 Physiological Differences

Concerning the physiological response of the strength endurance exercise performed by either legs or arms separately, there has been very little information published (Jurimae et al. 2009). Jurimae et al. (2009) assessed the relationship between rowing ergometer performance and physiological responses to upper and lower body exercises in 12 male college level rowers who rowed regularly 5-7 times per week for the previous 4-

6 years. First, rowers performed a 2000m maximal rowing test on a Concept II rowing ergometer. After one day a maximal 7-min bench press (arms) or leg press (legs) exercise was performed in a randomized order. The 7-min duration was chosen because it approximates the duration of a 2000m rowing. All three sessions were done at the same time of the day, between 5 and 8pm. Heart rate blood lactate, and Ratings of Perceived Exertion (RPE) were measured. It was hypothesized that the leg press exercise related to 2000m rowing ergometer test results, rather than the bench pull exercise. It was concluded that the leg press exercise could be used to measure sport-specific strength endurance in rowers.

A study was conducted by Gerzevic, Strojnik & Jarm (2011) to determine the muscles which most respond to the all-out rowing test, and could therefore be considered as the most relevant muscles for rowing. The study used 11 male rowers with at least 4 years rowing experience; mean age =20.18 ± 3.09 years. Two tests were conducted over two days, with at least 48 hours in-between tests. On the first day the subjects participated in a multiphase incremental blood lactate (LA) test on a Concept II rowing ergometer, which consisted of 5, 4-minute intervals with increasing speed of 0.11 m·s-1 every level. The next test completed was an all-out 6-minute rowing test, which simulated that of a 2000m race, with the aim of attaining the best time possible. To record the differences in muscle activation, a surface electromyographic (sEMG) signal was attained from the Gastrocnemius medialis (GC), rectus femoris (RF), vastus lateralis (VL), biceps femoris, gluteus maximus (GM), erector spinae (ES), lower latissimus dorsi (LD_lo), upper latissimus dorsi (LD_up), brachioradialis (BR), and biceps brachii (BB) muscles. The results showed that during the submax test, the average sEMG values increased significantly only in RF and LD_lo muscles. During the all-out test the sEMG values of the RF, VL, and GM muscles increased significantly. Compared to the submax test, the sEMG values of the GC, RF, VL, LD_lo, LD_up, and BB muscles were significantly higher during the all-out test. The results indicate that the most attention should be given to the leg and shoulder girdle extensors and arm flexors, and less to the trunk and hip extensor muscles.

Cosgrove et al. (1999) examined the relationship between physiological variables of rowers and rowing performance. 13 experienced male rowers from Glascow University Boat Club participated in this study. Three tests on separate days with at least a 48 hour interval between tests were carried out using a ConceptII Model B ergometer. On day one, height, body mass, % body fat and VO_{2max} were measured; on day II a lactate profile and rowing economy test were performed; and on day three a 2000m performance test was performed on the rowing ergometer. The best predictors of rowing performance were VO_{2max} and lean body mass, followed by endurance time in the VO_{2max} test, velocity in the VO_{2max} test, and velocity at a blood lactate concentration of $4mmol \cdot 1^{-1}$. The results suggested that rowers should devote time to the improvement of VO_{2max} and lean body mass (Cosgrove et al., 1999).

A study conducted by Izquierdo-Gabarren, Gonzalez, Villarreal, & Izquierdo, (2009) assessed physiological factors to predict traditional rowing performance. Differences in physical fitness, anthropometry, and rowing performance between elite (ER) and amateur (AR) rowers were the main focus of this study. 46 trained male rowers aged 21 -30 years with 8-15 years rowing experience and 5-10 years resistance training, all participated in this study. The two groups were determined based on their competition standard; the ER participated in the top category Spanish rowing league, while the AR participated in the second division Spanish rowing league. Each participant's anthropometric variables of height (m), body mass (kg), body fat (%), and free fat mass (kg) were measured. Each participant was required to attend five sessions within 2 weeks, with the testing time consistent throughout the study. Day 1 and day 2 consisted of maximal strength tests, muscle power output, and maximal numbers of repetitions during a bench pull before failing. Day 3 tested the anthropometric variables in ten strokes. During this first week blood lactate concentrations were measured from two rowing endurance sessions at low intensity. Day 4 included a progressive endurance test on the ergometer, while day 5 included a 20-min all-out test on the ergometer. These two days were separated by at least 48 hours to accommodate sufficient recovery. The anthropometric results showed that the ER group had greater body mass, greater percent fat and greater fat free body mass. The ER group also showed higher power output values compared to that of the AR group. There were significant relationships for both ER and AR with blood lactate concentrations and the 20 min all out row. It was concluded that the 20 min all out row, blood lactate concentration, and the strength indices for rowing performance were the most important predictors of traditional rowing performance in elite and amateur rowers (Izquierdo-Gabarren, 2009).

Yoshiga & Higuchi (2003) examined the rowing performance of female and male rower. It was hypothesized that the rowing performance for females is influenced by their small body size, and considered that the slower rowing time for the female rowers results from their lower fat-free mass and VO_{2max}. The study tested 71 female rowers with a mean age of 19 years and mean 2000m time of 498 s; 120 male rowers with a mean age

21 years, and mean 2000m time of 424 s. All subjects were required to complete an all-out 2000m row on a Concept II ergometer, designed to simulate an actual race on the water. On a separate day the subjects performed a progressive run on a treadmill. The females were required to run at an initial velocity of 140m min^{-1}, and the males at 160m min^{-1}; both at an incline of 3.0%, increased by 20m min^{-1} every 2 min. The results showed that rowing performance was significantly correlated to body height, body mass, fat free mass, and VO_{2max}. Rowing time was slower in the females than in the males with a similar body height and body mass. The results suggest that large individuals with higher aerobic capacity possess an advantage for a 2000m row on an ergometer. It was also suggested that among males and females the variation in body size and aerobic capacity did not explain the entire sex difference in ergometer rowing performance.

2.2 Energy Expenditure

Energy systems were investigated in conjunction with a rowing ergometer on and off a slide, and rowing in water. According to Mello, Bertuzzi, Franchini, & Grangeiro (2009), rowing technique in the water is considered more complex because it involves balance, efficiency and maintenance of speed on the recovery phase, and therefore the movement dynamics on the rowing ergometer are different. A 2000m race simulation test in three different situations; rowing ergometer (using the ConceptII), rowing ergometer with slide, and the water, were performed by 8 male adult rowers (mean age = 23.8 years). Each participant performed all three tests randomly with at least a 48 hour minimum and 72 hour maximum interval between tests. Blood lactate concentration, heart rate, and VO_{2max} were all measured for each test. Based on the results, the participation of the energy systems on the rowing ergometer with or without the slide was similar to the contribution in water, when values relative to time were used. The results also showed that HR and lactate were no different among the conditions (Mello et al., 2009).

Specific biomechanical and physiological rowing performance factor determines metabolic strain in rowing (Steinacker, Marx, Marx, & Lormes, 1986). Steinacker et al. (1986) examined the oxygen consumption and metabolic strain in rowing ergometer exercise. This study evaluated 61 outstanding oarsmen (age not specified) who were able to sustain a maximal workload of 5 $W \cdot kg^{-1}$ or more, and 10 well trained oarsmen (age not specified), and 6 cyclists (not experienced in rowing). A friction-braked rowing ergometer (RE) was used for all rowing subjects which calculated the workload expended and rowing strokes per minute. A standard bicycle ergometer (BE) was used for all cyclists. All subjects performed a multi-stage test which began at a load of 150 W and increased by 50 W every 2 minutes until maximum capacity was reached. An open spirometric system was used to measure oxygen uptakes every 15 seconds for both groups. Net efficiency was calculated at each stage from the caloric equivalents of oxygen consumption; maximal oxygen uptake (VO_{2max}), plasma lactate concentration, and heart rates (HR) were also measured. VO_{2max} was higher on the RE than BE, with the cyclists reaching a greater VO_2 on the BE than the oarsmen. HR showed no difference between the RE and the BE exercise, however higher net efficiency was recorded for the BE exercise compared to that of the RE exercise.

In a study by Yoshiga & Higuchi (2003), it was hypothesized that the cardiovascular response to rowing and running exercise is similar between males and females, but that body size affects the response. The study was conducted using 55 males, mean age 21 ± 3 years, 18 females were also studied, with an average age of 20 ± 2 years. All subjects performed two bouts of exercise; progressive running on a treadmill, and rowing on a Concept II rowing ergometer. The initial speed on the treadmill was set at 160m min^{-1} for males and 140m $min^{-1}$for females, and it was increased by 20m min^{-1} every 2 min, with a 3% incline of the treadmill. The exercise was discontinued when the subject could not perform a given running speed. On the rowing ergometer the initial load was 150 W for males and 125 W for females, and was increased by 50 W for the males and 25 W for the females every 2 min. The exercise was discontinued when the subject could no longer maintain the required intensity. The results showed that both VE_{max} and VO_{2max} were higher during rowing than running; however HR_{max} was lower during rowing than it was during running. The results also showed that both VO_{2max} and VE_{max} were both correlated to body mass and fat free mass. It was also shown that bending the body during rowing did not impair ventilation in males or females. The results indicate that the involvement of more muscles and the body position during rowing facilitates ventilation and venous return, as well as lowers maximal heart rate.

