Differences in Aerobic Response to Wheelchair Locomotion
in Spinal Cord Injured and Able-Bodied Men

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ABSTRACT

Differences in Aerobic Response to Wheelchair Locomotion in Spinal Cord Injured and Able-Bodied Men

David C. Pomfret

The purpose of this study was to explore the differences in the aerobic response to wheeling between wheelchair dependent individuals and able-bodied individuals of similar genders and ages. Five wheelchair dependent men (WC) and five able-bodied men (AB) performed a 13 minute wheeling test (5 min. at rest, 8 min. wheeling) at 4.0 km·hr⁻¹. Heart rate (HR) and VO₂ were recorded using a Vmax ST system during the constant speed test. There was no significant difference in HR or VO₂ between the two groups during rest. Both HR and VO₂ were higher for WC during exercise. The mean METS during exercise for WC and AB were 3.589 ± 0.516 and 2.726 ± 0.164, respectively. The results indicate that at a given workload a spinal cord injured wheelchair user will have a greater aerobic response than an able-bodied person in a wheelchair completing the same task.

KEYWORDS: aerobic response, wheelchair, wheelchair locomotion, spinal cord injury.

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Chapter 1

Introduction

Background of the Study

The rise of cardiovascular and metabolic diseases to epidemic levels has led to extensive research on the effectiveness of physical activity in combating morbidity and mortality due to these diseases. Paffenbarger, Hyde, Wing, Lee, Jung, & Kampert (1993) revealed a landmark connection between a lack of sufficient physical activity and an increased rate of mortality due to coronary heart disease. It is clear that physically inactive individuals have an increased risk of cardiovascular disease (CVD) (McMurray, Ainsworth, Harrell, Griggs, & Williams, 1998). Furthermore, people confined to wheelchairs due to physical disabilities may have accelerated risk of ischemic CVD as a result of a more sedentary lifestyle (Hrubec & Ryder, 1979). Regardless of functional capacity, there is no doubt among health professionals that physical fitness is essential for health and longevity.

Paraplegia, or the loss of the ability to move and/or feel both legs and the lower trunk, leads to a degenerative process resulting in decreased lean body mass, lowered aerobic capacity, an osteoporotic condition, and renal dysfunction (Cowell, Squires, & Raven, 1986). As a result of this degenerative process and a generally sedentary lifestyle, the paraplegic, quadriplegic, and bilateral amputee are at greater risk for advanced atherosclerosis, which is believed to be one of the greatest factors in the reduced life expectancy for paraplegics (Cowell et al., 1986). For the paraplegic individual whose locomotion is facilitated by a wheelchair, achieving a means to stay physically active can be more difficult than for the able-bodied individual who has seemingly limitless exercise

options. The everyday activities of many rehabilitated paraplegics are insufficient to obtain any cardiovascular health benefits (Hjeltne & Vokac, 1979). Researchers have developed specific caloric expenditure equations for different activities which facilitate and quantify exercise prescription for able-bodied individuals. However, researchers have not yet developed similar caloric cost equations to estimate the energy expenditure of wheelchair locomotion. The relative lack of practical exercise tools for the wheelchair user creates a need for research and development in this area.

Wheeling, or self-propulsion in a wheelchair, is a viable and easily accessible fitness option for most wheelchair users, which this researcher considers analogous to a walking fitness program for the able-bodied based on the speed of locomotion and functionality of the movement. There is considerable documentation of the physiological and biochemical responses to exercise for quadriplegic and paraplegic subjects (Cowell et al., 1986; Hoffman, 1986; Zwiren & Bar-Or, 1975). Much of the research on wheeling has been conducted on wheelchair treadmills, or on arm-crank ergometers; often using able-bodied participants only. Brattgard, Grimby, & Hook (1970) and Zwiren & Bar-Or (1975) used arm crank ergometers to exercise wheelchair dependent individuals, however, the concept of exercise specificity suggests that an exercise mode which resembles wheelchair activity may be more advantageous (Wuest & Bucher, 1999, p. 228). Considerably less research has been conducted in the field using only individuals with disabilities. In this study, the researcher used a field data collection method to collect data from wheelchair dependent individuals, and a comparison group of able-bodied individuals, in order to more closely replicate the activity of wheelchair

locomotion for individuals with spinal cord injuries and a reduced metabolically active muscle mass.

Purpose

The purpose of this study was to explore the differences in the aerobic response to wheeling between wheelchair dependent individuals and able-bodied individuals of similar genders and ages.

Hypothesis

There exists a difference between the VO_2 of wheelchair dependent individuals and able-bodied individuals when wheeling at $4.0 \text{ km}\cdot\text{hr}^{-1}$. (Null Hypothesis: There is no difference between the VO_2 of wheelchair dependent individuals and able-bodied individuals when wheeling at $4.0 \text{ km}\cdot\text{hr}^{-1}$.)

Delimitations

- The wheelchair dependent group participants in the study were male wheelchair users with spinal lesions at or below T5.
- The able-bodied group participants were all able-bodied males with no upper or lower body deficiencies.
- Participants were all more than six months post spinal cord injury for the wheelchair dependent group.
- Participants were between the ages of 18 and 65 years.
- The results of this study did not include variation in grade or speed.
- The participants of this study reported no evidence of cardiovascular disease or metabolic disease prior to testing.
- All testing was completed between February, 2006, and September, 2009.

Assumptions

- Participants of similar levels of spinal cord injury and body weight had similar aerobic responses.
- Able-bodied participants of similar body weight had similar aerobic responses.
- Participants were able to maintain a constant velocity of $4.0 \text{ km}\cdot\text{hr}^{-1}$ during data collection.

Limitations

- In order to standardize the weight and equipment used, all participants were required to use the same wheelchair which may have been significantly different than their own chair to which they were accustomed.
- A small sample size was tested during this research.

Definition of Terms

Autonomic dysreflexia. Autonomic dysreflexia (AD) is a condition that can occur in anyone who has a spinal cord injury at or above the T5 level. It is related to disconnections between the body below the injury and the neural control mechanisms for blood pressure and heart function. It causes the blood pressure to rise to potentially dangerous levels. AD can be caused by a number of things. The most common causes are a full bladder, bladder infection, severe constipation, or pressure sores. Any stimulus that would normally cause pain or discomfort below the level of the spinal cord injury can trigger dysreflexia. The symptoms that occur with AD are directly related to the types of responses that happen in the sympathetic and parasympathetic nervous systems. Symptoms such as a pounding headache, spots before the eyes, or blurred vision are the

direct result of the high blood pressure that occurs when blood vessels below the injury constrict. The body responds by dilating blood vessels above the injury, causing flushing of the skin, sweating, and occasionally goosebumps. Some patients describe nasal stuffiness and will feel very anxious. Uncontrolled AD can cause a stroke if not treated. (Source: http://www.spinalinjury.net/html/complications_continued.html, viewed August 7, 2005)

Parasympathetic Nerves. The parasympathetic nerves act in an opposite manner to the sympathetic nerves. These nerves tend to dilate blood vessels and slow down the heart. The vagus nerve carries parasympathetic signals to the heart to decrease heart rate. Other nerves supply the blood vessels to the organs of the abdomen and skin.

