Acute Exercise Response in Individuals with Spinal Cord Injuries during High Intensity Interval Training

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Spinal cord injuries (SCI) are limiting to an individual's health and reduce quality of life. Individuals with SCI are at higher risk for developing secondary health problems, due to physical inactivity.[1,2] Current exercise recommendation consist of moderate intensity of 20-60 min./week three to five times/week, though most do not met recommendation levels.[10,21] High Intensity Interval Training (HIIT) has been studied in various other populations, and deemed to be appropriate and beneficial to individual's health.[3,4,7,20,32,33] Health benefits from HIIT has not been studied within this population.

The objective of this study was to determine physiological and perceptual responses to HIIT in individuals with SCI and to describe between session variations, and differences among sub-categories: tetraplegia and paraplegia. Subjects participated in baseline- and post- graded exercise testing before and an exercise program consisting of 6 weeks (2x/week) of HIIT handcycling. Subject's maximum power output recorded during baseline testing determine their training range. Subjects completed 2, 20 minute supervised at-home sessions (ten 60 second bouts of exercise at 90% maximum power output, then 60 seconds of 0-20% maximum power output), per week. Variables analyzed consisted of: peak heart rate (bpm), cadence (RPM), power (W), rate of perceived exertion (RPE), and feeling, time to peak HR, cadence, power, RPE, and feeling, and average power and cadence.

Eight subjects were included in the analysis. Two subjects did not complete all twelve training sessions. Average and peak power (W), peak HR (bpm), and RPE improved significantly from subjects' first to last session of the exercise program. Between session variation showed a positive trend for average and peak power, peak feeling, and time to peak HR. A downward trend was observed for peak HR and RPE. No comparisons could be drawn between sub-groups due to the small sub-sample size.

HIIT was found to be safe, effective, and beneficial for individuals with SCI. Six weeks of HIIT handcycling elicited physiological and perceptual improvements within this population. The outcomes from this study should assist in validating HIIT exercise programming for individuals with SCI. Further research should expand to a larger sample size, and/or an increased HIIT intervention timeframe.

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Preface

There are many people who I would like to thank for their contribution and guidance on this project. First, I would like to thank my thesis committee, Dr. Alicia Koontz for allowing me step in and assist in her study, and Dr. Mita Lovalekar. I would also like to specifically thank my thesis advisor and committee chair, Dr. Katelyn Allison for her help throughout this endeavor.

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1.0 Introduction

Neuromuscular disorders are medical conditions that result in decreased functioning of the body's nervous and/or muscular system(s). Spinal cord injuries (SCI) are classified as a nonprogressive neurological disorder in that following the onset of injury, implications of injury do not continue to decrease.[14,25]

SCI is commonly caused from traumatic or disease incidences. Physiological effects can vary based on the location and severity of the injury from lower extremity to all extremity and trunk paralysis.[16,19,21] Individuals with spinal cord injuries often live sedentary lifestyles due to physical, psychological, and environmental barriers which can lead to various health risks. While previous research has demonstrated that living a sedentary lifestyle in any population increases risk for the development of secondary health risks, such as cardiometabolic complications (hypertension, dyslipidemia, obesity, etc.), sedentary individuals with neuromuscular conditions are at an even greater increased risk for these secondary health risks. [6,20,22]

Exercise has been shown to be an effective method for all populations to reduce the likelihood of developing said secondary health conditions. Currently, there are few exercise recommendations for individuals with spinal cord injuries but a vast amount for various other populations.[16,35] Methods of exercise for healthy and other clinical populations include circuit, resistance, and high intensity interval training (HIIT).[3,4,31,32,33] HIIT is traditionally performed using the lower extremity, thus inapplicable to wheelchair users. Little research has been done to determine if upper extremity HIIT would be an effective method of exercise for persons with SCI.[14]

HIIT is known to take a significant less amount of training time than moderate continuous aerobic training, and produce similar, if not better health benefits.[7,14,]

HIIT is found to be a reliable and valid form of exercise, regardless of mode of exercise, but there is a lack of evidence to indicate the benefit and between session response for individuals with spinal cord injuries. Thus, there is a need to examine the relationship between HIIT and exercise response variables within individuals with SCI. If individuals respond positively, this would help determine HIIT as an effective and safe method of exercise for this special population.

1.1 Definition of Spinal Cord Injuries

SCI can be defined as damage to any part of the spinal cord or nerves which results in permanent impairments in strength and coordination, sensation, and other bodily functions below the site of injury.[25]

1.1.1 Incidence and Prevalence

As of 2018, the National Spinal Cord Injury Statistical Center reported that the number of people with SCI living in the United States was approximately 288,000 persons, with a range from 247,000 to 358,000 persons. The average age for the occurrence of SCI is within the range of 16-30 years of age, with approximately 80% of SCI subjects being male.[25,26] According to the National Strength and Conditioning Association (NSCA), approximately 57% of individuals with spinal cord injuries are considered paraplegic (21.4% incomplete, 21.6% complete) with 43% of injuries classified as tetraplegic (40.8% incomplete, 15.8% complete).[16,19,25]

1.1.2 Etiology

SCI is a result of injury or disease to the spinal cord. The spinal cord is enclosed within the spinal column, specifically known as vertebrae. There are 33 vertebra that make up the spine: seven cervical, twelve thoracic, five lumbar, five sacral, and four coccygeal. The primary purpose of the spinal column is to protect the spinal cord, with secondary function to allow movement between vertebral spaces to absorb impact and force.[16,19] Traumatic injury can result in increased strain placed on the spinal column and cord resulting in injury. The spinal cord can be partially or completely cut (transected) or be contused by trauma. Initial injury lead to have further impairments due to secondary damages such as edema, restricting the circulatory blood flow to the region.[16]

The most common causes of injury to the spinal cord are from traumatic events, such as motor vehicle accidents (39%), falls (28%), acts of violence (15%), followed by recreational activities (8%).[14,22,23] To date, there are approximately 17,000 new cases on spinal cord injury per year within the United States.[25,26]

1.1.3 Types of SCI

An individual's ability to utilize and control their limbs post-SCI is dependent upon two factors: location of injury and the severity of injury, and type of lesion to the spinal cord.[25,26] Paraplegia is the paralysis of the lower extremity which can include portions of the abdominals, trunk, and pelvic organs. Injuries resulting in paraplegia occur from T1-L5. Tetraplegia, otherwise known as quadriplegia, is the paralysis of all four limbs including the trunk and abdominals. Spinal cord injuries resulting in tetraplegia are a result of injury to the cervical region of C1-C8.[16,19,25,26] Both forms of SCI can be further divided into two categories based on the type of lesion present during the occurrence of injury. An incomplete lesion is understood to be partial damage to the spinal cord; thus, some motor and sensory function remains below the site of injury. This function varies from person to person due to the severity of one's injury. Unlike an incomplete lesion, a complete lesion is the total loss of sensory and motor function.[16,19, 25] Both the severity and location of injury have various implications and effects on the individual.

1.2 Implications of Spinal Cord Injuries

Spinal cord injuries can cause impairments to an individual's quality of life and physical health. It is commonly seen that individuals with SCI live a primarily sedentary lifestyle which can place them at higher risk for developing secondary health conditions such as cardiometabolic diseases.[6,19,20,22] Reasons for developing a sedentary life and implications of said lifestyle are listed within this section.

1.2.1 Psychological

Following an injury, many individuals with spinal cord injuries have reported changes in their self-perception when performing both activities of daily living and exercise programs. Studies have shown that some of the most common psychological implications or barriers due to injury are self-conscious when visiting and/or using fitness facilities, the feeling of lack of support, fear of the unknown, and concerns about asking for assistance.[15,23] Individuals with SCI have reported perceptions of unfriendly environments (such as fitness facilities), with connections to negative attitudes and behaviors from other patrons to be the one of the leading causes for not attending a fitness facility.[15]

Often, these perceived barriers result in a decrease to complete absence in usage of fitness facilities, causing individuals to only participant in exercise during physical therapy and possibly exercise programs at home. Once participating in a home exercise program, in which the equipment is setup within the home, individuals reduce the negative attitudes and discomfort of exercising with the public but then report a lack of motivation to exercise.[15,23] This lack of motivation commonly results in inactivity, due to the loss/limited drive to perform exercise and maintain a healthy lifestyle. This in turn can result in health complications and other physiologic implications.

1.2.2 Accessibility Issues

Along with psychological implications and barriers of injury there are also environmental aspects as well. These barriers are uncontrollable by the individual, but studies have shown that they play a large role in the responsibility for inactivity. Individuals with SCI have commonly reported 3 factors that affect their ability and drive to perform physical activity. These factors include: lack of accessible facilities, lack of adaptive equipment, lack or limited knowledge and education of fitness professionals to aid in training programs for this population.[15,18,23] The deficiency of accessible facilities is determined based on the setup, design, and building structure. This includes doorways, ramps, and regulations set by the American Disability Act. Inaccessible equipment is determined by the lack of spacing between exercise machines within the facility, adaptive attachments for exercise equipment, and/or inability to allow either room to transfer to equipment or wheelchair accessible equipment model.[14,15] Studies have shown that these factors play a major role in the degree of physical activity participation in individuals with SCI. Often individuals with SCI reported a reduced drive to live a healthy style due to the difficulty to maintain one and the need to overcome many barriers.