2.3 Power Output

Bourdin, Messonnier, Hager, & Lacour (2004) tested the hypothesis that peak power output (Ppeak) sustained during maximal incremental testing would be an overall index of rowing ergometer performance over 2000m. 54 French oarsmen of national to international competition level, consisting of 23 lightweight (mean age 22.8 years) and 31 heavyweight (mean age 22.6 years) rowers were included in this study. The results of the annual physiological testing were used, in agreement with the French Rowing Societies' Federation. VO_{2max}, blood lactate concentration, and Ppeak were obtained for all oarsmen. Ppeak was the best predictor of rowing ergometer performance. These results demonstrate that Ppeak is an overall index of both physiological capacity and rowing efficiency in both heterogeneous and homogeneous groups (Bourdin et al., 2004).

Hofmijster, Van Soest, & Koning (2009) acknowledge the suggestion that the energy spent to move the rower's body back and forth is higher at higher stroke rates. Hofmijster et al. (2009) refutes this claim showing that gross efficiency during rowing is not affected by stroke rate. 17 female competitive rowers (mean age 22.5 years) all took part in this study. All tests took place on a Concept II rowing ergometer where two experiments were conducted. Test 1 was a 2000 m time trial after a 10 minute warm up, where subjects were asked to go as fast as they could for the entire distance. Test 2 was conducted between 2 days and 4 weeks after the 2000 m. Test 2 had the subjects perform three, 3 minute trials at 70% of their maximal power exerted in test 1; trial 1 had them row at 28 strokes per minute (SPM), trial 2 at 34 SPM, and trial 3 at 40 SPM. The results showed no significant differences in gross efficiency between conditions, and therefore internal losses in power are not influenced by stroke rate. It was also shown that as power increased with the increase in stroke rate, no relationship was found with gross efficiency. It was concluded that internal power losses are unrelated to rowing cycle frequency, within the range of stroke rates that are applied in competitive rowing.

Rowing involves both the upper and lower body and therefore is considered a total body exercise (Huang, Nesser & Edwards, 2007). Huang et al. (2007) determined which physiological variables account for the most variation in a 2000m rowing performance. This study served to make clear whether strength and/or muscle endurance are factors in rowing performance. The study used 10 males (age 17.4 ± 0.7 years) and 7 females (age 17.3 ± 0.6 years). All subjects were required to perform five tests on two separate days, with at least a three day interval between. On day 1 the participants completed a counter movement vertical jump on a Vertec vertical height measuring device to measure lower body power, and a 2000 m all-out rowing ergometer test on a Concept II rowing ergometer. On day 2 the subjects first performed a maximum number of inverted rows on a squat rack with a standard barbell to measure upper body muscle endurance. On the same day the participants then completed a 1-repetition maximum (1 RM) leg press to measure lower body strength, and finally a maximum number of back extensions to measure lower back muscle endurance. The results showed that there were significant correlations with the 2000 m rowing performance for the vertical jump (r = -0.736), inverted row (r = -0.624), leg press (r = -0.536), and height (r = -0.837). The results also showed that height and leg press were the strongest predictors of 2000 m rowing performance. The results of this study indicated that both strength and anaerobic power development were important in the development of male and female club level rowers.

Tachibana, Yashiro, Miyazaki, Ikegami & Higuchi, (2007) note that both muscle mass and fat free mass is the most important requirements for achieving success in rowing. Tachibana et al. (2007) hypothesized that the distribution of muscle mass in the thighs, trunk, and upper arms is well balanced in high caliber rowers. Their study tested 39 male rowers (mean age 20 ± 1 years) and 21 female rowers (mean age 20 ± 1 years). Muscle cross sectional area of the anterior thigh, posterior thigh, lower back, elbow extensors, and elbow flexors was measured by proton-magnetic resonance imaging. All participants completed all-out 2000m rows on different days on a Concept II rowing ergometer, which is designed to simulate the duration, intensity, and stroke rate of a race on the water. The best mean power was recorded and reported as the physically best conditioned performance. On a separate day the rowers took part in a 5 min row on another rowing ergometer called the RowPerfect. The RowPerfect was only used to monitor motion analysis. All subjects were required to row at 20 strokes per min in the first 2 min, increasing to 25, 30, and 35 strokes per minute in the third, fourth, and last minute, respectively. The results showed that the anterior thigh muscle best explained the power demonstrated by the leg drive (r^2 = 0.508); the posterior thigh and lower back muscles combined best explained the power demonstrated by the trunk swing (r^2 = 0.493); the arm muscles also showed a significant correlation (r^2 = 0.424) with the leg drive. Thus, all muscle cross sectional areas were associated with rowing performance either through the production of power or by transmitting work, and indicate that the rowing motion requires a well-balanced distribution of muscle mass throughout the body.

2.4 Blood Lactate Concentration

Maciejewski, Messonnier, Moyen, & Bourdin (2007) tested whether or not large increases in blood lactate concentration and/or body temperature occur during an endurance training session on a rowing ergometer. They suspected that the increase in body temperature and the associated strong activation of thermoregulatory processes may account for the exhaustion in some subjects. Ten highly trained rowers (5 light weight, <72.5 kg, 5 open class, > 72.5 kg), mean age 21.3 years, all participated in two randomized sessions, separated by at least one week on the ConceptII Model C ergometer. The first session was based on incremental exercise to exhaustion starting at 150W and 200W for lightweight and open class rowers, respectively. The second session included two, 30 minute, constant workload exercises in the control condition (two 30 minute workloads at a stroke rate of 19-20 min^{-1} with 10 minutes rest in between), or two, 30 minute constant workload exercises in the air ventilation condition (i.e. two ventilators in front of the rower to provide horizontal airflow, and one placed underneath and behind to provide vertical airflow). The results demonstrated that a steady state in blood lactate was not systematically observed during a training session on a rowing ergometer. Therefore, exertion would not necessarily be associated with blood lactate accumulation (Maciejewski et al., 2007).

Messonnier, Freud, Bourdin, Belli & Lacour (1997) noted that high level competition produces elevated blood lactate concentrations, which suggests that glycolytic processes play an important role in energy supply. Messonnier et al. (1997) looked at the lactate exchange and removal abilities in rowing performance. 12 male rowers (mean age 22 years) at an international or national level, all took part in this study. All tests were performed on a Concept II model C rowing ergometer, where each subject was required to perform 3 successive exercise sessions separated by at least 3 days. Session 1 included incremental exercise up to exhaustion where graded exercise started at 150 W and was increased by 50 W every 3 minutes, with 30 seconds rest in between. Session 2 was a performance test where the subjects were to cover 2500 m as fast as they could. Session 3 required the subjects to row for 6 minutes at 90% of their maximal aerobic power. During session three, blood samples were taken at rest, during and at the end of the exercise. Heart rate, oxygen maximal uptake (VO_{2max}), maximal aerobic power, and blood lactate concentration were all measured. The results suggest that improved lactate exchange and removal are associated with a better performance on the rowing ergometer. It was also observed that lactate removal correlated with the ability to row at high relative work rates. Increased lactate exchange and removal were displayed by the subjects that could probably be explained by metabolic adaptations associated with their high training status.

Lormes, Buckwitz, Rehbein & Steinacker (1993) state that the two most commonly used rowing ergometers are the Gjessing Ergometer (GE), and the Concept II Ergometer (CII). The GE is a friction braked flywheel ergometer, while the CII is a wind resistance braked ergometer (Lomes et al., 1993). Lomes et al. (1993) report that there are indications that power developed on these two types of ergometers is different. Their study examined 6 males (mean age 23 years) and 5 females (mean age 17 years). All subjects performed an incremental stage exercise on both the GE and the CII, in random order, with 1 or 2 days in between tests. The initial load was set at 100 W with increments 50 W every 3 min, with breaks of 30 s for blood sampling. The work rate was increased until exhaustion. Lactate, power, stroke rate, and heart rate were all measured. The results showed no significant differences in maximum lactate and heart rate between exercises on the two ergometers. However, maximum stroke rate and lactate were higher for GE, compared to CII. The results suggest higher anaerobic effort in GE rowing.

2.5 Mechanical Efficiency

Mechanical efficiency can be defined as the ratio between the energy expended by muscle contraction and the mechanical work performed (Fukunaga, Matsuo, Yamamoto, & Asami, 1986). Fukunaga et al. (1986) estimated gross, net, work, and delta efficiencies during rowing, while investigating the similarities and differences in the efficiency of rowing previously reported. Five varsity rowers (mean age 20.8 years) participated in this study. A rowing tank was used where subjects were required to row for as long as they could with an increase in intensity of 10% every 2 minutes with VO_{2max} and heart rate recorded. The results demonstrated that in the rowing ergometer compared to on water, an additional force was essential to accelerate the flywheel at the start of work after every interval, resulting in a lower mechanical efficiency. A higher efficiency on the rowing ergometer could be explained in terms of work done, i.e. the force was measured as "pumping water against resistance" (Fukunaga et al., 1986).

The Concept II rowing ergometers has been used in previous studies to examine rowing performance and physiological factors that may affect it. Steer, McGregor, & Bull, (2006) compared the kinematics and performance measures of two rowing ergometers, the Concept II and the WaterRower. They recruited 12 novice male rowers who had rowed a maximum of five years and a minimum of one year, average age of 21.7 years. The subjects performed a 300 meter bout at a rate of 18-20 strokes per minute, as well as a heart rate of 130-150 beats per minute. Once the rate was maintained data was recorded from approximately 50m into the bout until 10m from the end of the bout, therefore data was analyzed for 240m. Three sessions were performed randomly with either the Concept II or the WaterRower, with a one week interval in between at the repeated rate (18-20 strokes per minute), with one at the rate of 28-30 strokes per minute. Stroke rate, stroke length, peak force, percent point peak force occurred and power in watts were all measured. There were no significant differences between the two ergometers for all variables, and it was concluded that rowing kinematics can be quantified in an accurate and repeatable manner on the Concept II, but the WaterRower can lead to poor and inconsistent technique. Inconsistent technique stemmed from the design of the WaterRower which had a different angle between the footplate and the seat (Steer et al., 2006).