Spinal Cord Injury (SCI). Spinal cord injury is damage to the spinal cord that results in a loss of function such as mobility or feeling. Frequent causes of damage are trauma (car accident, gunshot, falls, etc.) or disease (polio, spina bifida, Friedreich's Ataxia, etc.).

Sympathetic Nerves. The sympathetic nerves cause constriction of the blood vessels throughout the body. Such constrictions can cause an increase in the amount of blood that is returned to the heart. These effects will increase blood pressure. Other effects include an increase in sweating and increased irritability or a sensation of anxiety.

Chapter 2

Review of Literature

In keeping with the purpose of this study to explore the differences in aerobic response between wheelchair dependent individuals and able-bodied individuals, this chapter provides background research about the spinal cord injured population and the physiological differences of arm exercise. In addition, research related to wheelchair exercise training and exercise testing is presented, which helped shape and justify the methods used in the present study.

Spinal Cord Injury Statistics

The estimated annual incidence of spinal cord injury (SCI) in the United States is approximately 40 cases per million population, or approximately 11,000 new cases each year. Approximately 259,000 persons were living with a spinal cord injury in the U.S. in 2008. Young adults have a higher incidence of SCI than any other age group. The average age at injury from 1973 to 1979 was 28.7 years, and most injuries occurred between the ages of 16 and 30. The average age at injury has steadily increased over time. Since 2005, the average age at injury is 40.2 years. The percentage of persons older than 60 years of age at injury has increased from 4.7% prior to 1980 to 10.9% among injuries occurring since 2000. Males represent 79.6% of all SCI reported to the national database since 2000. Since 2000, the most common cause of SCI was from motor vehicle crashes (47.5%) followed by falls (22.9%), acts of violence (13.8%), and recreational sporting activities (8.9%). The proportion of injuries that are due to sports has decreased over time while the proportion of injuries due to falls has increased. Acts of violence caused 13.3% of spinal cord injuries prior to 1980, and peaked between 1990

and 1999 at 24.8% before declining to only 13.8% since 2000. (Spinal Cord Injury Facts and Figures at a Glance, April 2009)

Physiology of Arm Exercise

The physiology of arm exercise differs from that of leg exercise. At maximal levels of exercise, VO_2 is 15% to 25% greater in leg work than arm work. (Cowell, Squires, & Raven, 1986). Depending on the level of impairment of the sympathetic nervous system, a reduction in the venous return results in a lower cardiac preload (Tolfey, Goosey-Tolfey, & Campbell, 2001). The higher heart rate during upper body exercise results from compensation for the reduced stroke volume. The smaller muscle mass of the upper body used in arm exercise results in an early onset of fatigue and a maximal workload of only 50% to 60% of that accomplished by leg exercise (Cowell et al., 1986). Cowell et al. (1986) noted that respiratory frequency is affected more in arm exercise by the frequency of rotary movement, which can result in the synchronization of the respiratory frequency and arm movements at very low levels. This disturbance to the breathing mechanics through higher frequency and lower tidal volume may adversely affect the circulation in the smaller arm muscles resulting in the earlier onset of fatigue (Vokac, Bell, Bautz-Holter, & Rodahl, 1975).

Differences in cardiovascular response to arm crank ergometry

Several researchers have demonstrated the difference in cardiovascular response to exercise between spinal cord injured subjects and able-bodied subjects using arm crank ergometry. Drory, Ohry, Brooks, Dolphin & Kellermann (1990) examined the effects of injury level on response to exercise for 98 long-standing spinal cord injury (SCI) participants. They divided the participants into four groups based on the neurologic

levels of SCI (cervical, upper thoracic, lower thoracic, and lumbar SCI). A group of 25 healthy, able-bodied men served as a control group. Using a Monark bicycle ergometer, adapted for arm crank ergometry, the participants performed multistage, near maximal arm crank ergometry. There was a clear linkage between physical work capacity (PWC) and level of SCI; the higher the level of SCI, the lower the PWC. The mean PWC was significantly lower for the cervical and thoracic SCI groups than the control group. There was no difference in mean PWC between the lumbar SCI group and the control group.

Effects of Training on Cardiovascular Fitness in Wheelchair Dependent Individuals

Significant improvements in both aerobic capacity and muscle strength have been shown through maximal training workloads in spinal cord injured patients (Chawla, Bar, Creber, Price, Andrews, 1979). Hoffman (1986) compiled the characteristics and results of 13 endurance training studies involving spinal cord injured subjects. With the exception of one, all of the reviewed studies show significant cardiovascular improvement from a variety of training programs ranging from submaximal to maximal intensities. The lack of improvement in VO_{2max} from an aerobic swimming program (Ornstein, Skrinar, & Garrett, 1983) may have been the result of VO_{2max} determination by arm or wheelchair ergometry. Swim training in paraplegics may be task specific and may not elicit a significant improvement in VO_{2max} when determined by arm ergometry (Andersen & Kasch, 1984).

Nilsson, Staff, & Pruett, (1975) conducted a study on twelve paraplegic subjects using weight and arm crank ergometry training. The participants performed two submaximal workloads at 50-60 rpm for 6 minutes each and one maximal workload designed to have the participant reach exhaustion in 4 to 6 minutes. Each minute, the

heart rate of the participant was measured on an ECG. After the initial screening and exercise testing, seven participants volunteered to take part in a seven week, specifically devised training program that consisted of arm crank ergometry and muscular endurance conditioning. The participants exercised three times per week for an unspecified session duration and at unspecified intensities. The researchers found an increase in mean $\text{VO}_{2\text{max}}$ from 1.88 to 2.08 l/min, or 12%, and a 31% increase in performance from 612 to 804 kpm/min. Additionally, after the seven week program, the participants' mean dynamic endurance (number of times they could lift 85% of maximal loads for a supine triceps extension) increased 80%, from 10 to 18 repetitions. Similarly, an increase in mean dynamic strength (the heaviest load the participants could lift using primarily their triceps from a supine position) from 64 to 76 kg, or 18.75%, was found.