1.2.3 Physiological

Along with the psychological implications and barriers to exercise, individuals with SCI face physiological ones as well. For many individuals, SCI is debilitating to their health and functional capacity leading to a reduction in their overall quality of life. The injury in itself along with psychological and environmental barriers all contribute to a sedentary lifestyle within this population. Physical implications of spinal cord injuries can be a variety of factors from functional capabilities to the development of secondary health-related conditions. Secondary health-related diseases and conditions such as cardiometabolic and hypokinetic are a result of a sedentary lifestyle.[4,6,35] Individuals with tetraplegia or those with paraplegia above T4 are at increased risk for autonomic dysreflexia, characterized by sudden onset of rapid heart rate and high blood pressure, which can be life-threatening if exercise is too intense.[16] The fear of this response has been seen to be a deterrent for some individuals with SCI.

Studies have shown that individuals with SCI usually carry a larger amount of fat-mass within the abdominal area than able-bodied matched subjects due to physical inactivity. It was reported that approximately 40% of individuals with SCI are overweight or obese.[4,6] Overweight and obesity was defined as their Body Mass Index (BMI) being greater than 25 kg/m.[2,4] Along with risk of obesity, research shows that individuals with SCI are at increased risk for coronary heart disease, hypertension, diabetes, impaired glucose tolerance, and abnormal lipid profile (dyslipidemia). The development of secondary health-related conditions can result a further decrease in physical functioning, independence to perform ADL's, and decrease in life expectancy.[4,6] Exercise has been seen to strongly aid in the reduction of incidence and development of these secondary health-related conditions within the SCI population.[4,6,10,16]

1.3 Exercise in SCI Population

Exercise has been known to improve functional capacity, bone density, cardiovascular endurance, muscle strength, psychological well-being, reduce spasticity and pain within individuals with spinal cord injuries.[10,16,20,21,] The majority of individuals with SCI are inactive and have low levels of fitness. Several health organizations have provided exercise recommendations for individuals with SCI in order to safely promote a positive healthy lifestyle.

Overall exercise recommendation for individuals with spinal cord injuries do vary greatly from that of the general population.[16]

The American College of Sports Medicine (ACSM) recommends that individuals with SCI perform 20-60 minutes of continuous aerobic exercise or in 10 minutes sessions, 5 times per week for a total of 150 minutes.[10,21,28] Emphasis of an exercise program should be centered around strengthening of intact muscles, maintaining and/or gaining muscle length and range of motion, and facilitating recovering and strengthening weakened muscles.[10,16,21,28,34] Though this recommendation may not be feasible for many individuals within this population for various physiological, psychological, and environments as mention previously.

Similar to the ACSM moderate intensity activity recommendation, the NSCA also includes vigorous aerobic activity guidelines for SCI. This consists of 3 days of vigorous aerobic activity for a total of 75 minutes per week.[16] According to the NSCA, aerobic exercise can be performed using a handcycle or arm crank. Participants should begin with light to moderate intensity of 30-60% VO_2 to more vigorous intensity 55-75% VO_2. Exercise intensity can be monitored on range 9-13 based on the Borg Scale 6-20-point scale.[16]

Research has shown that participation in low levels of physical activity within subjects with SCI has greatly improved anaerobic work capacity, isometric strength, and peak aerobic work capacity. One study investigated the outcomes of a 12-week HIIT program for a man with SCI. The subject was described to have a C8/T1 complete spinal cord injury, and took part in arm ergometry exercise 3 days per week. Training periodization consisted of 3 times 5 min at 70% Peak Power (W_{Peak}) followed by a 5 min recovery; 4 times 2.5 min at 85% W_{Peak} with 5 min recovery; and 10 times 1 min at 110% W_{Peak} with 2 min recovery.[14] Researchers observed a large increase in peak aerobic power and submaximal endurance performance following the 12-week training protocol.

A second study compared changes in cardiorespiratory and metabolic variables between two interval training protocols or moderate endurance training. 9 subjects (7 with paraplegia and 2 with tetraplegia) were spilt into 3 groups and performed a single session: moderate endurance training (ET), HIIT, or sprint interval training. ET subjects performed continuous arm cranking exercise for 25 min at 45% W_{Peak}; HIIT subjects performed 8 60sec bouts of arm cranking at 75% W_{Peak} followed by 1.5 min of active recovery; Sprint interval subjects completed 8 “all-out” effort at 105% W_{Peak} for 30 seconds followed by 2 min recovery.[1] Training protocols were designed to match in energy expenditure. Oxygen uptake, heart rate, and blood lactate concentration were measured throughout all sessions. Researchers found oxygen uptake and heart rate increased during both methods of interval training, as well as peak values were significantly higher than in moderate ET.[1] All participants preferred interval training as opposed to moderate exercise. HIIT was determined to be achievable and feasible for individuals with SCI. Researchers claimed that exercise intensity is recognized as the most important factor in optimizing cardiorespiratory and metabolic variables.[1,7,14]

1.4 High Intensity Interval Training

High intensity interval training (HIIT) is defined as an exercise regime of bouts of high levels of activity followed but a period of rest or low level of activity, with the primary goal of improving the cardiovascular system of the participant.[17] HIIT has been found to be an effective alternative method of training from the standard moderate continuous exercise. Several physiological adaptations are found from performing HIIT such as: improvement in aerobic capacity, endothelial and metabolic function, mitochondrial density, and insulin sensitivity.[12,17] These adaptations are largely dependent upon exercise volume, which is the product of exercise intensity (work per session), exercise duration (time per session), and training frequency (sessions per week). HIIT allows for a decrease in duration and frequency of an exercise program, while eliciting similar or even superior physiological adaptations in healthy individuals and diseased populations than moderate intensity exercise.[12,19]

1.4.1 Healthy Population

Traditional aerobic endurance training (ET) is defined by the ACSM as 20-60 minutes of moderate intensity exercise 5 days per week. [10,21,28] Several studies compared HIIT to traditional aerobic endurance training to determine if HIIT could produce similar health benefits. One study investigated the implications of HIIT on health-related fitness aspects within healthy adolescents. Researchers observed a large improvement in cardiorespiratory fitness and moderate improvement in body composition in comparison to moderate intensity exercise group over the course of the 4-week intervention. Study duration was determined to be a moderator for the effects of HIIT on body fat percentage; researchers indicated that training over 8-weeks would results in greater changes in body fat percentage.[7] This study determined HIIT to be a practical and time-efficient method for improving cardiorespiratory fitness and body composition within adolescent populations.

Another study explored metabolic adaptations during exercise after HIIT and traditional ET following a 6-week training protocol within healthy adult populations. Researchers spilt subjects into 2 groups: HIIT and ET. HIIT subjects performed four to six repeats of 30sec Wingate test with a 4.5 min recovery between bouts, 3 days per week.[4] ET subjects performed 40-60 min continuous moderate intensity (65% VO_2 peak), 5 days per week. Following the training program, researchers observed that both protocols resulted in similar increases in mitochondrial markers within skeletal muscle and lipid oxidation.[4] HIIT training showed to be much less of a time commitment and reduced overall training volume in comparison to ET. This led researchers to state that given the significantly lower training volume and time requirement for HIIT, suggests that high intensity interval training is a time-efficient method for increasing skeletal muscle oxidative capacity, and metabolic adaptations.[4,7,17,31]

1.4.2 Stroke Populations

Pervious research recommended moderate-intensity continuous endurance training to provide aerobic improvement and mobility following stroke. Current research produced by Boyne et. al. compared HIIT to moderate intensity ET to determine if HIIT was feasible and justified. Participants found HIIT to be an acceptable method of training. Results showed improvements in metabolic cost of gait, fractional utilization, and increased treadmill speed. Researchers identified a significant clinical improvement that treadmill speed increased by over 10%.[3] Further research is needed to determine within sessions and overall aerobic improvements within stroke populations.

1.4.3 Obese Populations

One study investigated the effects of exercise training intensities on abdominal visceral fat and body composition on obese individuals with metabolic syndromes. This study design split subjects into 3 groups for the course of 16 weeks: No exercise training (control), Low-Intensity exercise training (LIET), and High-Intensity exercise training (HIIT). Control group was instructed to maintain their current existing levels of physical activity; LIET group performed light-to-moderate intensity (below lactate threshold) exercise 5 days per week; HIIT subjects performed exercise above lactate threshold 3 days per week.[6] Results showed that HIIT subjects significantly reduced total abdominal fat, abdominal subcutaneous and visceral fat. Little to no difference was seen between control and LIET groups. Researchers state that HIIT is a more effective method of training to improvement body composition within obese populations with metabolic syndromes.[6]

A second study explored the effects of high intensity interval training on health-related outcomes within sedentary overweight/obese men. Subjects participated in a 2-week HIIT intervention consisting of 6 sessions of 4 to 6 bouts of 30 sec Wingate sprint with a 4.5 min recovery between bouts of exercise.[32] Following the intervention, significant decreases were seen in waist and hip circumferences compared to baseline. This led researchers to believe that even a short period of HIIT would significantly improve metabolic and vascular risk factors in overweight/obese populations.[6,32] A longer exercise intervention timeframe would provide for better improvements such as insulin sensitivity, blood pressure, adherence, and long-term benefits within said population.