The Concept II ergometers are commonly used to interpret physiological alterations to rowing training, as well as to provide specific training-intensity recommendations (Hahn, Bourdon, & Tanner, 2000). The Concept II manufacture has progressively developed newer models throughout the years, Vogler, Rice, & Withers (2007) examined physiological responses to exercise on different models of the Concept II rowing ergometer, Model IIC and Model IID. Six men and two women, all with more than five years rowing experience participated in the study. They all completed three identical 5 X 4-minute submaximal trials, with a single 4-minute maximal trial, over 5 to 8 days; with familiarization of the IID rower only, because all had prior experience with the IIC (trial 1); using a randomized crossover design such that half performed trial two on the IID and the other half on the IIC ergometer. VO_2max, peak power, and blood lactate concentration (before and after) were all measured for each test. It was concluded that incremental exercise performed on the Concept IID and Concept IIC ergometers display equivalent physiological responses (Vogler et al., 2007).

A rowing ergometer can be placed on a slide to imitate “on-water” rowing (Holsgaard-Larsen & Jensen, 2010). A study examining ergometer rowing with and without slides was conducted by Holsgaard-Larsen & Jensen (2010), where the ConceptII rowing ergometer was put on slides, making it move back and forth to provide an “on-water” feel. Holsgaard-Larsen et al. (2010) hypothesized that a reduced physiological cost would occur on slide ergometers as the lighter mass of the ergometer (~26kg) is moved back and forth during slide-rowing compared to movement of the greater body mass of the rower (~70kg) when using fixed ergometers. Elite female rowers (n=7) from the Danish National team, mean age 24 years, participated in this study. Randomly, they all performed two, 6 minute all out rows (to simulate a 2000m on water race), with at least a 48hr interval between each test, one test with, and one test without, the slides. Heart rate, VO_2, and power were all measured and showed no difference between the two tests. Stroke length was determined to be the same between ergometer types, with a higher oxygen deficit observed during the slide compared to the stationary ergometer. The study concluded that the biomechanical load is lower on a slide than a stationary ergometer; however, the slide ergometer seems just as demanding in terms of aerobic energy sources, and possibly even higher for anaerobic sources when compared to the stationary ergometer (Holsgaard-Larsen et al., 2010).

Most ergometers simulate resistance to on-water rowing by the rotation of a flywheel loaded by either friction of a weighted belt, or by air resistance created by rotating vanes; versions of these ergometers are the Gjessing (A.S. Haby, Norway) and the Concept II (Morrisville, VT), respectively (Mahony, Donne, & O'Brien, 1999). Mahony et al. (1999) compared physiological responses to rowing on friction-loaded and air-braked ergometers. 10 rowers (mean age 24 years) all took part in this study. Over 6-8 days, the subjects took part in one test on the Gjessing (friction-loaded), two tests on the Rowperfect (air-braked) fixed mechanism (older subjective ‘feel’ of the rowing action), and three tests on the Rowperfect free-mechanism (a new biomechanical simulation of the rowing action). This testing was non-random where each test consisted of a 3 min row at each power output, with a 1 min blood sampling interval between increments. The initial power was set at 160 W, with increments of 40 W until exhaustion. Heart rate

(HR), oxygen uptake (VO_2), ventilation (V_E), and blood lactate concentration were compared. The results indicated that similar physiological responses were recorded for all ergometers when compared at equivalent heart rates. It was concluded there were no differences in physiological variables between the Gjessing, Rowperfect fixed, and Rowperfect free ergometers (Mahoney et al., 1999).

Schabort, Hawley, Hopkins & Blum (1999) determined the reliability of performing a 2000m time trial lasting approximately 7 min, performed on a Concept II rowing ergometer. Schabort et al. (1999) observed that in the sport of rowing, athletes frequently perform laboratory based tests on air-braked ergometers (Concept II). They also note that work done on the ergometer is converted to an equivalent distance travelled, and the rower is instructed to cover the distance as quickly as possible. Coaches and athletes appear to be satisfied that this protocol produces the physical demands of the real event; however studies have not reported the reliability of this performance test (Schabort et al., 1999). 8 trained high school rowers, who trained seven sessions a week, on water training and off-water resistance training, who were familiar with the Concept II rowing ergometers, took part in this study. Each subject underwent four sessions. The first session was a progressive incremental test to exhaustion on a Concept II rowing ergometer to determine peak oxygen uptake and sustained power output. This test included a 5 min warm up at a self-selected intensity, a short rest, an initial workload of 100 W maintained for 60 s, increased by 50 W for a further 60 s, and increased by 25 W every minute until fatigue. The next tests included three, 2000m time trials on the rowing ergometer. All tests were performed with a three day rest period in between, at the same time of day, with strong verbal encouragement provided by the coach to the rowers. The results showed high reliability expressed as time to complete each test. The results indicate that the combination of ergometer, athlete and test protocol, are very suitable for monitoring rowing performance and for investigating factors that affect performance in short, high intensity endurance events.

2.6 Gender Differences

In a study conducted by Seiler, Spirduso & Martin (1998), individual race times of males and females reported in the annual World Concept II Rowing Ergometer Rankings, 1990-1994, were analyzed. Men (n=119) and women (n=78), above the 95th percentile, and between the ages of 24 and 74 years were used. Rowing power was calculated by a simplified equation (Power (W) = 1.114×10^8/ (pace per 500m in seconds)$^{2.75}$). The results indicated that age was only modestly correlated with performance in men or women, until the regression analysis was restricted to only the 95th percentile, which showed age as a strong predictor of performance. A greater decline in power was shown for women in both the early ages (between 24 and 50 years), as well as later ages (between 50 and 74 years). The study recognized that differences in physical stature, inherent endurance capacity, training habits, competitive desire, and a host of other factors are a greater source of performance variation than age alone (Seiler et al., 1998).

Mikulic & Markovic (2011) aimed to clarify gender associated differences in maximal intensity exercise performance within a relatively wide-aged range of adolescent athletes. The study used 193 rowers (mean age 14.9 ± 1.9 years), who were grouped on the basis of age; 12, 13, 14, 15, 16, 17, and 18 year olds. A Concept II rowing ergometer was used to conduct all tests in this study. After a short, low intensity warm up followed by a 2 minute rest period, participants were required to perform a 30-s trial at the highest drag factor. They all performed an all-out 30-s row with verbal encouragement from coaches and laboratory staff members. The results showed that there were age-related increases in performance. These increases were reduced by approximately half when the effects of body mass were statistically removed. Gender associated differences in performance were observed for age 13 to age 15 in favor of males while the ages 16, 17, and 18 showed little difference.

2.7 Literature Review Summary

The studies reviewed included the main variables as well as other factors that may have had an influence on the rowing stroke based on previous tests. Although studies were found for physiological differences, energy expenditure, power output, blood lactate concentration, mechanical efficiency, and gender differences, trained versus untrained studies could not be found. Contributions of the upper versus lower body by these variables in the rowing stroke were found in only two studies, thus, further research is necessary.

CHAPTER III

METHODS

3.1 Research Design

This study was an experimental design. The independent variables included upper and lower body rowing, gender, and training. The dependent variables were power output, energy expenditure, rowing time, blood lactate, heart rate and rate of perceived exertion.

3.2 Subjects

Participants were recruited from the Cleveland State University (CSU) Rowing Club, the Cleveland Rowing Foundation and CSU students. Among the 14 males and 14 females recruited, 7 males and 7 females were trained, while 7 males and 7 females were novice rowers. To qualify as a trained rower, the participant had to have had at least 6 months or more rowing experience. All trained rowers were recruited from both the CSU rowing club and the Cleveland Rowing Foundation, while the untrained rowers were recruited from the CSU student body. The CSU Rowing Club and the Cleveland Rowing Foundation members were notified of study objectives and interested volunteers were recruited. Each subject was administered the AHA/ACSM Pre-participation Screening Questionnaire (Appendix B) and was excluded from the study if “yes” was checked for any items that indicated a history of cardiovascular, metabolic, or respiratory disease, if taking any type of prescription medication that might affect the results of the study, or had any symptoms of chest discomfort, shortness of breath, or had experienced dizziness, fainting or blackouts. Healthy, low risk subjects were considered for this study. All participants signed an Informed Consent (Appendix C) approved by the CSU Institutional Review Board (Appendix D), which explained the study procedures, benefits, potential risks, and that their participation was voluntary.

3.3 Procedures

All testing occurred in the CSU Human Performance Laboratory using a Concept II Model E indoor rower (Appendix E). Participants performed two separate tests with at least 48 hours rest between test sessions. In Test 1 the participants used the full body rowing stroke for a 1000 meter all out row, preceded by a 100m warm up row, and concluded with a 100m cool down row. Test 2 followed the same procedures as Test 1 except the pull-chain from the row handle was directly attached to the seat of the Concept II to isolate only lower body rowing input (Appendix F). The average strokes per minute (SPM) completed in Test 2 was the same (SPM) performed during Test 1, with a digital metronome used for pacing cadence. Height, weight, and body composition were measured using a stadiometer, medical balance scale, and Tanita Bioelectrical Impedance Analysis (Model TBF-300A), respectively.