Hoffman (1986) noted that it is unclear whether training of the arm and upper trunk musculature can lead to a central training effect in paraplegics, however, peripheral training adaptations clearly improve work capacity. Hoffman (1986) based this conclusion on the inconsistencies in previous studies when studying central cardiovascular training responses. Clausen, Klausen, Resmussen & Trap-Jensen (1973) found no significant change in heart rate during submaximal leg exercise following an arm training program. In two groups of healthy subjects who performed arm training (n=5) and leg exercise (n=8), Clausen et al. (1973) measured the circulatory response to exercise performed with trained and untrained muscle groups. Both groups engaged in a five week supervised training program that involved five days of training per week for 50 minutes. Following a 15 minute warm-up, the participants performed intervals of 5 minutes at a workload that pushed heart rates above 170 beats per minute, followed by 5

minutes of rest. Post-tests after the five week training program indicated that arm training caused a pronounced reduction in heart rate (HR) during arm exercise (17%), but only a small reduction in HR during leg exercise (4%). Leg training, however, showed nearly equal reductions in HR for both leg exercise and arm exercise (10.5% and 11.8%, respectively). These findings indicate that leg training elicits central circulatory changes that benefit arm exercise, while arm training appears to primarily cause peripheral circulatory changes that offer little to no benefit during leg exercise. Conversely, Pollock, Miller, Linnerud, Laughridge, Coleman, & Alexander (1974) found an increased $\text{VO}_{2\text{max}}$ in treadmill running after arm training. The conflict between these studies reveals that it is still uncertain whether arm exercise can effectively elicit central circulatory changes.

The long term effects of endurance training in the spinal cord injured population are unclear, but the metabolic changes may be similar to those seen in able-bodied people during training programs. Reductions in the percentage of body fat (Pollock et al., 1974) and elevation in serum HDL cholesterol levels (Ornstein et al., 1983) have been reported following endurance conditioning in spinal cord injured patients, though there is no evidence as to whether these physiological changes will reduce the risk of CVD.

McMurray et al. (1998) reported that aerobic power appears to have more influence on CVD risk factors than physical activity (PA) levels in able bodied subjects. Physical activity with sufficient intensity to increase aerobic power by $3 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ (~ 1 MET) should be sufficient to have a positive impact on CVD risk. Such an increase in aerobic power can be seen in as little as nine weeks of exercise training (McMurray et al., 1998). McMurray et al. (1998) based the previous conclusions on a participant group of law

enforcement trainees ($n=576$) who were all classified as low aerobic power ($VO_{2max} \leq 30 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$). Each participant engaged in a nine week training program. Though the training programs were not specified, the researchers noted that different professional fitness trainer developed programs at each of the 25 training sites. The researchers reported that 231 participants had no change in VO_{2max} (NC group), while 345 participants had an increase in VO_{2max} ($> 3.0 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) (IN group). The American College of Sports Medicine (ACSM) states that the minimal training intensity threshold for improvements in VO_{2max} is approximately 40-50% of maximum oxygen uptake reserve (VO_{2R}) or HRmax reserve (HRR) which is equal to 55-65% of HR_{max} (ACSM Position Stand, 1998). It is possible that the NC group did not maintain a training intensity high enough to elicit an increase in VO_{2max} . Only the IN group had significant improvements in the CVD risk factors measured (cholesterol, blood pressure, percentage body fat, BMI). The varied exercise programs used, and the lack of control of dietary changes and lifestyle factors, are two limitations to this study.

Wheeling Speeds and Mechanical Efficiency for Wheelchair Exercise Studies

The wheeling speeds used by researchers in the existing wheelchair exercise studies vary greatly. Depending on the nature of the testing (submaximal or maximal), the speeds used in previous studies range from $1 \text{ km}\cdot\text{hr}^{-1}$ to $10.8 \text{ km}\cdot\text{hr}^{-1}$. Some maximal effort studies (Eriksson, Lofstrom, & Ekblom, 1988; Gass, Camp, Davis, Eager, & Grout, 1981) did not specify the speed at which the subjects reached exhaustion so speed ranges for these studies could have surpassed $10.8 \text{ km}\cdot\text{hr}^{-1}$. van der Woude, Bouten, Veeger, & Gwinn (2002) performed a standardized maximum wheelchair exercise test on 68 elite wheelchair athletes. The speeds for this study ranged from 0.28 to $1.39 \text{ m}\cdot\text{sec}^{-1}$ (or

approximately 0.6 to 3.1 mph, or 1 to 5 km·hr⁻¹) but the resistance was increased stepwise each minute by 3, 5, 10 or 15 W to elicit the maximal exertion of each athlete. The speed was individually selected prior to testing based on sports discipline and the participants' performance on a set of wheelchair sprint tests conducted in advance. To prevent localized muscular fatigue from ending the test prematurely, the maximum exercise test was limited to approximately 10 minutes and the test was terminated when velocity consistently remained below the required velocity despite strong verbal motivation.

In some of the earliest wheelchair research, Brattgard, Grimby & Hook (1970) used average speeds from 2.5-3.0 km·hr⁻¹ (0.69 – 0.83m·sec⁻¹) at two different power outputs to determine the mechanical efficiency and heart rate response to wheeling. In this study, 20 able bodied female participants performed exercise tests at two different power outputs (65 kpm·min⁻¹ and 110 kpm·min⁻¹) and three different wheel positions. The wheel positions included the pushrims in the posterior position, the pushrims at the anterior position, and the pushrims at the anterior position with a lower mounting position. In addition, the participants performed two different workloads (150 kpm·min⁻¹ and 300 kpm·min⁻¹) on an arm ergometer at 50 rpm. The eight different tests (four total positions with two workloads each) were each performed for 6 minutes. The researchers reported that the placement of the rim wheels in the posterior position showed slightly higher mechanical efficiency, though the overall efficiency of wheeling was estimated between 7 % and 8% at workloads between 65 and 110 kpm·min⁻¹. Mechanical efficiency of arm ergometry was estimated to be 18.6% at 150 kpm/min. Similarly, mechanical efficiencies for wheeling at 4 km·hr⁻¹ have been estimated at 7.7% (Hildebrandt, Voigt, Bahn, Berendes, & Kroger, 1970). Cooper, Boninger, Cooper,

Robertson, & Baldini (2003), found significantly higher mechanical efficiencies for wheeling than Brattgard, Grimby & Hook (1970). The gross mechanical efficiency for the twelve elite paraplegic wheelchair racers in this study was about 18%, ranging from 15.2% to 22.7%. Cooper et al. (2003) found no significant correlation between speed and efficiency. The higher mechanical efficiency values in this study compared with the existing literature were explained by the advancements in racing wheelchair technology and the study population of elite wheelchair athletes.