1.4.4 Cardiovascular Disease Populations

Previous literature has shown that exercise training reduces symptoms of chronic heart failure. Wisloff et al. developed a study to compare the effect of moderate endurance training and HIIT on cardiovascular function within patients with post-infarction heart failure. Twenty-seven subjects were divided into 2 groups. Subjects in the moderate ET exercised on a treadmill at 70% of maximum heart rate for 30 minutes, while the HIIT group exercised on a treadmill at 95% of their maximum heart rate for 1 minutes followed by 2 minute active recovery for a total of 20 minutes (38 minutes total), 3 days per week over the course of 12 weeks.[35] Following the exercise intervention, researchers found an increase in VO_2 peak, decrease in left-ventricle (LV) end-diastolic and end-systolic volumes within HIIT subjects only. Researchers also observed LV ejection fraction increased by 35%, as well as improvement in brachial artery dilation and increased mitochondrial function within the vastus lateralis muscle of HIIT subjects.[20,35] Exercise intensity is seen to play a vital factor in improving aerobic capacity and quality of life within patients with post-infarction heart failure.[35]

1.5 Definition of Problem

HIIT has been well established as a method of training for various populations, and known for its health and fitness improvements.[4,6,20,33] Limited studies have investigated participation in HIIT in individuals with spinal cord injuries due to their inability to perform lower extremity exercise protocols unlike populations that were previously discussed. A limitation within the study done by Harnish et al. consisted of the extremely small sample size of one subject, thus raising to question if this training protocol is translatable to all individuals with SCI. A secondary study by Astornio et al. presented several limitations as well. Such as little analysis was conducted to understand the within session differences between types of training and response to exercise program.[1] This study also included a limited number of subjects with tetraplegia, thus not providing a well reversed understanding of individuals with SCI response to HIIT. Only one other study has included subjects of various injury types, such as tetraplegia and paraplegia, both incomplete and complete.[1] There is also limited research in regards to HIIT exercise recommendation, duration, intensity, and frequency, for this specific population.

1.6 Purpose of Study

The purpose of this study is to investigate acute exercise responses in individuals with spinal cord injuries during high intensity interval training sessions. HIIT allows for a reduce exercise duration and frequency, which would be extremely beneficial if proven to be safe and effective for this population. This study will examine peak heart rate (HR), power output, cadence, feeling scale, rate of perceived exertion (RPE), and time to peak for each variable.

1.7 Significant Aims and Hypotheses

<u>Specific Aim 1</u>: To compare acute exercise responses between the first and last HIIT sessions in a non-ambulatory spinal cord injury population.

Hypothesis 1a: Time to peak heart rate and peak heart rate will significantly change from the first to last session.

Hypothesis 1b: Time to peak cadence, peak cadence, and average cadence will significantly change from first to last session.

Hypothesis 1c: Time to peak power, peak power, and average power will significantly change from first to last session.

Hypothesis 1d: Time to peak RPE and peak RPE will significantly change from first to last session.

Hypothesis 1e: Time to peak feeling and peak feeling will significantly change from first to last session.

Specific Aim 2: To describe acute exercise response within and between sessions in individuals with SCI over duration of upper extremity HIIT program.

Hypothesis 2: Describe average power output and cadence, peak power, cadence, feeling scale, RPE, and heart rate.

Specific Aim 3: To further describe acute exercise response and exercise tolerance in injury subtypes, such as paraplegia, incomplete and complete, and tetraplegia, incomplete and complete.

Hypothesis 3: Describe the relationship between level of injury and power output, cadence, feeling scale, RPE, heart rate, and percentage of time training range in tetraplegia and paraplegia individuals during HIIT.

1.8 Study Significance

Many individuals with SCI often have lower levels of fitness than that of healthy counterparts. Though, one of the greatest challenges for individuals with SCI are maintaining an independent healthy lifestyle, such as the ability to perform activities of daily living (ADLs), and performing regular exercise. Metabolic and cardiovascular disease are commonly seen within this population with an increased mortality rate.[19,20] Exercise is a necessary and healthy method for combatting these risk factors and to improving physical fitness and overall functional capabilities. This study will investigate an effective and practical HIIT upper body exercise program for individuals with spinal cord injury to improve physical fitness and functional capacity. This study aids individuals with often time restrictions and limited to no access to adaptive programs, equipment, and facilities. Understanding the difference in exercise response between individuals with tetraplegia and paraplegia in regards to injury level and type can provide an outline for further research. A positive study outcome could provide groundwork for spinal cord injury exercise guidelines to incorporate HIIT with arm ergometers and/or handcycles.

2.0 Methodology

2.1 Experimental Design

This experiment was a repeated measures study conducted as part of an ongoing study designed to evaluate feasibility and adherence of individuals with SCI to HIIT. The purpose of this research was to determine changes in HIIT fitness ability between individuals with paraplegia and those with tetraplegia.

2.1.1 Dependent Variables

The dependent variables for this experiment included time to peak heart rate, peak power output, peak cadence, peak RPE, and peak feel score; Overall peak values of heart rate, cadence, power output, RPE, and feeling score. Average values throughout work bouts of cadence, power output, RPE and feeling score; number of successful bouts of HIIT, and resting heart rate. All variables are considered a proxy measure to of physiological and perceptual responses to exercise.

2.1.2 Independent Variables

The independent variables for this study included exercise intervention, the individual's level and type of spinal cord injury (tetraplegia or paraplegia), and time.

2.2 Subjects

2.2.1 Subject Recruitment

STUDY1940142 was approved by the Institutional Review Board (IRB) at the University of Pittsburgh. Subject recruitment was performed through Human Engineering Research Laboratories (HERL) in which advertisements were sent by email to previous subjects and to organizations supporting this population. If individuals were interested in participating in the study, they were directed to contact HERL. Researchers pre-screened individuals to ensure that the inclusion and exclusion criteria were met, and obtained a signed medical release from a primary care physician. This ensured that subjects were cleared to engage in maximal exertion testing and vigorous exercise 2-3 times per week on a hand cycle prior to participation.

2.2.2 Subject Consent

On the initial test day, subjects came to UPMC Montefiore Hospital Endocrine and Metabolism Laboratory for informed consent, completion of initial questionnaires, baseline and post-exercise testing. An informed consent document was read, understood, and signed by all subjects. At the time of consent, all subjects' questions about the study were answered. Informed consent was completed prior to beginning testing. Baseline and post testing were performed within the UPMC setting as per requirement of the IRB when working with a clinical population. Training sessions were performed within the subject's home.

2.2.3 Power Analysis

This study's sample size was pre-determined in that the data was collected for another study within HERL. Based on previous studies and recommended guidelines, the sample size was set to 12 for the feasibility and adherence of HIIT training study in SCI population.[9] Eleven subjects were studied within this sub-study. Ten subjects were needed to determine the within subject changes for peak workload based on an alpha = 0.05, power of 0.8, and a paired t-test. To account for a 20% attrition rate, we aimed to recruit 12 subjects for the study. Previous studies showed that ten individuals with spinal cord injuries was a realistic sample size to be achieved.[9,12]

2.2.4 Inclusion Criteria

Inclusion criteria consisted of

- Medical clearance from a physician
- Spinal cord injury must have occurred at least 6 months prior to the start of the study
- Individual must use a manual wheelchair as a primary means of mobility (spending 30 + hours per week)[23]
- Be between the ages of 18 and 65; live within one hour of driving distance from HERL research center
- Be able to transfer independently to and from a wheelchair

- Have adequate strength and upper extremity function to operate a hand cycle or arm ergometer.[27]

2.2.5 Exclusion Criteria

Subjects were excluded on the circumstances that they did not meet the inclusion criteria. Subject were also excluded if they presented with any of the following factors:

- History of fractures or dislocations in the upper extremity from which the participant has not fully recovered,
- Upper limb pain or injury that interferes with the ability to perform aerobic exercise
- No current or recent (last 6 months) participation in a structured fitness program
- Recent hospitalization for any reason (within the past three months)
- Pregnancy
- History of coronary artery disease, coronary bypass surgery or other cardiorespiratory events or conditions
- Likely to experience clinically significant autonomic dysreflexia and/ or orthostatic hypotension in response to performing vigorous exercise.[27]
- Subjects were excluded if any other conditions were deemed a contraindication to participation in arm ergometer exercise stress testing or vigorous exercise by their primary care physician.

2.3 Instrumentation

2.3.1 Garmin Edge 520 Plus

Two standard 17” handcycle wheels were custom laced with a PowerTap power sensing hub (PowerTap, SRAM, LLC, Spearfish, SD). A cadence sensor (Garmin International Inc., Olathe, KS) was mounted to the crank handle of each bike. A speed sensor (Garmin) was mounted to the hub of the power sensor wheels. A heart rate sensor (Garmin), was attached to the subject’s chest via a strap. All these sensors were connected via Bluetooth to a bike computer, Garmin Edge 520 Plus (Garmin Edge 520 Ltd., Schaffhausen, Switzerland), which collected the sensor data during each session. This instrument was utilized to monitor subject’s heart rate and power output by speed and cadence during activity. The sensor observed optimal performance zone of power output, determined by cadence and gear, for subjects to maintain throughout training sessions. Heart rate was not used as a target for HIIT training due to its variance among individuals with SCI but was monitored for collection and analysis.[21] For this reason, power output was the primary parameter for training and was individualized per subject. Power output has been seen to be a valid form of training measurement within individuals with SCI.[1] Garmin sensors provided live feedback of power output, as well as displayed a training range to encourage optimal performance.