3.3.1 Energy Expenditure

Energy expenditure was measured in kilocalories ($Kcal\cdot min^{-1}$) using the COSMED K4 portable oxygen/carbon dioxide analyzer (Appendix G). Subjects were fitted with a collecting mask adjusted to assure no leaks of expired air. The COSMED K4 was calibrated prior to all testing. The COSMED K4 measured oxygen consumption and carbon dioxide production, and computed energy expenditure ($Kcal\cdot min^{-1}$) using the respiratory exchange ratio (RER), of CO_2 production to O_2 consumption (RER= CO_2/ O_2). The average $Kcal\cdot min^{-1}$, VO_2 ($ml\cdot kg\cdot min^{-1}$), and HR (Polar heart rate monitor), were recorded for each test for the 1000m rowing distance. Rate of Perceived Exertion (RPE) using the Borg Scale (6-20) was taken at the end of each test (Appendix H). Upper body energy expenditure was calculated by subtracting lower body energy expenditure from total body energy expenditure.

3.3.2 Blood Lactate Analysis

A pre and post exercise lactate was measured using a micro technique. Post exercise blood lactate was collected 2 minutes post cool down period. The micro technique required a finger prick with a lancet to acquire a small drop of blood. The finger was cleaned prior to stick with alcohol and dried with gauze. A Microtouch lancet was then used to make a small stick to obtain a drop of blood. The blood was placed into the Lactate Plus analyzer and values were recorded in mMol/dl. A band aid was placed over the wound.

3.3.3 Power Measurement

Power output (Watts per minute) was measured each 100 meters of the 1000 m all out row and averaged. Upper body power output contribution to rowing stroke was calculated by subtracting lower body power output from total body power output. Power output was recorded using the RowPro software compatible with the Concept 2 Model E Indoor Rower, connected to a laptop computer. A printout with the Power Output, Distance per stroke (DPS), Strokes per minute (SPM), Total time, and Pace was collected (Appendix I).

3.4 Data Analysis

Descriptive statistics were obtained for all measures. A repeated measures ANOVA was used to analyze differences in upper versus lower body measures, as well as the interaction with gender and training. Independent t-tests were used to further analyze gender and training differences. SPSS (version 18) was used for all analyses with .05 used as the level of significance.

CHAPTER IV

RESULTS & DISCUSSION

4.1 Results

All subjects successfully completed the two tests to determine the contribution of the upper and lower body during the rowing stroke. Subject characteristics by gender are shown in Table 1, and characteristics by training are shown in Table 2.

Table 1. Characteristics of subjects by gender.

	Males (N=14) Trained/Untrained (7 / 7)	**Females (N=14) Trained/Untrained (7 / 7)**	**Sig. (2-tailed) Gender**
Age (years)	26.3 ± 8.4	25.1 ± 8.4	.704
Weight (kg)	82.6 ± 13.4	69.2 ± 9.1	.005*
Height (in)	69.6 ± 3.3	67.2 ± 2.5	.036*
Body Fat (%)	13.0 ± 4.3	23.2 ± 4.2	.000*

* Significant difference (p<.05)

Table 2. Characteristics of subjects by training.

	Trained (N=14) Males/Females (7 / 7)	Untrained (N=14) Males/Females (7 / 7)	Sig. (2-tailed) Training
Age (years)	31.4 ± 10.8	23.9 ± 2.8	.269
Weight (kg)	74.5 ± 11.7	77.2 ± 14.8	.592
Height (in)	68.6 ± 2.8	68.3 ± 3.4	.767
Body Fat (%)	17.3 ± 7.1	18.8 ± 6.3	.569

* Significant difference (p<.05)

Subject characteristics showed no significant difference between gender for age (p=.704). However, the males had a significantly greater weight (p=.005) and height (p=.036), and the females possessed a significantly greater body fat percent (p=.000). Trained versus untrained showed no significant difference for age (p=.269), weight (p=.592), height (p=.767), or body fat percent (p=.569).

4.2 Upper versus Lower Body Comparisons

Comparison of Upper and Lower Body Power Output

Upper body power output (UPO) and lower body power output (LPO) are shown in Table 3. Upper body power output was significantly higher than lower body power output (p=.001).

Table 3. Comparison of Power Output (W).

	Subjects	Mean (Watts)	Std. Deviation (Watts)	Sig.
UPO Upper Body Power Output	N= 28	188.6	60.5	.000*
LPO Lower Body Power Output	N= 28	60.2	28.5	

* Significant difference (p<.05)

Comparison of Upper and Lower Body Energy Expenditure

Upper body energy expenditure (UEE) and lower body energy expenditure (LEE) are shown in Table 4. Lower body energy expenditure was significantly greater than the upper body energy expenditure (p=.043).

Table 4. Comparison of Energy Expenditure ($kcal \cdot min^{-1}$).

	Subjects	Mean ($kcal \cdot min^{-1}$)	Std. Deviation ($kcal \cdot min^{-1}$)	Sig.
UEE Upper Body Energy Expenditure	N= 28	5.5	4.5	.043*
LEE Lower Body Energy Expenditure	N= 28	8.5	3.8	

* Significant difference (p<.05)

Comparison of Total and Lower Body Rowing Time

Total body rowing time (TRT) and lower body rowing time (LRT) are shown in Table 5. Total body rowing time was significantly faster (151.2 sec) than lower body rowing time (p=.001).

Table 5. Comparison of Rowing Time (seconds).

	Subjects	Mean (seconds)	Std. Deviation (seconds)	Sig.
TRT Total Body Rowing Time	N= 28	227.5	22.6	.000*
LRT Lower Body Rowing Time	N= 28	378.7	68.4	

* Significant difference (p<.05)

Comparison of Total and Lower Body Blood Lactate

Total body blood lactate (TBL) and lower body blood lactate (LBL) are shown in Table 6. Total body blood lactate was significantly higher than lower body blood lactate (p=.001).

Table 6. Comparison of Blood Lactate (mMol/dl).

	Subjects	Mean (mMol/dl)	Std. Deviation (mMol/dl)	Sig.
TBL Total Body Blood Lactate	N= 28	12.9	3.1	.000*
LBL Lower Body Blood Lactate	N= 28	4.5	3.8	

* Significant difference (p<.05)

Comparison of Total and Lower Body Heart Rate

Total body rowing heart rate (THR) and lower body rowing heart rate (LHR) are shown in Table 7. Total body rowing heart rate was significantly higher than lower body rowing heart rate (p=.001).

Table 7. Comparison of Heart Rate (bpm).

	Subjects	Mean (bpm)	Std. Deviation (bpm)	Sig.
THR Total Body Heart Rate	N= 28	167.3	10.3	.000*
LHR Lower Body Heart Rate	N= 28	134.9	20.5	

* Significant difference (p<.05)

Comparison of Total and Lower Body Rate of Perceived Exertion

Total body rowing rate of perceived exertion (TRPE) and lower body rowing rate of perceived exertion (LRPE) are shown in Table 8. Total body rowing rate of perceived exertion was significantly greater than lower body rowing rate of perceived exertion (p=.001).

Table 8. Comparison of Rate of Perceived Exertion (RPE).

	Subjects	Mean (RPE)	Std. Deviation (RPE)	Sig.
TRPE Total Body RPE	N= 28	17.4	1.5	.000*
LRPE Lower Body RPE	N= 28	12.4	1.7	

* Significant difference (p<.05)

Summary: Upper versus Lower Body Comparisons

Upper body power output was significantly higher than lower body power output, whereas lower body energy expenditure was significantly greater than upper body energy expenditure. Total body rowing time was significantly faster (151.2 sec) than lower body rowing time. Total body rowing blood lactate, heart rate, and rate of perceived exertion were all significantly higher than lower body values.

4.3 Gender Comparisons

Comparison of Upper and Lower Body Power Output

Total body rowing power output (TPO), upper body power output (UPO) and lower body power output (LPO) by gender are shown in Table 9.

Table 9. Comparison of Power Output (W) by Gender.

	Gender	Mean (Watts)	Std. Deviation (Watts)	Sig. (2-tailed)
TPO Total Body Power Output	Male N=14	273.9	85.2	.083
	Female N=14	223.8	59.6	
UPO Upper Body Power Output	Male N=14	215.0	66.7	.018*
	Female N=14	162.3	40.8	
LPO Lower Body Power Output	Male N=14	58.9	32.9	.811
	Female N=14	61.5	24.3	

* Significant difference (p<.05)

There was a significant (p=.006) gender interaction as illustrated in Figure 1.

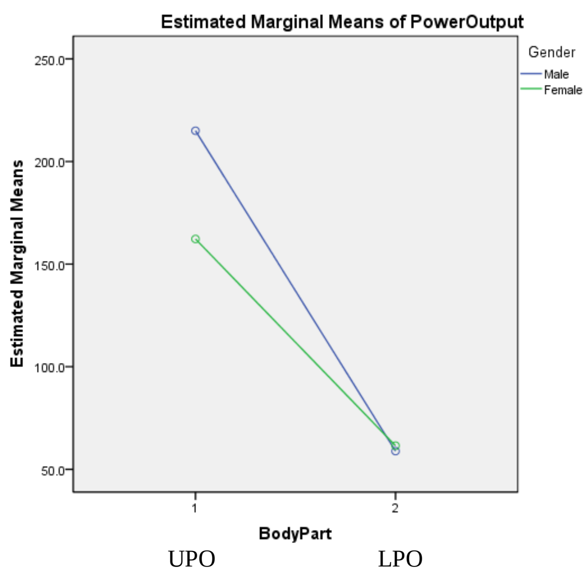

Figure 1. Comparison of Power Output (W) by Gender.