Glaser, Sawka, Durbin, Foley, & Suryaprasad, (1981) had thirteen able bodied females maintain 180 m/min fly wheel velocity on a wheelchair ergometer, which is equal to $10.8 \text{ km}\cdot\text{hr}^{-1}$. Though Cooper et al. (2003) found no significant correlation between speed and efficiency, several other studies indicate that the mechanical efficiency of wheeling is dependant on speed. Vanlandewijck, Spaepen, & Lysens (1994) performed research to investigate wheelchair propulsion efficiency and movement pattern changes to speed changes. The results indicate that between 1.67 m/sec and 2.22 m/sec, or approximately $6 \text{ km}\cdot\text{hr}^{-1}$ and $8 \text{ km}\cdot\text{hr}^{-1}$, respectively, there is a decreased mechanical efficiency explained by a significant change in the acceleration of the wheelchair-user system during recovery phase. The changes in the arm and trunk movements induce inertial forces to act on the wheelchair, thereby reducing efficiency.

Glaser, Foley, Laubach, Sawka, & Suryaprasad, (1978) stated that the energy costs of wheeling and walking were roughly equal at $3.5 \text{ km}\cdot\text{hr}^{-1}$. In a more recent review, Cowell et al. (1986) updated the equal energy comparison of wheeling and walking to $4.0 \text{ km}\cdot\text{hr}^{-1}$. The present study used a constant speed of $4.0 \text{ km}\cdot\text{hr}^{-1}$ during testing.

Continuous versus Discontinuous Workload Testing for Wheelchair Exercise Studies

Prior to the study by Whiting, Dreisinger, & Hayden, (1984), much of the data for wheelchair research had been collected by discontinuous testing methods. It was believed that continuous exercise testing in wheelchairs would lead to early onset fatigue because of the smaller upper body muscle mass, which would adversely affect heart rate, blood pressure and oxygen uptake. Whiting et al. (1984) compared continuous and discontinuous submaximal data collection methods. Ten able-bodied subjects each completed two submaximal wheelchair exercise tests on separate days. Four workloads were selected on a wheelchair ergometer. Each workload stage lasted 3 minutes. The continuous test progressed directly to the next workload at the end of each 3 minute stage while a 5 minute rest interval was added between each stage for the discontinuous testing. As expected, a positive linear relationship was reported between heart rate, systolic blood pressure and VO_2 with increasing workloads for each type of testing. Furthermore, no significant difference was found between the data collection methods despite the small muscle mass of the upper body. Whiting et al. (1984) concluded that wheelchair exercise testing can be performed using a continuous format at submaximal levels without sacrificing physiological data.

Field Research in Wheelchair Exercise Studies

The majority of the wheelchair exercise research has been conducted on wheelchair ergometers and arm crank ergometers. In one field based study, Rhodes, McKenzie, Coutts, & Rogers, (1981) designed a study to establish the relationship between a twelve minute wheel around a 400m track and maximal oxygen consumption. Each of thirty subjects (10 quadriplegics, 20 paraplegics) performed a $\text{VO}_{2\text{max}}$ test on a

wheelchair ergometer (day 1) and a maximal effort twelve minute wheel around a 400m track (day 2). The thirteen data variables collected were entered into a stepwise multiple regression analysis to determine which variables provided the optimal prediction of VO_{2max} for the field evaluation. Predictive equations were developed for the various groups (total, paraplegics, and quadriplegics). The best equations used the following forecasting variables: distance, blood pressure (resting systolic and diastolic) and weight ($VO_{2max} = 0.984 \text{ Distance} + 0.011 \text{ BP}_S - 0.009 \text{ BP}_D + 0.007 \text{ Wt.} - 1.051$). The researchers recognized that multiple factor analysis provides a better estimate of aerobic capacity than single variable equations but cautioned that the predictors selected using multiple regression procedures may be biased toward mathematical rather than physiological considerations. The researchers further recommended that it is important to consider the accuracy of the prediction as reflected by the standard error of the estimate and the coefficient of variation (CV), as well as the R. As in other studies (Tolfrey, Goosey-Tolfey, & Campbell, 2001, & Eriksson, Lofstrom, & Ekblom, 1988), the difficulty in equating the functional capacities of the subjects was listed as a limitation to the application of the predictive equations. Since the subjects had different locations for their spinal lesions, both singular and grouped data treatments were analyzed to help identify the important variables.

The information above highlights the unique elements of the physiology of arm exercise and exercise testing. Though a growing number of studies have been completed on wheelchair locomotion, a greater percentage of those studies used only able-bodied individuals as participants. If the hypothesis of this study is correct than more research would have to be conducted using wheelchair dependent individuals to gain more

applicable results. In addition, field-based tests that more closely mimic real life situations are valuable additions to the current knowledge base since few wheelchair users are likely to have access to a wheelchair ergometer. Based on previous research, a continuous testing method while wheeling at $4.0 \text{ km}\cdot\text{hr}^{-1}$ in a field setting was used as part of the methods described in the following chapter.

Chapter 3

Methods

Participants

A convenience sample of five non-amputee wheelchair-dependent men and five able-bodied men volunteered to participate in this research project. Cowell, Squires, & Raven, (1986) cited that a spinal lesion at level T4 or above is capable of disturbing sympathetic drive to the cardiovascular system. In addition, autonomic dysreflexia (AD) can occur for spinal injuries above T5 (see Definitions for more on AD). For this reason, all participants qualified for this study if they met the following criteria:

- Able to operate a manual propulsion sport chair.
- Absence of other upper extremity disability that would hinder the ability to propel and navigate a wheelchair.
- No pre-existing or current cardiovascular diseases.
- No pre-existing or current metabolic diseases.
- No use of medications that would affect heart rate, blood pressure or metabolic rate.

Additionally, the wheelchair dependent group had to meet the following qualifications:

- Spinal lesion below T5, and/or no history of AD.
- Wheelchair dependent for a minimum of 6 months.

Location

Initial consultations with prospective participants were conducted via telephone or in the Human Performance Laboratory (room 250), Bldg. 43A on the campus of California Polytechnic State University, San Luis Obispo, California. Testing was

conducted on the all-weather track facility at California Polytechnic State University, San Luis Obispo, California.

Design

A static-group comparison pre-experimental design was used for this study (Campbell & Stanley, 1963.) This design allows a group which has experienced X (some spinal cord injury below T4) to be compared with the second group which has not, in order to establish the effect of X. There is no means of certifying whether the two groups would have been equivalent had it not been for the spinal cord injuries to the first group so the groups may have differed even without the occurrence of X, however, selective recruiting for the able-bodied group was used to influence the similarities of the two groups.