2.3.2 Rate of Perceived Exertion Scale

Subject perceived exertion of HIIT training sessions was recorded using the Borg’s rate of perceived exertion (RPE) scale developed by Dr. Gunnar Borg.[2] This scale was used to correlate overall feeling including psychophysical measures. Following each high intensity bout within the training session, subjects were asked to report their overall physical feeling using a visual scale on a score of 6-20.[13] Borg's RPE scale was set in relation to heart rate indicating a score of 6 be translatable to a heart rate of 60 bpm. Borg's RPE has been repeatedly tested for reliability and validity providing a sound basis for recording subject's overall perceived exertion.[2,5,13] RPE has been found to be a valid form of measurement, though not relating to heart rate within this population, of perceived exertion in relation to overall exercise within this population.[9,13]

2.3.3 Feeling Scale

Affective (overall emotional) response to exercise was determined by the Feeling Scale developed by Hardy and Rejeski.[11] This scale measured subjects' valence (pleasure-displeasure) response during activity. The scale was rated on an 11-point system from very good (+5), neutral (0), to very bad (-5). Following each one minute of high intensity training, subjects were asked to report how they felt at that moment in time. Studies have shown this scale to be a valid method to relate exercise and affective response. Researchers have stated it is expected that as intensity increases a more negative affect response develops in activities higher than individual's ventilatory threshold such as within HIIT programs.[11, 17,25] Feeling scale was found to be a valid and reliable measurement for affective response within this population.[8]

2.3.4 Hand Cycle

A hand cycle (Top End 3 Force, Pinellas Park, Florida) was utilized for HIIT training sessions. For the purpose of this study, all sessions were performed on the same hand cycle to maintain consistency and familiarity for subjects. A hand cycle was selected due to capabilities of participants with SCI. This instrument, in conjunction with the Garmin cadence and power sensors, allowed for power output during training to be measured. Resistance on the hand cycle remained the same as subjects progressed to allow for consistent and reliable measurements. Dependent on subject's response to training and ability to perform within the training intensity zone, researchers could increase cadence zone to ensure a near maximal effort throughout training. Power output was progressed during the six weeks for a few subjects. This was either done by increasing the gear (keeping cadence the same) or by increasing the cadence (keeping the gear the same). Subjects were offered assistance to transfer in and out of the hand cycle.

2.4 Testing Procedures

Subjects reported to a UPMC hospital for the initial and final test sessions, where they filled out questionnaires and performed maximal exertion tests. Prior to beginning testing, all subjects were consented as well as obtained a physician's clearance. Subjects then completed health and demographic questionnaires. Upon completion of the health questionnaire, subjects performed a Maximal Oxygen Consumption (VO_2) test followed by a Wingate anaerobic test on the arm ergometer. Testing order was the same for each participant, with the initial and final days used to test maximal aerobic and anaerobic capacities. Considerations for all days of testing and training should be noted: subjects were to refrain from participating in intense exercise 24 hours prior, no large meals at least two hours prior, and use of lavatories prior to testing and training sessions.

Following the initial visit, subjects then coordinated with tester to develop a training schedule to perform HIIT 2-3 times a week at home. Subjects performed 12 HIIT training sessions over the course of 6 weeks. During HIIT training, sessions were monitored by a trainer to ensure that subjects were performing within their optimal power output range, as well as monitoring heart rate, perceived exertion, and overall feeling. Training sessions were separated by at least 48 hours. Upon completion of the HIIT protocol, subjects reported back to UPMC for post testing to repeat the VO_2 max test, Wingate Anaerobic test, and completion of questionnaires within one week of finishing the training intervention.

2.4.1 HIIT Training

Subjects were provided with an introduction to the home HIIT exercise program by two researchers assisting with the HIIT training. Prior to beginning training, subjects informed researchers of the location within their home that was best suited for a handcycle. Subjects were informed at the start of each session of the training protocol, such as any changes in training power output zone, as well as what would occur during the session. Prior to beginning training, subjects were fitted with a Garmin chest strap, which was placed below the nipple line, with the sensors placed in front of the xiphoid process. Researchers verified that the Garmin was properly recording heart rate, and if not, a small amount of water was placed on the sensors and the strap was tightened around the subject. Blood pressure and resting heart rate were measured after being seated for five minutes. Heart rate was continuously record throughout the training session. Subjects were familiarized with all scales (feeling and RPE) prior to beginning each training session

Warm up: Subjects cranked on the handcycle for 2-3 minutes with minimal to no resistance to prepare for exercise. Researchers also used this time to ensure that all equipment was working properly.

HIIT Workout: Following the warm up, subjects were briefed on how the HIIT exercise works. Subjects performed ten 60 second bouts of exercise at 90% maximum power output, followed by 60 seconds of 0-20% maximum power output. Following each high intensity bout, subjects were asked to verbally report their perceived exertion level, and overall feeling score. Subjects stated RPE score based on overall physical exertion including arms, chest, breathing, overall fatigue, to understand how hard they perceive to be working. Researchers informed subjects that feeling score was determined by their overall affective response to the training bout. These values were recorded in the daily training sheet. Subjects were encouraged to perform all ten bouts in order for testing to be considered completed. Verbal encouragement was provided to subjects throughout the sessions. Power and cadence sensors provided live feedback to subjects in regards to power output. This ensured that subjects stayed within the preset training range. Training range was prescribed to be a 10W range, such as 55W-65W.

Cool down: Following the ten exercise bouts, subjects were instructed to crank for 2-3 minutes with no resistance. Researchers provided subjects with water and allowed for their heart rate to return to resting values. Post workout blood pressure and heart rate were taken 5 minutes after the cool-down and recorded.

Subjects completed a minimum of 12 training sessions over the course of six weeks. Two sessions were supervised with a tester present at the subject's home, and a single optional unsupervised session per week. Progression through training program was determined by researchers. Subjects progressed if after three sessions they were able to maintain or extend their current training power output range. Training range was increased by 5- 10 W.

2.5 Data Reduction

2.5.1 Heart Rate

Heart rate measurements were collected using the Garmin chest strap and Garmin Connect computer application. Data was uploaded from the Garmin chest strap via Bluetooth to Garmin Connect to be stored and analyzed. The Garmin Connect, an online health and fitness platform allowed for tracking, analyzing and sharing fitness activities from the Garmin sensors. The heart rate was recorded as beats per minute. Data collection occurred throughout each training session with heart rate measurements occurring once every ten seconds.[14,27] Peak heart rate was determined for each session by the maximum HR (bpm) that was reached during the active bouts of exercise. Time to reach peak value was then determined in correlation to peak HR (bpm).

2.5.2 Power and Cadence

Power and cadence measurements were collected using the Garmin Edge sensors placed on the crank of the hand cycle. Garmin monitor provided visual feedback using a spectrum on screen for subjects to see if they were within their target power output zone.[9] Data collection throughout training was continuous, with monitors placed on two separate portions on the hand cycle. Cadence data was determined to be the rate of cranking known as the number of revolutions per minute (RPM). Power output data was determined to be the subject's ability to perform work, Watts (W). Average power was calculated from the ten, 60 second bouts of exercise at 90% maximum power output for each session. Over the training sessions a continuous increase in power would be indicative of a positive response to the HIIT training program. Training zone was a preset power output range, determined by researchers based on subject's 90% maximum power output during initial testing. Average power and cadence were assessed using all ten active bouts of exercise within each session. Peak power and cadence were determined for each session by the maximum power (W) and cadence (RPM) that were reached during the active bouts of exercise. Time to reach peak value was then determined in correlation to its peak value.

2.5.3 Rate of Perceived Exertion

Rate of perceived exertion measurements were recorded by researchers following each bout of high intensity exercise. Data was inputted into the computer. Training sessions were considered successful if the subject achieved all 10 bouts of HIIT and reached an RPE at or over 17 for the last three bouts of HIIT.[2,5] Researchers followed change in RPE over sessions and over the course of the training program to determine if subjects responded well to the exercise intervention.

2.5.4 Feeling Scale

Overall affective feeling was recorded using the Feeling Scale. Following each bout of high intensity hand cycling, subjects were asked to state their affective feeling on a score of -5 (very bad) to +5 (very good).[11] Data measurements for feeling were recorded by a researcher and later inputted into the computer for analysis. A higher feeling value was indicative of a more positive response to the exercise intervention program.[11,24]

2.6 Statistical Analysis

Descriptive statistics were calculated for all variables (mean, standard deviation, median, interquartile range, or proportions) as appropriate. Sharpo-Wilk test revealed that the data was not normally distributed. A Wilcoxon signed-rank test (exact method) was used to compare all dependent variables (average power, cadence, peak HR, power, cadence, feeling, RPE, and time to peak for each variable) between participants' first training session (baseline) to their final training session. This analysis was repeated after stratification by spinal cord injury level (tetraplegia vs. paraplegia) to assess if changes in response to training were influenced by injury level. Alpha was set *a priori* at 0.05, two sided.

Change in dependent variables over supervised sessions and between spinal cord injury levels was described. Medians plot was used to describe changes throughout the training program. These results were used to answer the research question in specific aim 2. Temporal changes in each variable and time to reach peak were compared between sessions. Exercise (physiological and perceptual) response to HIIT training for both individuals with paraplegia and tetraplegia was described.