There was no significant difference between total or lower body rowing power output by gender; however, upper body rowing power output was significantly greater for the males than the females (p=.018) (Table 8).

Comparison of Upper and Lower Body Energy Expenditure

Total body rowing energy expenditure (TEE), upper body energy expenditure (UEE), and lower body energy expenditure (LEE) by gender are shown in Table 10. There was no significant interaction (p=.716). While total body rowing energy expenditure, upper body energy expenditure, and lower body energy expenditure were greater for the males than the females, these differences were not significant ($p \geq .05$).

Table 10. Comparison of Energy Expenditure by Gender.

	Gender	Mean ($kcal \cdot min^{-1}$)	Std. Deviation ($kcal \cdot min^{-1}$)	Sig. (2-tailed)
TEE Total Body Energy Expenditure	Male N=14	15.1	4.9	.168
	Female N=14	13.0	2.6	
UEE Upper Body Energy Expenditure	Male N=14	5.8	5.6	.758
	Female N=14	5.3	3.2	
LEE Lower Body Energy Expenditure	Male N=14	9.3	4.1	.280
	Female N=14	7.7	3.3	

Comparison of Rowing Time

Total rowing time (TRT) and lower body rowing time (LRT) by gender are shown in Table 11. There was no significant interaction (p=.200). Although total rowing time was faster for the males, while lower body rowing time was faster for the females; however, neither of these differences was significant ($p \geq .05$) (Table 11).

Table 11. Comparison of Rowing Time (sec) by Gender.

	Gender	Mean (seconds)	Std. Deviation (seconds)	Sig. (2-tailed)
TRT Total Rowing Time	Male N= 14	219.7	23.2	.066
	Female N= 14	235.4	19.8	
LRT Lower Body Rowing Time	Male N= 14	385.0	75.0	.631
	Female N= 14	372.3	63.3	

Comparison of Blood Lactate

Total body rowing blood lactate (TBL) and lower body rowing blood lactate (LBL) by gender are shown in Table 12. As illustrated in Figure 2, there was a significant gender interaction (p=.046), with males having significantly (p=.004) higher lower body rowing blood lactate than females but there was no significant gender difference for total body rowing blood lactate (Table 12).

Table 12. Comparison of Blood Lactate by Gender.

	Gender	Mean (mMol/dl)	Std. Deviation (mMol/dl)	Sig. (2-tailed)
TBL Total Body Blood Lactate	Male N=14	13.3	3.2	.567
	Female N=14	12.6	3.0	
LBL Lower Body Blood Lactate	Male N=14	6.5	4.1	.004*
	Female N=14	2.5	2.1	

* Significant difference (p<.05)

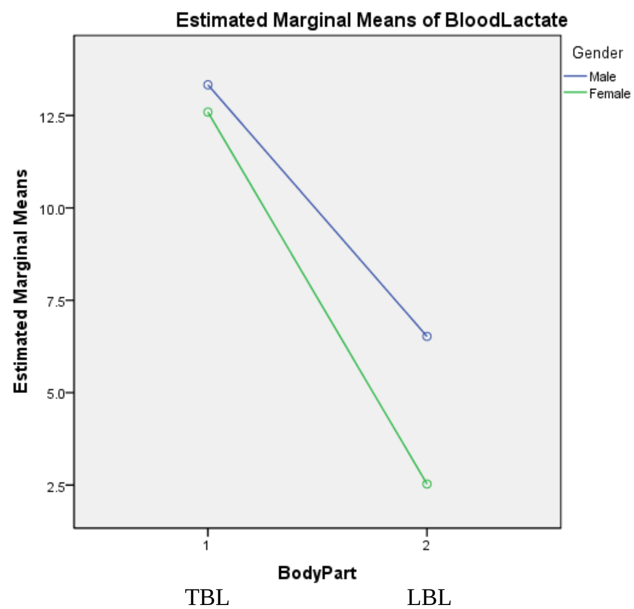

Figure 2. Comparison of Blood Lactate by Gender.

Comparison of Heart Rate

Total body rowing heart rate (THR) and lower body rowing heart rate (LHR) by gender are shown in Table 13. There was no significant interaction (p=.175) and no significant differences for total or lower body rowing heart rates between males and females (Table 13).

Table 13. Comparison of Heart rate by Gender.

	Gender	Mean (bpm)	Std. Deviation (bpm)	Sig. (2-tailed)
THR Total Body Heart Rate	Male N=14	167.8	11.2	.804
	Female N=14	166.8	9.8	
LHR Lower Body Heart rate	Male N=14	139.7	24.0	.216
	Female N=14	130.0	15.6	

Comparison of Rate of Perceived Exertion

Total body rowing rate of perceived exertion (TRPE) and lower body rowing rate of perceived exertion (LRPE) by gender are shown in Table 14. There was no significant interaction (p=.172) and no significant (p ≥ .05) differences for total or lower body rate of perceived exertion between males and females (Table 14).

Table 14. Comparison of Rate of Perceived Exertion by Gender.

	Gender	Mean (level)	Std. Deviation (level)	Sig. (2-tailed)
TRPE Total Body RPE	Male N=14	17.0	1.5	.140
	Female N=14	17.9	1.5	
LRPE Lower Body RPE	Male N=14	12.6	1.7	.521
	Female N=14	12.1	1.8	

Summary: Gender Comparisons

There was no significant difference between total or lower body rowing power output by gender; however, upper body power output was significantly greater for the males than the females. While total body rowing energy expenditure, upper body rowing energy expenditure, and lower body rowing energy expenditure were greater for the males than the females, these differences were not significant. Total body rowing time was faster for the males, while lower body rowing time was faster for the females; however, neither of these differences was significant. Males had a significantly higher lower body rowing blood lactate than females but there was no significant gender difference for total body rowing blood lactate. There were no significant differences for total or lower body rowing heart rates and rate of perceived exertion between males and females.

4.4 Trained versus Untrained Comparisons

Comparison of Upper and Lower Body Power Output

Total body rowing power output (TPO), upper body rowing power output (UPO) and lower body rowing power output (LPO) by training are shown in Table 15. While there was no significant difference between lower body rowing power output or upper body rowing power output, lower body rowing power output was significantly (p=.008) greater for the trained than the untrained. However, the interaction was not significant (p=.555).

Table 15. Comparison of Power Output (W) by Training.

	Experience	Mean (Watts)	Std. Deviation (Watts)	Sig. (2-tailed)
TPO Total Body Power Output	Trained N= 14	270.0	95.2	.145
	Untrained N= 14	227.6	46.3	
UPO Upper Body Power Output	Trained N= 14	196.1	75.4	.526
	Untrained N= 14	181.2	43.0	
LPO Lower Body Power Output	Trained N= 14	74.0	28.1	.008*
	Untrained N= 14	46.4	22.0	

* Significant difference (p<.05)

Comparison of Upper and Lower Body Energy Expenditure

Total body rowing energy expenditure (TEE), upper body rowing energy expenditure (UEE), and lower body rowing energy expenditure (LEE) by training are shown in Table 16. As shown in Figure 3, there was a significant interaction (p=.049) by training.

Table 16. Comparison of Energy Expenditure (kcal·min^{-1}) by Training.

	Experience	**Mean (kcal·min^{-1})**	**Std. Deviation (kcal·min^{-1})**	**Sig. (2-tailed)**
TEE Total Body Energy Expenditure	Trained N= 14	14.5	4.3	.488
	Untrained N= 14	13.5	3.8	
UEE Upper Body Energy Expenditure	Trained N= 14	4.5	2.8	.213
	Untrained N= 14	6.6	5.6	
LEE Lower Body Energy Expenditure	Trained N= 14	10.1	3.3	.021*
	Untrained	6.9	3.6	

* Significant difference (p<.05)

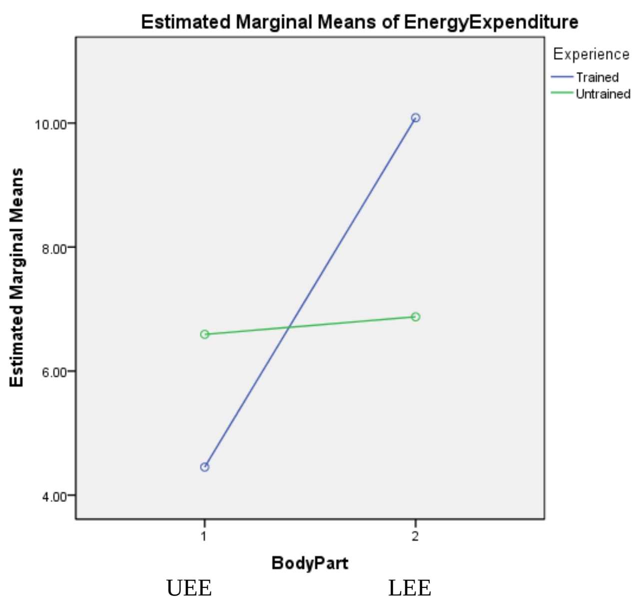

Figure 3. Comparison of Energy Expenditure (kcal·min^{-1}) by Training.

The independent t-tests (Table 16) showed total body rowing energy expenditure was greater, while upper body rowing energy expenditure was less, for the trained but these differences were not significant. However, lower body rowing energy expenditure was significantly (p=.021) greater for the trained than untrained rowers.

Comparison of Rowing Time

Total body rowing time (TRT) and lower body rowing time (LRT) by training are shown in Table 17.

Table 17. Comparison of Rowing Time (sec) by training.