Procedures

Five wheelchair dependent volunteer participants were screened for eligibility for the study using a basic questionnaire and PAR-Q. A comparison group of five able-bodied volunteers was recruited based on similar representation to the gender and age of the wheelchair dependent participants. Participants selected for testing read and signed an informed consent document (See Appendix A.). The participants then completed a detailed Health Screening document (See Appendix B.). Oxygen uptakes and heart rates were measured using a VmaxST system (Cortex, Leipzig, Germany)

Upon arrival at the track on the testing day, the participants were fitted with an appropriately sized mask, mess head strap and Polar Heart Rate Transmitter. The shoulder mounted VmaxST Base System was fitted comfortably to the participant so not to restrict movement. The Volume Transducer, windshield and gas sample line were all

attached. The participants were given final testing instructions and the resting measures commenced. Metabolic recordings were conducted at resting levels for 5 minutes while the participant sat motionless on the starting line of the track. During the resting measures, the researcher measured and recorded the atmospheric condition, and made note of the general weather conditions. Testing was aborted on two days due to high winds that significantly affected the testing. Immediately following the resting measures, the participant began 8 minutes of continuous exercise on the track at California Polytechnic State University, San Luis Obispo, California. The participants were asked to gradually accelerate to $4.0 \text{ km}\cdot\text{hr}^{-1}$ within the first 50-meters of the exercise test and maintain a consistent speed for the duration of the test. The goal speed of $4 \text{ km}\cdot\text{hr}^{-1}$ was paced using the Trek Incite 9i speedometer (Trek Bicycle Corporation, Waterloo, Wisconsin) mounted on the sportchair where the participant could see the display. The participants self-paced based on the feedback they received from the speedometer.

The test began at the start of the 100-meter straight-away on the track so the participants could more smoothly accelerate in a straight line without having to also navigating the curve of the track. Once at $4.0 \text{ km}\cdot\text{hr}^{-1}$, the participants were encouraged to maintain a consistent and rhythmic wheeling rate that would help to maintain a steady state condition. The participants were also given time updates from the researcher so they knew how much time was remaining. When the participants finished the 8 minutes of exercise testing, the test was stopped, the total distance wheeled was measured and recorded, and the mask and mess head strap were removed. The participants were encouraged to continue wheeling at approximately $2.0 \text{ km}\cdot\text{hr}^{-1}$ for 3 minutes for a cool-

down period prior to removing the remaining test equipment and being provided with debriefing instructions.

Weight measurements were performed immediately after the conclusion of testing due to scheduling availability and convenience. In order to accurately measure body weight, the participants were instructed to meet the researcher at the San Luis Obispo Renal Care Center where a roll on scale was used to accurately determine body weight for the wheelchair group. First the participant and the chair were weighed, followed by the chair alone in order to calculate the mass of participant alone.

Qualification and Safety

The primary researcher was a Certified ACSM Health and Fitness Instructor with four years of exercise testing experience. The primary researcher was also American Red Cross CPR and First Aid certified. A secondary researcher was on site for all testing to assist the primary researcher with data recording and supervision. A first aid kit and cell phone were carried to the field location in case of emergency.

Equipment

The primary data collection tool was the VmaxST (Cortex, Leipzig, Germany). The VmaxST is a lightweight, portable cardiopulmonary system for pulmonary gas exchange measurements under real conditions. The data collected by the VmaxST was downloaded in to Dell PC for presentation and analysis using Metasoft software. All participants used the same sport wheelchair. The chair was outfitted with a Trek Incite 9i speedometer (Trek Bicycle Corporation, Waterloo, Wisconsin) that was capable of displaying real-time speed as well as recording average speed and distance traveled.

Though the speedometer also recorded time, a stopwatch was used to allow the researcher to provide time updates to the participants and as a backup measure.

Data Analysis

Small sample size and difficulty recruiting more eligible participants eliminated the possibility of performing a valid regression analysis. Descriptive statistics for the groups, including group means, were tabulated using MINITAB. The testing results were graphically displayed using MicrosoftTM Excel. The VmaxST software program supplied metabolic equivalents (METS) which were used for analysis. The mean METS during rest and exercise for the two groups were calculated using MINITAB, which was also used to run a two-sample T-test to determine if the two groups were statistically different from each other. The general trends for the sample groups were used as a basis to determine if this testing method is reliable for future research projects.

Chapter 4

Results and Discussion

Though difficulty arose during participant recruiting, with few participants willing to join the study, there was evidence of patterns in the data. This chapter reports the descriptive data for the two groups and graphically presents the results for the groups both individually and comparatively. A discussion of the identifiable trends follows. The data presented may be relevant to encourage future studies using this, or a similar testing protocol for a controlled experimental design.

Participants

All the wheelchair dependent participants were male and had thoracic lesions ranging between T5 and T12. Table 4.1 presents the descriptive statistics for the wheelchair dependent group. The mean age in years for the group was 42.8 ± 11.3 with a range from 30 to 55 years of age. The mean weight for the group was 72.68 ± 11.28 kg, with a range of 58.50 to 90.40 kg.

Table 4.1 *Descriptive Statistics for the Wheelchair Dependent Group Tested at California Polytechnic State University, San Luis Obispo, CA.*

Participant ID	Weight (kg)	Age** (yrs)	Spinal Lesion Level
WC01M	74.80	54	T8/T9
WC02M	75.00	55	T8/T9
WC03M	90.40	40	T11/T12
WC04M	74.70	30	T10
WC06M	58.50	35	T5/T6
Group Means	74.68 ± 11.28	42.8 ± 11.3	n/a

**Age at the time of testing

Table 4.2 represents the descriptive statistics of the able-bodied group. The able-bodied group was also comprised of five male participants with a mean age of 42.4 ± 11.9 years with a range from 30 to 58 years. The mean weight for the able-bodied group was 84.60 ± 4.54 kg with a range from 76.80 to 87.70 kg.

Table 4.2 *Descriptive Statistics for the Able-Bodied Group Tested at California*

Polytechnic State University, San Luis Obispo, CA.

Participant ID	Weight (kg)	Age** (yrs)	Spinal Lesion Level
ABM01	84.70	30	n/a
ABM02	87.70	40	n/a
ABM03	87.70	58	n/a
ABM04	86.10	33	n/a
ABM05	76.80	51	n/a
Group Means	84.60 ± 4.54	42.4 ± 11.9	n/a

***Age at the time of testing*

Physiological Data

The heart rate data for the wheelchair dependent participants are displayed in Figure 4.1. As described in the previous chapter, the testing procedure using the VMax ST took a total of 13 minutes. Time 0:00 through 5:00 were at rest measurements, and time 5:00 through 13:00 were measurements during wheelchair locomotion at $4 \text{ km} \cdot \text{hr}^{-1}$. During the fifth minute of exercise, when the participant began wheeling, heart rate increased quickly and then began to plateau at a new steady state within approximately 120 seconds. The heart rate for participant WC03M continued to climb for approximately 5 minutes before reaching a steady state and was significantly higher than all other participants. Participant WC03M was unable to maintain an average speed of

4.0 km·hr⁻¹ for the duration of the test and fell off pace during the last minute. All other participants were able to maintain 4.0 km·hr⁻¹ while wheeling for the entire 8 minutes.