3.0 Results

3.1 Demographic Information

A total of eleven subjects volunteered to participate in this study. All subjects met the required inclusion and exclusion criteria in order to participate in the training protocol. Of the eleven subjects, three subjects withdrew due to health reasons unrelated to the study. Power analysis initially showed that a sample size of N = 10 would be needed to complete data collection. The data from the remaining eight subjects were included for the analysis of this paper.

Demographic data are presented in Table 1 for all potential subjects. Table 2 details demographic information subjects included within this analysis. The age range for the sample was 17-58 years old. Two subjects were female; the remaining six subjects were male. Five of the subjects presented with tetraplegia, and the remaining three subjects with paraplegia.

Table 1 Demographic Information of all Participants

	Total (N=11)	**Paraplegia** (N=3)	**Tetraplegia** (N=8)
Age (years)	38.7 ± 13.37	50.20 ± 4.76	27.20 ± 6.98
Height (in)	69.60 ± 3.20	68.80 ± 1.79	70.40 ± 4.28
Weight (lbs.)	171.50 ± 40.69	184.00 ± 36.81	159.00 ± 44.50

Mean and Standard Deviation

Table 2 Demographic Information of Paraticipants who completed the study

	Total (N=8)	**Paraplegia** (N=3)	**Tetraplegia** (N=5)
Age (years)	36.63 ± 14.28	51.5 ± 4.36	33.86 ± 13.12
Height (in)	69.75 ± 3.62	68.75 ± 2.06	69.14 ± 4.45
Weight (lbs.)	163.13 ± 41.57	178.75 ± 40.29	165.00 ± 40.41

Mean and Standard Deviation

3.2 Response to HIIT Program

3.2.1 Changes from First to Last Intervention Session in All Subjects

Change in physiological and perceptual response to exercise was assessed using a pre-post comparison of all variables determined by subjects' first and last session. These variables include peak: power, cadence, HR, RPE, and feeling, time to peak: power, cadence, HR, RPE, and feeling, and average: power and cadence. Change in exercise response from first to last intervention session for all subjects are presented in Table 3. Duration of training program varied among subjects, with some subjects ending after 6 sessions, and others after 15 sessions.

When looking at average (standard deviation) and median, the results of Wilcoxon signed-rank tests revealed statistically significant increase between total first session average power (50.29 ± 36.37, 45.67W) to last session average power (62.19 ± 37.56, 52.43W, p = 0.016). Table 3 shows peak heart rate significantly decreased for all subjects in that first session peak heart rate changed to last session peak heart rate. As seen in Table 3, peak power significantly increased from first session peak power to last session peak power output. Lastly, peak RPE for subjects significantly decreased from pre- to post-HIIT program. No significant changes were observed from pre-to post- values for any other variable.

Table 3 Change in Physiologcial and Perceptual Response following Intervention (N=8)

	First Intervention Session		*Last Intervention Session*		
	Mean ± SD	**Median**	**Mean ± SD**	**Median**	**Wilcoxon (p-value)**
Average Power (W)	50.29 ± 36.37	45.67	62.19 ± 37.56	52.43	0.016*
Average Cadence (RPM)	50.40 ± 19.32	53.24	51.36 ± 12.16	50.39	0.844
Peak Heart Rate (bpm)	125.63 ± 27.69	118.5	120.75 ± 26.69	113.00	0.016*
Time to Peak HR (sec)	777.50 ± 328.45	730.00	866.25 ± 294.85	1010.00	0.563
Peak Power (W)	66.50 ± 23.46	70.50	94.38 ± 34.16	83.00	0.023*
Time to Peak Power (sec)	462.50 ± 393.29	555.00	271.25 ± 292.94	130.00	0.383
Peak Cadence (RPM)	82.75 ± 18.98	83.00	72.25 ± 17.81	70.00	0.461
Time to Peak Cadence (sec)	581.25 ± 209.93	640.00	566.25 ± 348.26	575.00	0.945
Peak RPE	18.50 ± 1.85	19.00	16.50 ± 1.60	16.00	0.031*
Time to Peak RPE (sec)	1020.00 ± 157.12	1080.00	930.00 ± 319.12	1020.00	1.000
Peak Feeling	3.13 ± 1.46	3.50	4.38 ± 0.92	5.00	0.156
Time to Peak Feeling (sec)	90.00 ± 84.85	60.00	90.00 ± 55.55	60.00	1.000

Asterisk (*) denotes significant variables within the table

3.2.2 Changes from First Intervention Session to Last Intervention Session for Subjects with Paraplegia and Tetraplegia

Subjects were classified into two sub-groups based on injury level: tetraplegia and paraplegia. Table 4 and Table 5 detail data that is categorized based on injury level in relation to change in exercise response. No inferential statistics were conducted to determine significant differences in these sub-groups, but trends of data can be described. Within individuals with tetraplegia, there was a positive trend of improvement for average and peak power, peak HR, cadence, RPE, and feeling. Individuals with paraplegia presented with similar results, except for a decreased response in peak cadence. Due to the extremely small sample size of each subgroup, N=

5 and N= 3, respectively, the sub-categories did not allow enough statistical power to draw inferential comparisons.

Table 4 Change in Physiological and Perceptual Response in subjects with tetraplegia (N=5)

	First Intervention Session		*Last Intervention Session*		
	Mean ± SD	**Median**	**Mean ± SD**	**Median**	**Wilcoxon (p-value)**
Average Power (W)	36.34 ± 22.22	30.05	49.69 ± 23.15	44.27	0.063
Average Cadence (RPM)	43.30 ± 17.29	52.65	48.33 ± 7.42	48.67	0.625
Peak Heart Rate (bpm)	115.60 ± 9.45	113.00	110.20 ± 10.26	107.00	0.063
Time to Peak HR (sec)	744.00 ± 287.89	560.00	748.00 ± 321.43	900.00	0.813
Peak Power (W)	65.80 ± 30.38	71.00	84.40 ± 22.94	74.00	0.188
Time to Peak Power (sec)	370.00 ± 327.34	500.00	284.00 ± 319.66	130.00	0.813
Peak Cadence (RPM)	72.60 ± 12.89	71.00	73.60 ± 13.67	73.00	1.000
Time to Peak Cadence (sec)	602.00 ± 102.32	610.00	506.00 ± 283.07	500.00	0.813
Peak RPE	17.60 ± 1.82	18.00	16.00 ± .71	16.00	0.125
Time to Peak RPE (sec)	1020.00 ± 146.97	1020.00	876.00 ± 401.60	1020.00	1.000
Peak Feeling	3.20 ± 1.48	3.00	4.40 ± .89	5.00	0.250
Time to Peak Feeling (sec)	108.00 ± 107.33	60.00	84.00 ± 53.67	60.00	1.000

Table 5 Change in Physiological and Perceptual Response in subjects with paraplegia (N=3)

	First Intervention Session		*Last Intervention Session*		
	Mean ± SD	**Median**	**Mean ± SD**	**Median**	**Wilcoxon (p-value)**
Average Power (W)	73.54 ± 48.42	49.30	83.03 ± 53.14	56.28	0.500
Average Cadence (RPM)	62.24 ± 19.30	66.05	56.43 ± 18.59	52.11	0.250
Peak Heart Rate (bpm)	142.33 ± 42.83	164.00	138.33 ± 39.27	160.00	0.500
Time to Peak HR (sec)	820.00 ± 454.31	1020.00	1063.33 ± 66.58	1030.00	1.000
Peak Power (W)	67.67 ± 8.74	70.00	110.00 ± 48.66	87.00	0.250
Time to Peak Power (sec)	616.67 ± 519.65	860.00	250.00 ± 308.06	130.00	0.500
Peak Cadence (RPM)	99.67 ± 15.54	95.00	70.00 ± 26.91	62.00	0.500
Time to Peak Cadence (sec)	546.67 ± 361.16	740.00	666.67 ± 489.93	780.00	0.750
Peak RPE	20.00 ± 0	20.00	17.33 ± 2.52	17.00	0.500
Time to Peak RPE (sec)	1020.00 ± 207.85	1140.00	1020.00 ± 120.00	1020.00	1.000
Peak Feeling	3.00 ± 1.73	4.00	4.33 ± 1.16	5.00	0.750
Time to Peak Feeling (sec)	60.00 ± 0	60.00	100.00 ± 69.28	60.00	1.000

3.2.3 Changes from First Intervention Session to Session 6 in All Subjects

Subjects were encouraged to perform all twelve sessions, though some did not meet this recommendation. Following session 6, 2 subjects withdrew from the study. Analysis was performed to understand subject's state half way through the intervention, as well as when all subjects were present. Change in exercise response for all subjects, through the sixth session of the HIIT program are presented in Table 6. The table displays average, standard deviation, and median for all subjects for session 1 and session 6. Average power and peak power significantly increased from session 1 to session 6. No other variables were found to be statistically significant when using the Wilcoxon signed-ranks test.