	Experience	Mean (seconds)	Std. Deviation (seconds)	Sig. (2-tailed)
TRT Total Rowing Stroke	Trained N= 14	222.6	27.5	.256
	Untrained N= 14	232.5	16.0	
LRT Lower Body Rowing Stroke	Trained N= 14	346.6	55.5	.010*
	Untrained N= 14	410.8	66.5	

* Significant difference (p<.05)

As shown in Figure 4, there was a significant (p=.010) interaction between rowing time and training.

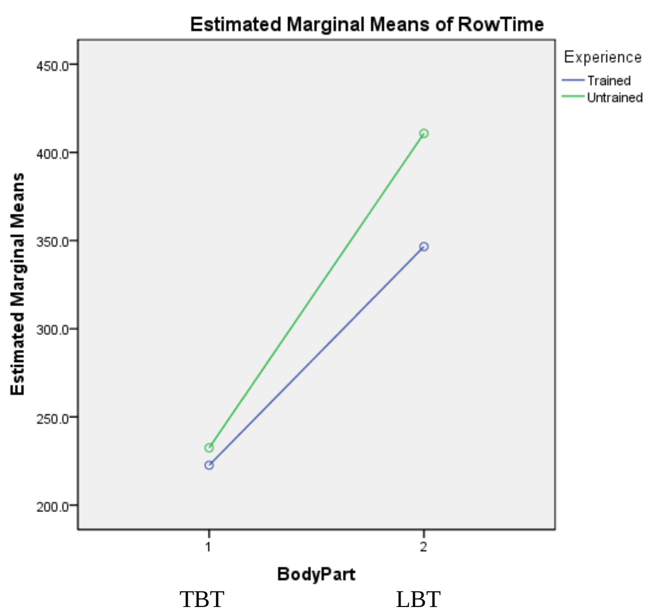

Figure 4. Comparison of Rowing Time by Training (sec)

The independent t-tests showed that total body rowing time was faster for the trained but this was not significant. However, lower body rowing time was significantly (p=.010) faster for the trained versus the untrained.

Comparison of Strokes Per Minute

Total body strokes per minute (TSPM) by training are shown in Table 18.

Table 18. Comparison of Strokes per Minute (SPM) by Training.

	Experience	Mean (spm)	Std. Deviation (spm)	Sig. (2-tailed)
TSPM Total Body Strokes per Minute	Trained N=14	33.4	3.5	.000*
	Untrained N=14	42.9	7.0	

* Significant difference (p<.05)

The independent t-tests showed a significantly (p=.001) greater total body rowing strokes per minute for the untrained compared to trained rowers.

Comparison of Distance Per Stroke

Total distance per stroke (TDPS), upper body rowing distance per stroke (UDPS), and lower body rowing distance per stroke (LDPS) by training are shown in Table 19.

There was a significant (p=.001) interaction between upper body rowing distance per stroke and lower body rowing distance per stroke by training (Figure 5).

Table 19. Comparison of Distance per stroke by Training

	Experience	Mean (meters)	Std. Deviation (meters)	Sig. (2-tailed)
TDPS Total Body Distance per Stroke	Trained N=14	8.1	.5	.000*
	Untrained N=14	6.2	1.0	
UDPS Upper Body Distance per Stroke	Trained N=14	2.9	.5	.304
	Untrained N=14	2.7	.7	
LDPS Lower Body Distance per Stroke	Trained N=14	5.3	.7	.000*
	Untrained N=14	3.6	.8	

* Significant difference (p<.05)

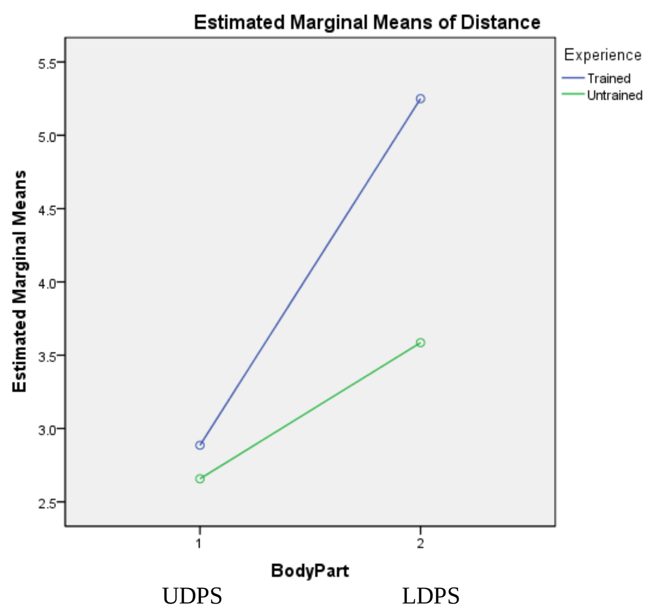

Figure 5. Comparison of Distance per Stroke by Training

The independent t-tests showed a significantly greater total body rowing and lower body rowing distance per stroke for trained compared to untrained rowers. However, there was not a significant difference for upper body distance rowing per stroke between groups.

Comparison of Blood Lactate

Total body rowing blood lactate (TBL) and lower body rowing blood lactate (LBL) by training are shown in Table 20. There was no significant interaction (p=.554) and no significant (p= ≥ .05) difference for total body or lower body rowing blood lactate for trained versus untrained rowers (Table 20).

Table 20. Comparison of Blood Lactate by Training.

	Experience	Mean (mMol/dl)	Std. Deviation (mMol/dl)	Sig. (2-tailed)
TBL Total Body Blood Lactate	Trained N=14	13.0	3.6	.976
	Untrained N=14	12.9	2.6	
LBL Lower Body Blood Lactate	Trained N=14	5.0	3.9	.472
	Untrained N=14	3.9	3.8	

Comparison of Heart Rate

Total body rowing heart rate (THR) and lower body rowing heart rate (LHR) by training are shown in Table 21. There was no significant interaction (p=.206) and no significant (p ≥ .05) differences for total or lower body rowing heart rate between trained and untrained (Table 21).

Table 21. Comparison of Heart Rate by Training.

	Gender	Mean (bpm)	Std. Deviation (bpm)	Sig. (2-tailed)
THR Total Body Heart Rate	Trained N=14	170.3	8.2	.127
	Untrained N=14	164.3	11.7	
LHR Lower Body Heart rate	Trained N=14	141.9	18.6	.066
	Untrained N=14	127.8	20.4	

Comparison of Rate of Perceived Exertion

Total body rowing rate of perceived exertion (TRPE) and lower body rowing rate of perceived exertion (LRPE) by training are shown in Table 22.

There was a significant (p=.011) interaction between RPE and training (Figure 6).

Table 22. Comparison of Rate of Perceived Exertion by Training

	Experience	Mean (RPE)	Std. Deviation (RPE)	Sig. (2-tailed)
TRPE Total Body RPE	Trained N=14	16.9	1.5	.083
	Untrained N=14	17.9	1.4	
LRPE Lower Body RPE	Trained N=14	13.0	1.9	.047*
	Untrained N=14	11.7	1.3	

* Significant difference (p<.05)

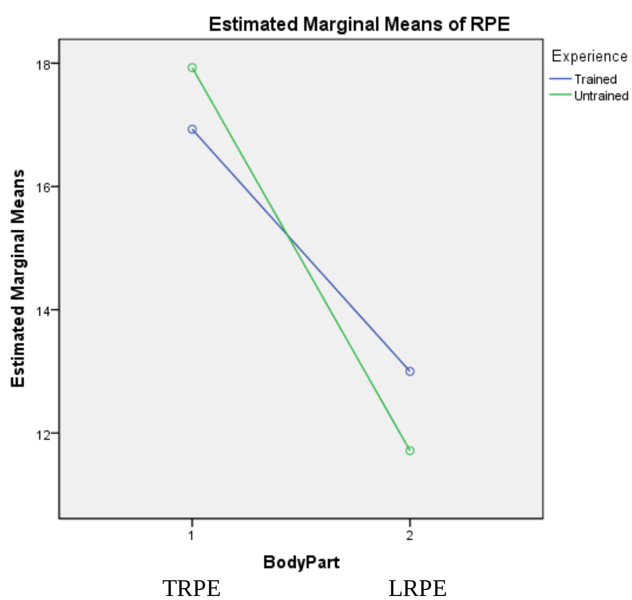

Figure 6. Comparison of Rate of Perceived Exertion by Training

The independent t-tests (Table 21) showed total body rowing RPE was lower for trained versus untrained but this was not significant. However, there was a significant (p=.047) difference for lower body rowing RPE with the trained having a higher value.

Summary: Trained versus Untrained

The trained rowers had significantly higher values for lower body rowing power output, lower body rowing energy expenditure, lower body rowing time, total body rowing strokes per minute, total body rowing distance per stroke, and lower body rowing distance per stroke as compared to the untrained group. No significant differences were shown for total body or lower body rowing blood lactate or heart rate for trained versus untrained rowers. There was, however, a significant difference for lower body rowing RPE with trained being higher.