Figure 4.1 Heart rate data recorded while at rest and during wheelchair locomotion for all wheelchair dependent participants tested at California Polytechnic State University, San Luis Obispo, CA

Figure 4.2 displays the heart rate data recorded during testing for the able-bodied participants. The general heart rate trend appears similar to the trend observed in Figure 4.1, though the steady state during exercise was reached at a lower heart rate.

Inspection of Figure 4.3 reveals that the group mean heart rates for the wheelchair dependent group, during both rest and exercise ($M = 79.45$ bpm and $M = 118.05$ bpm, respectively) were higher than the group mean heart rates for the able-bodied group ($M = 74.31$ bpm and $M = 90.63$ bpm, respectively). Additionally, the difference between the

mean exercise heart rates (27.43 bpm) was greater than the difference between the mean resting heart rates (5.15 bpm).

Figure 4.2. Heart rate data recorded while at rest and during wheelchair locomotion for all able bodied participants tested at California Polytechnic State University, San Luis Obispo, CA.

Figure 4.4 displays the VO_2 data for each wheelchair dependent participant tested while at rest and during exercise. Similar to the heart rate trend in Figures 4.1, VO_2 increased at 5 minutes when the participants transitioned from resting to wheeling at $4.0 \text{ km} \cdot \text{hr}^{-1}$. The erratic measurements are believed to be sampling variations related to participant breathing patterns.

Figure 4.3. Group mean heart rates for the Wheelchair Dependent Group (WC) and the Able Bodied Group (AB) during testing at California Polytechnic State University, San Luis Obispo, CA.

As can be seen in Figure 4.5, the same predictable trend occurred for the able-bodied group as displayed for the wheelchair dependent group in Figure 4.4 though at a lower magnitude. Both groups displayed the expected positive correlation between VO_2 and increased workload. The difference in mean VO_2 for the two groups is displayed in Figure 4.6. The same trend as observed in Figure 4.3 is seen in Figure 4.6 where the mean values during rest and exercise for the wheelchair dependent group ($M = 4.28 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ and $M = 13.26 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, respectively) are higher than the values for the able-bodied group ($M = 3.91 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ and $M = 9.13 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, respectively).

Figure 4.4. VO₂ data recorded while at rest and during wheelchair locomotion for all wheelchair dependent participants tested at California Polytechnic State University, San Luis Obispo, CA.

Table 4.3 presents the difference in energy cost of wheeling, expressed in Metabolic Equivalents (METS), for the two groups. The mean METS at rest did not differ as a function of the two groups, $t(8) = -0.72$, $p = 0.492$. The mean METS during exercise for the wheelchair dependent group was significantly greater than the mean METS during exercise for the able-bodied group, $t(8) = -3.56$, $p = 0.007$.

Figure 4.5. VO₂ data recorded while at rest and during wheelchair locomotion for all able-bodied participants tested at California Polytechnic State University, San Luis Obispo, CA.

Figure 4.6. Group mean VO₂ for the Wheelchair Dependent Group (WC) and the Able Bodied Group (AB) during testing at California State Polytechnic University

Table 4.3 *Mean Metabolic Equivalents (METs) for Wheelchair Dependent Group and the Able-Bodied Group While at Rest and During Exercise.*

	Mean METS resting	Mean METS exercising
Wheelchair Dependent Group (n = 5)	1.193 ± 0.229	3.589 ± 0.516
Able-bodied Group (n = 5)	1.100 ± 0.170	2.726 ± 0.164
Difference between groups	0.093	0.863*

*significant at p<.05

Discussion of results

The original goal of this study was to investigate any unique physiological responses to exercise for wheelchair dependent individuals, specifically with regard to the aerobic response associated with wheeling at $4 \text{ km}\cdot\text{hr}^{-1}$ on an all-weather track facility. As stated in the previous chapter, few participants were successfully recruited. Despite the small sample size, useful information was collected that should shape future research on the topic. This chapter will discuss the relevant results of the study. In addition, there will be a discussion of the challenges encountered during this study and recommendations for future research on this topic.

The results of this study demonstrate a clear difference in the aerobic response to wheelchair locomotion between a male spinal cord injured, wheelchair dependent population and a male able-bodied population. While no difference between mean VO_2 was observed during rest, the wheelchair dependent group had a significantly ($p < 0.05$) higher mean VO_2 (expressed in METS) while wheeling at $4 \text{ km}\cdot\text{hr}^{-1}$ than the able bodied group ($t(8) = -3.56$, $p = 0.007$) (Table 4.3). This indicates that the wheelchair group used approximately 45% more energy than the able-bodied group to accomplish the same task. This finding supports the results of Drory, Ohry, Brooks, Dolphin & Kellermann's study (1990), which found the same response to exercise during arm crank ergometry for upper thoracic and cervical spinal cord injured participants as compared to able-bodied participants. The similar findings between Drory et al.(1990) and the present study indicate that the cardiovascular response to upper body exercise is not mode specific, as both arm crank ergometry and wheelchair propulsion yielded the same effect.

The differences between the groups are likely the direct result of the spinal cord injury which results in lower levels of metabolically active tissue and a generally more sedentary lifestyle for the wheelchair dependent individual. We are unable to know if the differences in VO_2 between the two groups are exclusively the result of spinal cord injury since we do not have data about the wheelchair group before they were injured. It is also not clear what aspect of having a spinal cord injury influences the difference observed from the able-bodied group. Further research would be necessary to conclude whether the reduced metabolically active tissue, the more sedentary lifestyle, or some other factor was the most likely cause for the difference. With this cross-sectional design, it is possible that the two groups could have had different VO_2 measurements despite incidence of injury. Since a longitudinal design that includes measurements before injury is not possible, the limitations of a cross-sectional design must be accepted. Certainly the significant difference observed with this small sample size, and supported by other studies, justifies further research on the topic.

Discussion of challenges encountered during the study

Participant recruitment was the greatest challenge for this project. Posting research flyers around campus yielded no response largely due to the fact that there is a very small wheelchair subpopulation at Cal Poly. Further postings around the San Luis Obispo community also yielded no response. Establishing contacts at hospitals and physical therapy centers seemed like a great method of reaching the wheelchair community, however, receiving assistance from these centers was difficult. Effective means of recruitment came from interpersonal networking, involving reaching out to contacts with information regarding the study. Once contact was established with one

wheelchair user, connections were made with several other wheelchair users in the area. The wheelchair users in San Luis Obispo remain a fairly close community and many of them meet on a monthly basis as part of a support group. San Luis Obispo has a low population density of wheelchair users, so local recruitment was difficult. Not everyone qualified for the study based upon the delimitations of this study mentioned in the Introduction. Additionally, some potential participants who did qualify based on the screening questionnaire were not interested in participating.