Table 6 Change in Phyisological and Perceptual Response to HIIT Training from Session 1 to Session 6 (N=8)

	Session 1		*Session 6*		*P-Value*
	Mean ± SD	**Median**	**Mean ± SD**	**Median**	
Average Power (W)	50.29 ± 36.37	45.67	62.70 ± 33.88	54.79	0.008*
Average Cadence (RPM)	50.4 ± 19.32	53.24	55.16 ± 10.02	56.64	0.641
Peak Heart Rate (bpm)	125.63 ± 27.69	118.5	121.88 ± 27.38	114.50	0.117
Time to Peak HR (sec)	772.5 ± 328.45	730.00	851.25 ± 395.24	1005.00	0.688
Peak Power (W)	66.5 ± 23.46	70.50	91.75 ± 36.84	78.00	0.023*
Time to Peak Power (sec)	462.5 ± 393.29	555.00	430.00 ± 340.50	500.00	0.945
Peak Cadence (RPM)	82.75 ± 18.98	83.00	68.63 ± 15.80	66.50	0.148
Time to Peak Cadence (sec)	581.25 ± 209.93	640.00	626.25 ± 289.48	735.00	0.688
Peak RPE	18.5 ± 1.85	19.00	17.0 ± 1.83	18.00	0.063
Time to Peak RPE (sec)	1020.00 ± 157.12	1080.00	951.43 ± 167.67	900.00	0.406
Peak Feeling	3.13 ± 1.46	3.50	4.13 ± 1.13	4.50	0.250
Time to Peak Feeling (sec)	90.00 ± 84.85	60.00	105.00 ± 62.11	60.00	1.000

Asterisk (*) denotes significant variables within the table

3.3 Between-Session Variation

Between-session variation for each variable was measured using median values to establish a general understanding of changes throughout the training program for all subjects, individuals with tetraplegia, and with paraplegia. Mean, standard deviation, and interquartile 1 and 3 were calculated for analysis as well. Sessions 13, 14 and 15 were removed from analysis due to further reduced sample size and no comparison was capable (session 13 (N=2), sessions 14 and 15 (N=1)). Peak HR for all subjects and subgroups, did not change significantly from session to session, but a 10.6% decrease was detected. It was observed, that individuals with paraplegia had significantly higher peak HR than individuals with tetraplegia, and all subjects combined, throughout the entire duration of the intervention. Figure 1 displays change in median peak heart rate and median time to peak heart rate across all twelve training sessions.

Over the course of twelve sessions, a positive trend presented for average power for all subjects of 14.8%. A greater response was seen within the tetraplegia subgroup, 34.0%, than the paraplegia subgroup, 14.2%, though almost all sessions saw some improvement. All subjects and paraplegia subgroup saw a positive response in peak power output throughout the training program 17.7%, and 24.3%, respectively. A decreased response in peak power was observed within individuals with tetraplegia. Figure 2 presents median average power, peak power and time to peak power across all twelve training sessions.

All subjects and both subgroups observed a decrease in time to peak power, cadence, and RPE. Average cadence for all subjects, and subjects with tetraplegia, remained approximately within 1 RPM from the initial session. Subjects with paraplegia observed 21.1% decrease in average cadence throughout the training program; whereas a positive trend for peak cadence was only observed for individuals with tetraplegia (16.9%). Figure 3 presents median average cadence, peak cadence, and time to peak cadence for all subjects and subgroups throughout the training program.

A small decrease was noted in all subjects and subgroups for median peak RPE. Total median RPE decrease 15.8%, tetraplegia median 13.9%, and paraplegia median 15.0%. As with a decrease in peak RPE, it was also noted a decrease in time to peak RPE for all subjects and subgroups. Median peak feeling, affective response, was seen to increase for all throughout of the duration of the training program. Figure 4 displays median peak RPE, time to peak RPE, median peak feeling, and time to peak feeling for all subjects and subgroup across all training sessions. Table 7 details all variable for all subjects' changes throughout the course of the intervention program, and subject sample size.

Table 7 Change in Variables (Median) throughout HIIT

	Median Value												
Session	**N**	**Average Power (W)**	**Average Cadence (rpm)**	**Peak Heart Rate (bpm)**	**Time to Peak HR (sec)**	**Peak Power (W)**	**Time to Peak Power (sec)**	**Peak Cadence (rpm)**	**Time to Peak Cadence (sec)**	**Peak RPE**	**Time to Peak RPE (sec)**	**Peak Feeling**	**Time to Peak Feeling (sec)**
1	8	45.67	53.24	118.50	730.00	70.50	555.00	83.00	640.00	19.00	1080.00	3.50	60.00
2	8	49.28	53.1	114.50	1110.00	74.50	940.00	76.00	530.00	16.00	1140.00	3.50	60.00
3	8	52.73	60.97	114.00	1080.00	76.50	1045.00	75.00	1090.00	17.50	1140.00	4.50	60.00
4	8	53.32	57.96	114.50	865.00	78.50	430.00	66.50	745.00	17.50	1080.00	4.50	60.00
5	8	52.61	57.23	109.00	1020.00	73.50	870.00	70.00	580.00	18.00	1020.00	5.00	60.00
6	8	54.79	56.63	114.50	1005.00	78.00	500.00	66.50	735.00	18.00	900.00	4.50	60.00
7	6	50.78	61.56	111.50	1145.00	78.50	790.00	76.50	1055.00	17.50	1140.00	4.50	60.00
8	6	54.36	61.58	106.50	1075.00	79.50	190.00	73.00	870.00	16.00	1020.00	3.00	60.00
9	6	52.70	61.95	112.50	925.00	82.00	730.00	72.00	970.00	17.00	1080.00	4.00	60.00
10	6	56.77	62.18	112.50	945.00	86.50	140.00	73.00	575.00	15.50	1020.00	5.00	60.00
11	6	51.74	55.53	108.00	960.00	77.50	495.00	64.50	395.00	16.00	1020.00	4.00	60.00
12	6	52.43	52.77	106.00	960.00	83.00	555.00	74.50	390.00	16.00	960.00	5.00	60.00

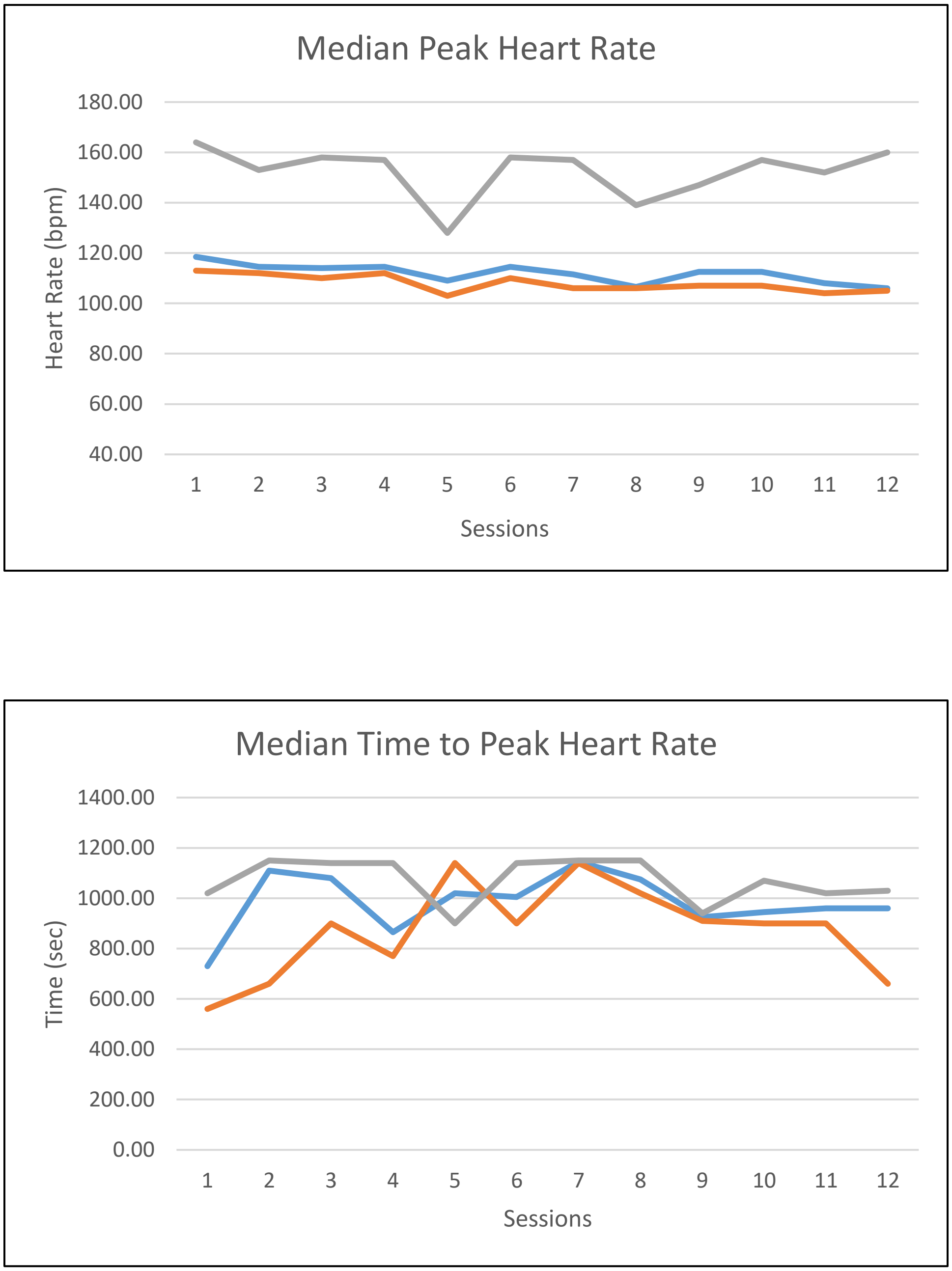

Figure 1 Median Peak Heart Rate, and Time to Peak Heart Rate for all subjects and sub-groups