4.5 Discussion

4.5.1 Upper versus Lower Body Differences

Tachibana et al. (2007) stated that the rowing motion requires a well-balanced distribution of muscle mass throughout the body. However, the results of this study showed a significantly higher upper body rowing power output as compared to lower body rowing power output. Jurimae et al. (2010) demonstrated that leg press exercise could be used to measure strength endurance in rowers, and found a correlation between power output and the leg press. It is important to note that upper body rowing power output involved the use of the core muscles. This may explain why the upper body produced higher results when compared to the lower body which has more muscle mass. Lower body rowing energy expenditure was significantly greater than upper body rowing energy expenditure. Cosgrove et al. (1999) suggested that rowers should devote time to the improvement of VO_{2max} and lean body mass, while Yoshiga & Higuchi (2003) state that VO_{2max} correlates to body mass and free fat mass. Lower body rowing time was significantly slower than total body rowing time. Jurimae et al. (2010) attributed that the contribution of the arms to the rowing stroke was much smaller than that of the legs. However, blood lactate, heart rate, and rate of perceived exertion were all significantly greater with the total body rowing than the lower body rowing. Upper versus lower body rowing differences show that the lower body is more important in determining better rowing performance. Therefore, greater time should be devoted to the development of the lower body.

4.5.2 Gender Differences

While there was no significant difference between lower body rowing power output by gender, upper body rowing power output was significantly greater for the males than the females. Upper body rowing energy expenditure and lower body rowing energy expenditure were greater for the males than the females, but these differences were not significant. Mello et al. (2009) argues that energy expenditure can be due to the type of ergometer used, the method used to estimate the contribution of the energy systems, as well as the equipment used to measure $VO_{2.}$ Total body rowing time was faster for the males while lower body rowing time was faster for the females; however, neither difference was significant. Yoshiga & Higuchi (2003) demonstrated that rowing time was slower in females than in males of a similar body height and mass. No significant differences in heart rate and rate of perceived exertion were shown for either upper or lower body rowing exercise by gender. There was however a significantly greater blood lactate for males using the lower body. Little gender differences speculates that technique, body composition (i.e. height, lean body mass, etc.), or other factors may be more influential in the rowing stroke.

4.5.3 Training Differences

Trained rowers showed a greater lower body rowing power output, however there was not a significant difference in upper body rowing power output between trained and untrained rowers. Seiler et al. (1998) showed a greater decline in power was shown for women in both the early ages (between 24 and 50 years), as well as later ages (between 50 and 74 years). Seiler et al. (1998) indicated that differences in physical stature, inherent endurance capacity, training habits, competitive desire, and other factors are a source of performance variation. This finding may explain the significant difference between the groups' upper body rowing power output and lower body rowing power output by gender, but no significant difference for power output between trained and untrained rowers; although many of the trained athletes had rowing experience of 6 months or greater, some may not have been physically in shape at the time of testing.

Upper body rowing energy expenditure did not significantly differ between trained and untrained rowers although upper body rowing energy expenditure for the untrained was greater than for the trained. It is important to note that the trained upper body rowing distance per stroke and lower body rowing distance per stroke was greater than the untrained. This illustrates that trained rowers used less energy to cover the same distance, and did so at a faster rate. This suggests that the technical ability and experience of the trained rowers enhances rowing performance. The results showed that while there was not a significant difference between the upper body rowing distance per stroke and training, there was a significant difference for lower body rowing distance per stroke between trained and untrained; this again exhibits a greater lower body emphasis to rowing performance by the trained rowers. Total body rowing time and lower body rowing time were both faster for the trained versus the untrained, but only the lower body difference was significant.

No significant difference for blood lactate and heart rate between the upper and lower body rowing was shown for training; however, there was a significantly greater lower body rowing rate of perceived exertion for the trained rowers. The strokes per minute completed by the trained were significantly less than the untrained. While there was no significant difference in the total body row time by training, the trained used significantly less strokes to cover the same distance. This illustrates the mechanical advantage of trained. Training appeared to be more important than gender in this rowing study. Greater time should be dedicated to improving the rower's technique and biomechanical ability.

4.5.4 Chapter Summary

Overall, the results of this study suggest that the lower body plays a greater role in the sport of rowing, and therefore coaches, trainers, and rowers of all competitive divisions, should take this into account in training to improve rowing performance. The majority of differences found in this study were due to training rather than gender. This supports the literature (Yoshiga & Higuchi, 2003). Lower body training should be considered a major predictor of rowing performance.

CHAPTER V

SUMMARY & CONCLUSION

5.1 Summary

Previous research has shown that rowing involves a total body effort to produce competitive results. Research has also shown that a greater emphasis should be placed on the lower body, not neglecting the work generated by the upper body. The results of this study support previous literature suggesting that training, whether male or female, plays a significant role in rowing performance.

5.2 Conclusion

Based on the results there was greater energy expenditure but not power output with the lower body; therefore the primary hypothesis was partially supported. Upper versus lower body differences show the lower body to be more important in determining better rowing performance. The results showed no significant difference between lower body energy expenditure and power output between males and females which reject the secondary hypothesis. Minor gender differences assume that technique, body composition (i.e. height, lean body mass, etc.), or other factors may be more influential in the rowing stroke. The results showed that there was a significantly greater lower body energy expenditure and power output in the trained versus untrained supporting the third hypothesis. These results suggest that training is more important than gender in rowing performance.

5.3 Limitations

The study was conducted on one type of rowing ergometer which may have an impact on the technique of the stroke performed. A different ergometer could elicit different results. Each participant was required to row for 1000 m, this may have been too much or too little of a distance for some subjects. Subjects may or may not have been familiarized with the rowing equipment due to it being a more recent model, which may have favored the trained rowers. A larger sample size may also contribute to a different outcome. Though the trained subjects had at least 6 months experience, more experience may have elicited different results.

5.4 Future Research Recommendations

Further research is necessary to compare power output, energy output, and stroke differences between trained and untrained individuals. Research is also necessary to further investigate upper and lower body differences in the rowing stroke between males and females.

5.5 Application

This study has shown that a lower body emphasis, as well as training, may have a positive impact on rowing performance. Coaches and athletes may benefit by putting a greater focus on lower body muscle strength and endurance, as well as technical and biomechanical training. Apart from competition, rowing can serve as a good type of aerobic exercise for everyday training. As shown by the energy expenditure results, rowing provides a high caloric burn based on intensity.

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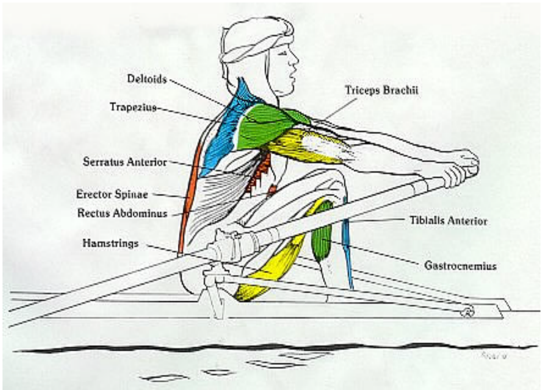
APPENDICES

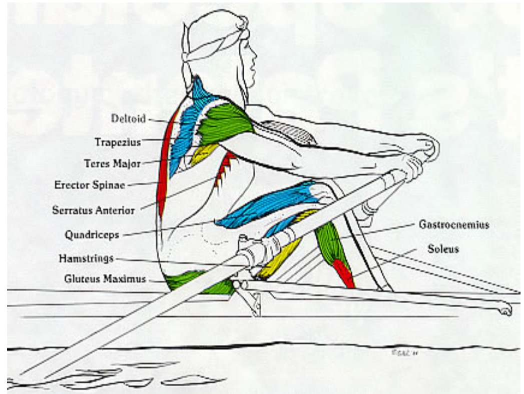
Appendix A

Muscles Used while Rowing

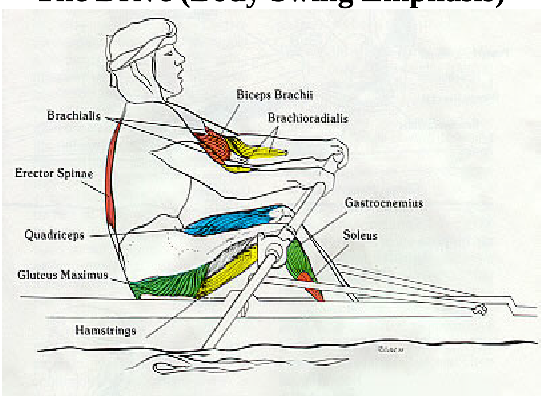
The Catch



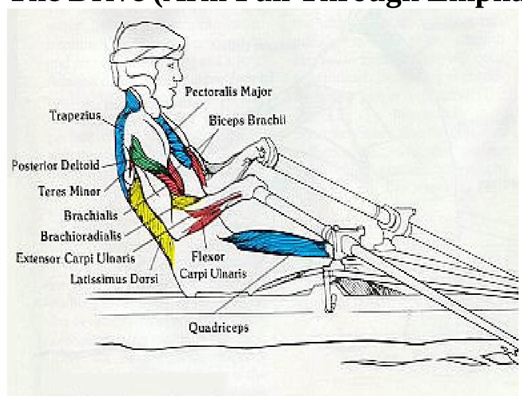
The Drive (Leg Emphasis)



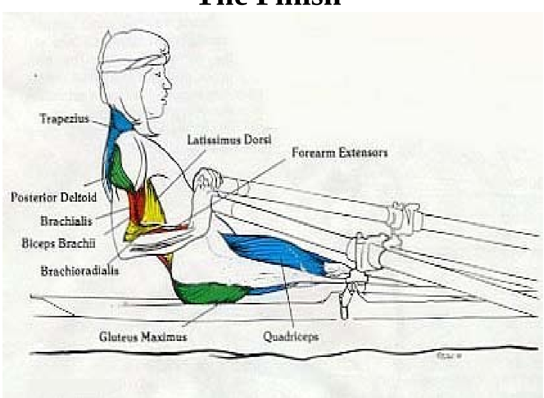
The Drive (Body Swing Emphasis)



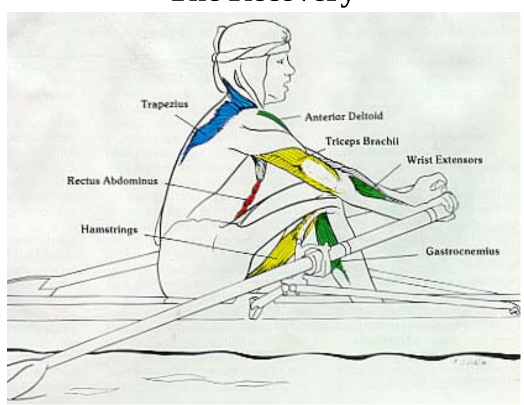
The Drive (Arm Pull Through Emphasis)



The Finish



The Recovery



Appendix B

Name _________________ Date ____________

AHA/ACSM Pre-participation Screening Questionnaire

Assess Your Health Needs by Marking all ***true*** statements

History

You have had:

□ A heart attack
□ Heart Surgery
□ Cardiac Catheterization
□ Coronary angioplasty (PTCA)
□ Pacemaker/implantable cardiac
□ Defibrillator/rhythm disturbance
□ Heart valve disease
□ Heart failure
□ Heart transplantation
□ Congenital heart disease

Recommendations:
If you marked any of the statements in this section, consult your healthcare provider before engaging in exercise. You may need to use a facility with a medically qualified staff.