Recruitment from out of the area was as challenging and unproductive as local recruitment. The most promising lead for larger numbers of participants came from a rehabilitation hospital in Santa Barbara, California. However, despite ample follow-up and communication, the center gradually stopped returning phone calls and inquiries.

Testing conditions were another challenge for this project. Any study conducted in the field will have unique challenges that could be easily controlled in a lab setting. The real world aspects of this field study offered the researcher the opportunity to observe the issues that a practitioner may encounter outside the lab. Perhaps the most significant challenge of the outdoor field study was the atmospheric conditions. Fortunately, in San Luis Obispo, the weather is consistent and favorable for outdoor studies. Relatively low annual rainfall totals and temperate temperatures mean that on most days of the year, outdoor conditions mimic lab conditions. Wind is a significant variable and a challenge that was encountered in the present study. On two testing days, testing had to be rescheduled due to extremely high winds. The challenge that the high winds placed on the participant meant that wheeling was much more difficult into the wind and it was virtually possible to coast in downwind situations. Furthermore, steering

in cross wind situations was also a challenge and made it more difficult to maintain a consistent pace. The variability due to the wind meant there was no period of steady state for heart rate data collection.

Chapter 5

Summary, Conclusions and Recommendations

Summary and Conclusions

The purpose of this study was to explore the differences in the aerobic response to wheeling between wheelchair dependent individuals and able-bodied individuals of similar genders and ages. Two participant groups (wheelchair dependent and able-bodied) performed a wheeling task around a 400 meter track to test the hypothesis that there exists a difference between the VO_2 of wheelchair dependent individuals and able-bodied individuals when wheeling at $4.0 \text{ km}\cdot\text{hr}^{-1}$. The outcome of the two-sampled T-test was significant at $p < .05$, thereby rejecting the null hypothesis, which supports the original hypothesis. Though the groups appeared similar during rest, the results indicated that there is a significant difference between the two groups during exercise, which supports previous research on the topic.

Recommendations for future research

There are several design elements of this study that could be modified to benefit future research. The present project sought to measure aerobic response at only one speed ($4.0 \text{ km}\cdot\text{hr}^{-1}$). In order to gather further information regarding the relationship between speed, and aerobic response and energy expenditure, testing at several different speeds would be recommended. Testing should be designed such that the participant could reach a steady state heart rate at each speed before progressing to the next speed. In the present study, the participants were able to reach a steady state heart rate within about 2 minutes at the new intensity. Given a large enough sample size and using the results from testing at multiple speeds, a valuable regression equation could be developed

that would allow wheelchair exercisers to estimate their energy expenditure based on speed and duration, similar to the ACSM equations to estimate caloric expenditure while walking or running.

Another element of the present project that future researchers may want to address is the use of one standardized wheelchair. For this project, a common wheelchair was used for all participants in order to standardize the weight and performance of the chair throughout testing. It became clear during testing, however, that wheelchair fit for a wheelchair user is very specific, as the user becomes very accustomed to the fit of his own chair. Most chairs are custom fitted for those who will be in them permanently. Consequently, all the participants subjectively reported that the testing chair felt awkward compared to their own. Some found they were sitting substantially lower than in their own chair or that the relative position of the push rims was uncomfortable. All participants said it felt good to get back into their own chair after testing. In future studies, a chair with more adjustment capabilities may resolve this issue. Future researchers may also choose to allow participants to test in their own chair and normalize the measurements to account for differences in chair weight. A pilot study that tested participants in several different chairs would reveal any significant differences due to the chair design.

One variable that was not controlled in this study was the training state of each participant prior to testing. Subjective observation of the tests revealed that some participants found the physical demands of testing to be easier than others. The present study did not record rating of perceived exertion (RPE), but it is recommended for future research since RPE data are easily collected and could strengthen the relationship

between wheeling speed and VO_2 . The RPE could be affected by a better training state, younger age, level of spinal lesion, and/or other factors. A multivariable regression analysis would reveal which factors were most influential to the results, provided the number of subjects was sufficient to offer statistical power.

References

- Andersen, E. C., & Kasch, F. W. (1984). Maximum oxygen uptake of trained paraplegics during arm ergometry and tethered swimming (Abstract.). *Medicine & Science in Sports & Exercise*, 16, 148.
- Blair, S. N., Kohl, H. W., Barlow, C. E., Paffenbarger, R. S. Jr, Gibbons, L. W., & Macera, C. A.. (1995). Changes in physical fitness and all-cause mortality: A prospective study of healthy and unhealthy men. *JAMA*, 273, 1093-1098.
- Brattgard, S. O., Grimby, G., & Hook, O. (1970). Energy expenditure and heart rate in driving a wheel-chair ergometer. *Scandinavian Journal of Rehabilitative Medicine*, 2, 143-148.
- Campbell, D. T., & Stanley, J. C. (1963). *Experimental and Quasi-Experimental Designs for Research*. Boston; Houghton Mifflin Company.
- Chawla, J. C., Bar, C., Creber, I., Price, J., & Andrews, B. (1979). Techniques for improving the strength and fitness of spinal injured patients. *Paraplegia*, 17(2), 185-9.
- Clausen, J.P., Klausen, K., Rasmussen, B., & Trap-Jensen, J. (1973). Central and peripheral circulatory changes after training of the arms or legs. *American Journal of Physiology*, 225,675-682.
- Cooper, R. A., Boninger, M. L., Cooper, R., Robertson, R. N., & Baldini, F. D. (2003). Wheelchair racing efficiency. *Disability and Rehabilitation*, 25(4-5), 207-212.
- Cooper, R. A., Quatrano, L. A., Axelson, P. W., Harlan, W., Stineman, M., Franklin, B., Krause, J. S., Bach, J., Chambers, H., Chao, E. Y. S., Alexander, M., & Painter, P. (1999). Research on physical activity and health among people with disabilities: A consensus statement. *Journal of Rehabilitation Research & Development*, 36(2), 142-54.