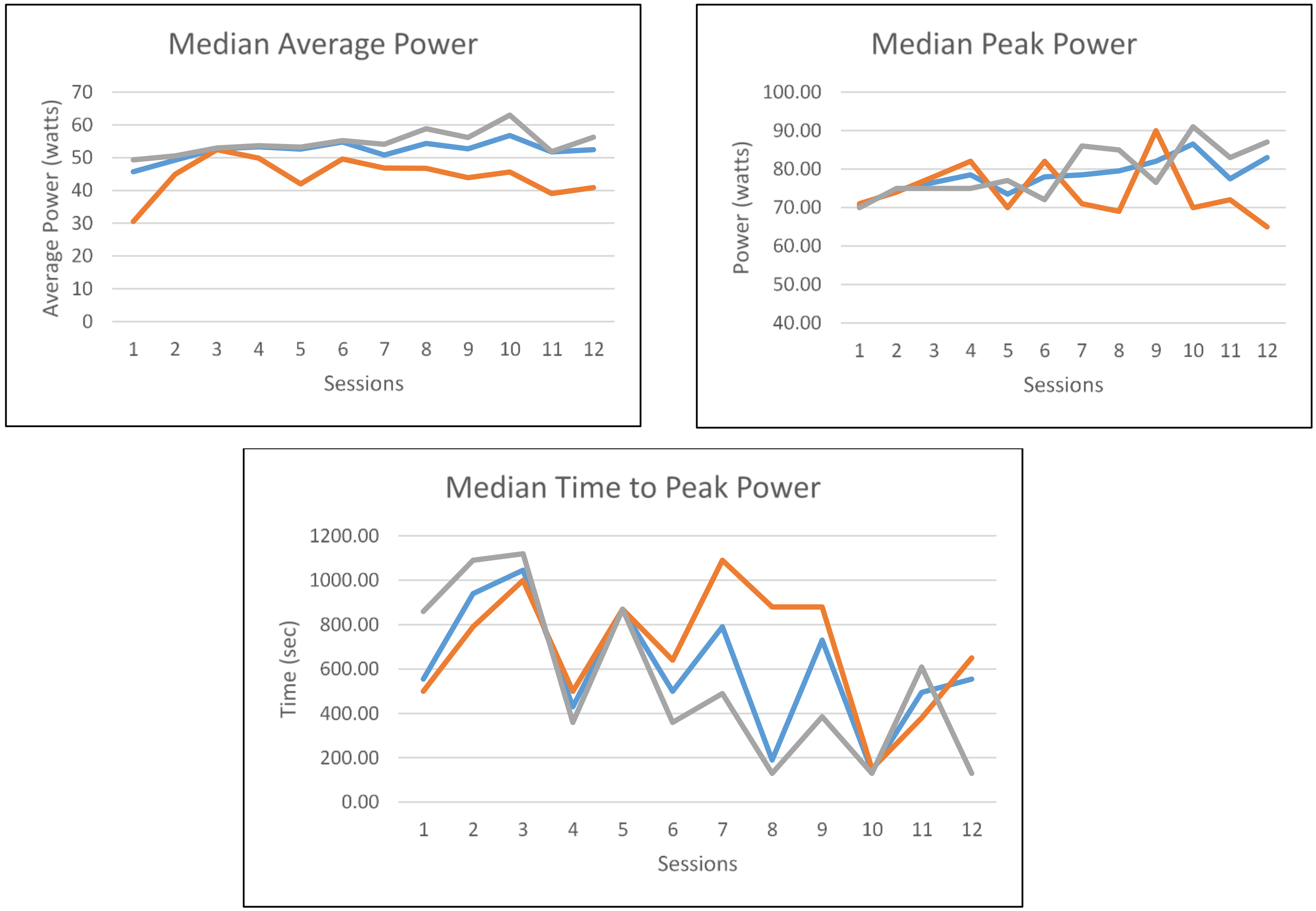

Figure 2 Median Average Power, Peak Power, and Time to Peak Power for all subjects and sub-groups

Figure 3 Median Average Cadence, Peak Cadence, and Time to Peak Cadence for all subjects and sub-groups

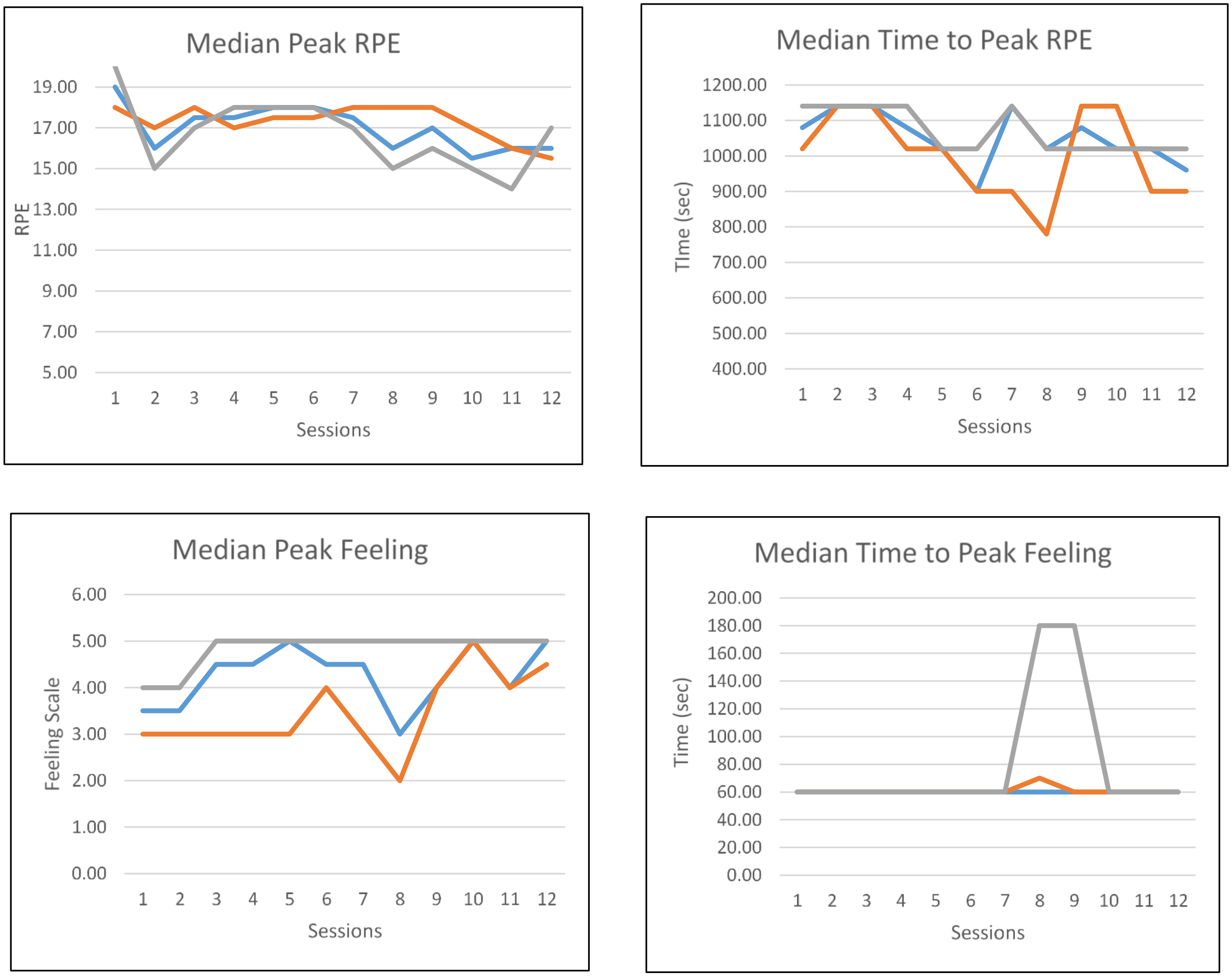

Figure 4 Median Peak RPE, Time to Peak RPE, Peak Feeling, and Time to Peak Feeling for all subjects and sub-groups

4.0 Discussion

The purpose of this study was to determine the physiological and perceptual responses during HIIT within individuals with SCI. Performances on a hand cycle during HIIT training were measured and utilized to determine if physiological and perception exercise variables changed from the beginning to the end of the training program.

It was hypothesized that there would be a significant change in physiological and perceptual response from subjects' first to last session. These hypotheses were supported by the results of this study in that a significant change in average power, peak power, HR, and RPE was present from the first to last session. Additionally, the study aimed to describe exercise response between sessions in individuals with SCI over the duration of upper extremity HIIT training. Both focuses of this study were further analyzed based on injury level of each subject. However, the small size of sub-groups did not allow enough statistical power to draw inferential comparisons.