Other health issues:

□ You have musculoskeletal problems. *(Specify on back)**
□ You have concerns about the safety of exercise. *(Specify on back)**
□ You take prescription medication (s). *(specify on back)**
□ You are pregnant

Symptoms

□ You experience chest discomfort with exertion.
□ You experience unreasonable breathlessness.
□ You experience dizziness, fainting, blackouts
□ You take heart medications.

Cardiovascular risk factors

□ You are a man older than 45 years.
□ You are a woman older than 55 years or you have had a hysterectomy or you are postmenopausal.
□ You smoke.
□ Your blood pressure is greater than 140/90 mm Hg.
□ You don't know your blood pressure.
□ You take blood pressure medication.
□ You don't know your cholesterol level.
□ You have a blood cholesterol >240 mg/dl.
□ You have a blood relative who had a heart attack before age 55 (*(father/brother)* or 65 *(mother/sister)*.
□ You are diabetic or take medicine to control your blood sugar.
□ You are physically inactive *(i.e., you get less than 30 minutes of physical activity on at least3 days/week)*.
□ You are more than 20 pounds overweight.

If you marked two or more of the statements in this section, you should consult your healthcare provider before engaging in exercise. You might benefit by using a facility with a professionally qualified staff to guide your exercise program.

□ None of the above is true.

You should be able to exercise safely without consultation of your healthcare provider in almost any facility that meets you needs.

- Proceed with test if musculoskeletal problems are minor, concerns about safety of exercise are normal, and prescription medications are not for cardiac, pulmonary, or metabolic disease.

Risk Status (Low, Moderate, High): _________________

Appendix C

Informed Consent Form

Contribution of Upper and Lower Body to Energy and Power Output and Gender Differences in the Rowing Stroke

This study is being conducted by Davon Jones and supervised by Dr. Kenneth Sparks, Director of the Human Performance Laboratory from Cleveland State University, Department of Health, Physical Education, Recreation and Dance and Health Sciences.

Purpose of the Study: I understand that the purpose of this study is to examine the contribution of energy expenditure and power output in upper body and lower body rowing and to compare males and females with an indoor rowing machine.

I understand that I will be asked my age and required to complete the American Heart Association/American College of Sports Medicine prescreening questionnaire to determine whether I am at low risk for the occurrence of a cardiovascular problem as a result of exercise. If I am found to be at anything other than a low risk level, I will not be allowed to participate in this study.

I understand that I will be asked to come into Cleveland State University for two sessions. The first session will be approximately 30 minutes, and the second session will also take approximately 30 minutes. This is a total time commitment of approximately 1 hour. I also understand that I will be using Concept 2 Model E Indoor Rower in each of the sessions.

Procedures

I understand that all testing will occur in the CSU Human Performance Laboratory. I understand that I will be subjected to two separate tests with at least 48 hours rest between tests. I understand that the full body test will be performed first, followed by lower body rowing in test 2. All rowing conducted in this experiment will be performed using a Concept 2 Model E Indoor Rower.

Upper Body Energy Input and Power Output

I understand that one session will include participants rowing using the full body, while test 2 would require rowing with only the lower body. I understand that each of the two tests will include a warm up of rowing at easy tempo for 100 meters. At the conclusion of the warm-up period, I will be asked to maximally row for 1000 meters. I will then recover with a 100 meter low intensity rowing.

In addition, my blood lactate, a blood marker of exercise intensity, will be measured both before and after this pedaling test. Blood will be taken using a finger prick with a blood lancet to acquire a small drop of blood. My finger will be cleaned prior to the stick with alcohol and dried with gauze. A bandage will be placed over the wound.

Measurement of Lower Body Energy Input and Power Output
I understand that measurement of lower body variables will require me to have a harness attached to the lower portion of my body to isolate only lower body rowing input

Risks and Benefits:
I understand the potential risks associated with this study include mild muscle soreness resulting from rowing on the machine and discomfort experienced from giving finger sticks for obtaining blood lactate. I also, understand that during exercise testing, there exists the possibility of certain changes occurring; these include abnormal blood pressure, fainting, disorders of the heart rhythm, and rare instances of heart attack, stroke or death (1:20,000 exercise tests). I understand the laboratory has emergency procedures in place and every effort will be made to minimize these risks.

Responsibilities of the Participant
I will need to complete a medical history using the American Heart Association/ American College of Sports Medicine prescreening questionnaire. This screening tool is used to ascertain that I am at a low risk of experiencing cardiovascular problems as a result of exercising. The information I submit and that is contained therein will be used in the determination of my eligibility to participate in this study.

Confidentiality:
I understand that any information obtained during my testing will be treated as confidential and will not be revealed to any individual without my consent. However, information obtained during my test may be used for research purposes with my right to privacy retained.

The medical and research information recorded about me will be used within Cleveland State University as part of this research. Tests and procedures done solely for this research study may be placed in my file to indicate my participation in this study. Upon completion of the study, I will have access to the research information recorded about me. Any publication of data will only use group data and not identify me by name.

Freedom of Consent:
My participation in this study is voluntary. I know that I am free to stop at any time, if I so desire.

Contacts and Questions:
The researchers conducting this study are Kenneth Sparks and Davon Jones. I may ask them any questions concerning this research study. If I have additional questions at a later time, I can reach Kenneth Sparks at 216-687-4831 or k.sparks@csuohio.edu, or Davon Jones at 216-687-4870 or d.i.jones05@csuohio.edu.

Participation:
I understand that participation in this study is voluntary and that I have the right to withdraw at any time with no consequences.

I understand that if I have any questions about my rights as a research participant, I can contact Cleveland State University's Review Board at (216) 687-3630.

Patient Acknowledgement:
The procedures, purposes, known discomforts and risks and possible benefits to me and to others have been explained to me. I have read the consent form or it has been read to me and I understand it. I have had an opportunity to ask questions that have been answered to my satisfaction. I voluntarily consent to participate in this study and I have been given a copy of this consent form.

____ ________________

Signature of Participant Date

____ ________________

Signature of Witness Date

Appendix D

Investigation Review Board Approval Letter

Cleveland State University

Office of Sponsored Programs and Research
Institutional Review Board (IRB)

Memorandum

To: Kenneth Sparks
HPERD

From: Barbara Bryant *Barbara*
IRB Recording Secretary

Date: February 22, 2011

Re: Results of IRB Review of your project number: **29256-SPA-HS**
Co-Investigator: Davon Jones
Entitled: Contribution of the upper and lower body energy input and power output in the rowing stroke: Gender differences

The IRB has reviewed and approved your application for the above named project, under the category noted below. Approval for use of human subjects in this research is for one year from today. If your study extends beyond this approval period, *you must contact this office to initiate an annual review of this research.*

By accepting this decision, you agree to notify the IRB of: (1) any additions to or changes in procedures for your study that modify the subjects' risk in any way; and (2) any events that affect that safety or well-being of subjects. Notify the IRB of any revisions to the protocol, including the addition of researchers, prior to implementation.

Thank you for your efforts to maintain compliance with the federal regulations for the protection of human subjects.

Approval Category: **Date: 2/17/2011**

X Expedited Review: Project approved, Expedited Category 2

cc: Project file

Mailing Address: 2121 Euclid Avenue, PH-3rd Floor • Cleveland, Ohio 44115-2214
Campus Location: Parker Hannifin Hall • 2258 Euclid Avenue • Cleveland, Ohio
(216) 687-3630 • Fax (216) 687-9382

Appendix E

Concept II Model E Rower

Appendix F

Chain Attached to Seat

Appendix G

Portable Oxygen Analyzer

Appendix H

Borg Scale 6-20- Rate of Perceived Exertion

Rating of Perceived Exertion
Borg RPE Scale

6		How you feel when lying in bed or sitting in a chair relaxed. Little or no effort.
7	Very, very light	
8		
9	Very light	
10		
11	Fairly light	
12		Target range: How you should feel with exercise or activity.
13	Somewhat hard	
14		
15	Hard	
16		
17	Very hard	How you felt with the hardest work you have ever done.
18		
19	Very, very hard	
20	Maximum exertion	Don't work this hard!

Appendix I

RowPro Screenshot