- Cowell, L. L., Squires, W. G., & Raven, P. B. (1986). Benefits of aerobic exercise for the paraplegic: A brief review. *Medicine & Science in Sports & Exercise*, 18(5), 501-508.
- Drory, Y., Ohry A., Brooks M.E., Dolphin D., Kellermann J.J. (1990). Arm crank ergometry in chronic spinal cord injured patients. *Archives of Physical Medicine and Rehabilitation*, 71, 389-392.
- Emes, C. G. (1981). Fitness and the physically disabled: A review. *Canadian Journal of Applied Sport Sciences*. 6(4), 176-178.
- Eriksson, P., Lofstrom, L., & Ekblom, B. (1988). Aerobic power during maximal exercise in untrained and well-trained person with quadriplegia and paraplegia. *Scandinavian Journal of Rehabilitative Medicine*, 20, 141-147.
- Gass, G. C., Camp, E. M., Davis, H. A., Eager, D., & Grout, L. (1981). The effects of prolonged exercise on spinally injured subjects. *Medicine & Science in Sports & Exercise*, 13(5), 277-283.
- Glaser, R. M., Foley, D. M., Laubach, L. L., Sawka, M. N., & Suryaprasad, A. G. (1978). An exercise test to evaluate fitness for wheelchair activity. *Paraplegia*, 16, 341-349.
- Glaser, R. M., Sawka, M. N., Durbin, R. J., Foley, D. M., & Suryaprasad, A.G. (1981). Exercise program for wheelchair activity. *Canadian Journal of Physical Medicine*, 60(2), 67-75.
- Hildebrandt, G., Voigt, E. D., Bahn, D., Berendes, B., & Kroger, J. (1970). Energy costs of propelling wheelchair at various speeds: Cardiac response and effect on steering accuracy. *Archives of Physical Medicine & Rehabilitation*, 51, 131-136.
- Hjeltne, N. & Vokac, Z. (1979). Circulatory strain in everyday life of paraplegics. *Scandinavian Journal of Rehabilitation Medicine*, 11, 67-73.

- Hoffman, M. D. (1986). Cardiorespiratory fitness and training in quadriplegics and paraplegics. *Sports Medicine*, 3, 312-330.
- Huonker, M., Schmid, A., Sorichter, S., Schmidt-Trucksab, A., Mrosek, P., & Keul, J. (1998). Cardiovascular differences between sedentary and wheelchair-trained subjects with paraplegia. *Medicine & Science in Sports & Exercise*, 30(4), 609-613.
- Hrubec, Z. & Ryder, R.A. (1979). Report to the Veterans' Administration Department of Medicine and Surgery on Service-Connected Traumatic Limb Amputations and Subsequent Mortality from Cardiovascular Disease and Other Causes of Death. *U.S. Committee on Veterans Affairs U.S. Senate, U.S. Government Printing Office*.
- Knechtle, B., & Kopfli, W. (2001). Treadmill exercise testing with increasing inclination as exercise protocol for wheelchair athletes. *Spinal Cord*, 39, 633-636.
- Kofsky, P. R., Davis, G. M., Shephard, R. J., Jackson, R. W., & Keene, G. C. R. (1983). Field Testing: Assessment of physical fitness on disabled adults. *European Journal of Applied Physiology*, 51, 109-120.
- McMurray, R. G., Ainsworth, B. E., Harrell, J. S., Griggs, T. R., & Williams, O. D. (1998). Is physical activity or aerobic power more influential on reducing cardiovascular disease risk factors? *Medicine & Science in Sports & Exercise*, 30(10), 1521-1529.
- National Spinal Cord Injury Statistical Center (NSCISC). (2009). Spinal Cord Injury Facts and Figures at a Glance. April 2009. Retrieved July 27th from the World Wide Web: <http://www.spinalcord.uab.edu/show.asp?durki=119513&site=4716&return=19775>
- Nilsson, S., Staff, P. H., & Pruett, E. D. (1975). Physical work capacity and the effect of training on subjects with long-standing paraplegia. *Scandinavian Journal of Rehabilitative Medicine*, 7(2), 51-6.

- Ornstein, L. J., Skrinar, G. S., Garrett, G. G. (1983). Physiological effects of swimming training in physically disabled individuals. (Abstract.) *Medicine and Science in Sports and Exercise*, 15, 110.
- Paffenbarger, R. S., Hyde, R. T., Wing, A. L., Lee, I. M., Jung, D. L., & Kampert, J. B. (1993). The association of changes in physical-activity levels and other lifestyle characteristics with mortality among men. *New England Journal of Medicine*, 328, 538-545.
- Pollock, M. L., Baesser, G. A., Butcher, J. D., Despres, J. P., Dishman, R. K., Franklin, B. A., & Garber, C. E. (1998). ACSM position stand on the recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in adults. *Medicine & Science in Sports & Exercise*, 30(6), 975-991.
- Pollock, M. L., Miller, H. S., Linnerud, A. C., Laughridge, E., Coleman, E., & Alexander, E. (1974). Arm pedaling as an endurance training regimen for the disabled. *Archives of Physical Medicine and Rehabilitation*, 55(9), 418-424.
- Rhodes, E. C., McKenzie, D. C., Coutts, K. D., & Rogers, A. R. (1981). A field test for the prediction of aerobic capacity in male paraplegics and quadriplegics. *Canadian Journal of Applied Sport Sciences*, 6(4), 182-186.
- Tolfrey, K., Goosey-Tolfey, V. L., & Campbell, I. G. (2001). Oxygen uptake-heart rate relationship in elite wheelchair racers. *European Journal of Applied Physiology*, 86, 174-178.
- van der Woude, L. H. V., Bouten, C., Veeger, H. E. J., & Gwinn, T. (2002). Aerobic work capacity in elite wheelchair athletes. *American Journal of Physical Medicine & Rehabilitation*, 81, 261-171.

- Vanlandewijck, Y. C., Spaepen, A. J., & Lysens, R. J. (1994). Wheelchair propulsion efficiency: Movement pattern adaptations to speed changes. *Medicine & Science in Sports & Exercise*, 26(11), 1373-1381.
- Vokac, Z., Bell, H., Bautz-Holter, E., & Rodahl, K. (1975). Oxygen uptake/ heart rate relationship in leg and arm exercise, sitting and standing. *Journal of Applied Physiology*, 39(1), 54-59.
- Whiting, R. B., Dreisinger, T. E., & Hayden, C. R. (1984). Wheelchair exercise testing: Comparison of continuous and discontinuous exercise. *Paraplegia*, 22, 92-98.
- Wuest, D. A. & Bucher, C. A. (1999). *Foundations of Physical Education and Sport* (13th ed.). Boston: The McGraw-Hill Companies, Inc.
- Zwiren, L. D., & Bar-Or, O. (1975). Responses to exercise of paraplegics who differ in conditioning level. *Medicine & Science in Sports & Exercise*, 7(2), 94-98.

Appendix A: Informed Consent Form

Appendix B: Health History Form