4.1 Physiological and Perceptual Response to HIIT

4.1.1 Change in Physiological Response

Physiological response was measured with the following variables: average power and cadence; peak power, cadence, and heart rate; time to peak power, cadence, and heart rate. The training range (target power output) was modified in accordance to each subject's power output reported during their initial testing. Change in average power output significantly increased by a mean of 12.00 W, indicating that subjects favorably adapted to the HIIT training and saw fitness improvements from the program. This improvement shows that subjects were able to continuously produce a higher amount of work during the intervals of HIIT throughout the course of the intervention. Change in peak power significantly increased from the first session (peak power: 66.50 ± 23.46, 70.50 W) to last session (peak power: 94.38 ± 34.16, 83.00 W, $p = 0.023$). This indicates that subjects were able to produce higher maximum power output during their last session, showing a positive response to exercise. These two variables, average power and peak power output, together show that not only were subjects able to maintain a higher power output but increase their maximum power output when comparing first session and last session data.

It was hypothesized that the variables (average and peak power output) of this study would significantly change when comparing subjects' first and last session of HIIT. Peak power is a commonly used parameter for exercise programming and response measurements for individuals with spinal cord injuries, as utilized by Harnish et al. and Van der Scheer et al.[17] Within this study, researchers looked to evaluate the efficacy of HIIT in an individual with SCI. Following the first two weeks, they observed that power output continuously increased throughout the study, demonstrating the ability of the individual with SCI to progress in workload over the course of 12 weeks.[17] The results of our study were similar to those reported by Harnish et al., strengthening our findings. Time to peak power was observed to take approximately half the amount of time through the HIIT interval bouts when comparing first to last session, although no significant changes were noted for time to peak power output. This may due to subjects becoming more familiar with the protocol and aware of their capabilities, thus, allowing them to reach their peak power output quicker, while maintaining the output within the training range for the duration of the session.

Previous research has shown that HIIT induces various physiological adaptations, improving overall health and physical fitness.[12,17] HIIT is characterized by high intensity, short duration, repeated bouts of anaerobic exercise. Participants may have significantly improved power output from the first session to last session in the training intervention because of the physiological adaptations to repeated bouts of anaerobic exercise, including increased muscular endurance, change in neuromuscular inhibition, pH buffering capability, lactate clearance, and change in glycolic processes.[12,17] Over 6-weeks, muscular endurance may have improved, allowing for an increase in force production throughout the training sessions. Future research could examine cross-sectional areas of upper extremity muscles to understand the contraction properties in order to determine if muscular endurance improvements did occur.[17] Power output improvements following HIIT could further be related to an increase in activity of anaerobic capacity enzymes further regulating non-oxidative energy metabolic processes (increased glycolic processes), increased muscle pH buffering capacity, and lactate clearance capabilities. Though these physiological processes were not studied within this experiment, but should be investigated in future research within this population.

For individuals with low levels of fitness, neuromuscular inhibition may affect their ability to produce power. Thus, following the program and with repetition (performing the same exercise 2x/week for 6 weeks) may have allowed for familiarization as well as a reduction in neural inhibition. With a decrease in neuromuscular inhibition improvement in power output may be seen due to increase in firing rate and motor neuron recruitment.[16] It is important to note that this specific population already presents with neuromuscular disconnect and is be injury-level dependent. Because of this, change in neuromuscular inhibition may only have caused a small effect on first session- to last session- power output change.

A continuous increase in median average and peak power was observed over the course of the twelve sessions for all subjects. Figure 2 presents changes for all subjects, and sub-groups over the course of the study, detailing a gradual improvement for median average and peak power, while a more variable response in median time to peak power.

Unlike healthy individuals, heart rate within SCI population is understood to be extremely variable. Following an injury, the loss of supraspinal control of the autonomic nervous system causes a decrease in sympathetic pathways that are responsible for heart rate regulation. Due to this autonomic dysfunction, HR in individuals with SCI is observed to be lower and irregular in comparison to healthy individuals.[38] Heart rate was deemed to be an unreliable physiological measurement in order to determine the success of a training session due to its vast irregularity within the population, thus power output and RPE were utilized. Though it is important to note subjects' heart rate response to the training protocol.

The results of this study did align with the current literature, in that normally one would see maximum HR remain the same or slightly decrease over the course an exercise program indicating a physiological improvement from exercise.[9] Our data showed that peak heart rate was significantly decreased by 5 bpm from subjects' first to last session. First session peak heart rate for all subjects (125.63 ± 27.69, 118.50) was higher than last session peak heart rate (120.75 ± 26.69, 113.00, $p = 0.016$). A potential reason for these findings of this study could align with the time to peak heart rate response. Time to peak heart rate was reported to be nonsignificant. Though, it is important to note that there was an increase in time to peak heart rate. Potentially, the subject may have increased their aerobic threshold, as well as adapted to the training protocol. When noting the two variables, time to peak HR and peak HR, together one sees a positive response to exercise. Possibly, a decrease in peak HR with an increase in time to peak may indicate that the subjects true peak HR was not reached during the 20 minutes of HIIT. A potential reason for this may be due to training duration of 20 minutes total, was no longer being a sufficient timeframe for individuals to reach their true peak. Another potential reason for a decrease in peak HR could be an improvement in recovery during rest periods of the protocol. Becoming more aerobically fit may have allowed subjects to achieve a lower heart rate during rest periods, thus once again leading to more time needed to reach peak.[9, 35]

Table 7, along with Figure 1, detail change in median peak HR and time to peak HR over the course of this study. When looking from session to session, a gradual decrease in peak HR is observed for all subjects, and a moderate increase in time to peak HR. This aligns with the pre-to post- changes in peak HR and time to peak heart rate in that as training progresses subjects may be becoming more aerobically efficient. When comparing sub-groups, individuals with paraplegia presented with higher peak HR than all subjects and tetraplegia sub-group throughout the study, relating more closely to the HR response of a healthy population. Dependent on the location of injury, autonomic impairment may be observed in heart rate in individuals with SCI, indicating that individual HR response is injury-dependent. Current research shows that if individuals present with high-cord lesions (C1-T6), there is a ceiling effect in which HR cannot continue to increase.[38] Within this study, subject HIIT-06 (injury T10-T12) presented with an average HR of 155 bpm, whereas subject HIIT-10 (injury C5-C6) presented with 109 bpm. The current study is further supported by the current literature, in that HR response is injury-dependent.

Pre-to post- changes for average cadence, peak cadence, and time to peak cadence were all found to be nonsignificant. Average cadence and time to peak cadence presented with minimal changes 53.24 RPM to 52.77 RPM, and 640.00 sec. to 390.00 sec, respectively, whereas peak cadence was noted to decrease by 10.00 RPM when comparing first to last session. As stated in the methods, subjects were instructed to stay within a set power output range, but there was no set parameter for cadence. A potential reason for a decrease in peak cadence may be due to the increased production of power. This could have allowed for subjects to crank at higher power while at a lower speed.[34] Another potential reason may be that while resistance on the handcycle increased throughout the training program, subjects were unable to crank at speeds previously recorded, but produce higher power. It was hypothesized that average cadence, peak cadence, and time to peak cadence would significantly change.

Over the duration of this study, the group median of individual average session cadence remained relatively constant for all subjects and sub-groups, whereas peak cadence was noticeably higher for both sub-groups, tetraplegia and paraplegia, than all subjects but remained fairly constant as well (Figure 3), showing that despite power output being the training range parameter, subjects remained consistent in cadence production. Minimal changes in group median of individual average and peak cadence were observed throughout the twelve sessions for subjects were able to perform at higher power output while maintaining speed. Between-session variation for median time to peak cadence was highly variable across all subjects and sub-groups. A potential reason for this may be dependent on how the subject was feeling that session, and how quickly one could get into the training mentality.

When looking at sub-categories of spinal cord injuries, tetraplegia and paraplegia, several interesting trends were observed. Five subjects with tetraplegia presented with improvements in average power (36.34 ± 22.22 to 49.69 ± 23.15), cadence (43.30 ± 17.29 to 48.33 ± 7.42), and peak power (65.80 ± 30.38 to 84.40 ± 22.94). Individuals with paraplegia experienced an increase in average power (73.54 ± 48.42 to 83.03 ± 53.14), time to peak heart rate (820.00 ± 454.31 to 1063.33 ± 66.58), and peak power (67.67 ± 8.74 to 110.00 ± 48.66). It should be noted that peak power for individuals with paraplegia almost doubled in comparison to the tetraplegia sub-group. A potential reason for this may be due to the fact that individuals with paraplegia present with similar upper body functioning and capabilities to that of able-bodied individuals, thus allowing for power output to increase to a greater extent than individuals with tetraplegia, due to possible functional inhibition of the upper extremity based on the location of injury.[22,28,29] Though inferential statistics were unable to be calculated for the injury sub-groups, positive responses were still observed, potentially correlating HIIT training to health improvements for both sub-groups. Future research has the capability to expand on this aspect.

4.1.2 Change in Perceptual Responses

Perceptual response was determined to be subjects' affective response to exercise. Peak RPE was found to be significantly lower during the last intervention session compared to the first intervention session. Change in peak RPE significantly decreased when comparing subjects' first and last session as seen in Table 3. Previous research has stated that a decrease in RPE is indicative of a positive response to an exercise program. It is seen that exercising at or above the prescribed training range with less perceived effort is a sign of a positive affective response because subjects can work at greater intensity while maintaining better aerobic efficiency.[2,5,8] The results found in this study match that of the current literature, supporting the importance of our findings. Time to peak RPE was not found to be statistically significant, nor was a large change present (Table 3). A potential reason for this may be from the rest periods that allowed subjects to recover before each work phase thus increasing the time to maximum perceived exertion.

A downward trend in peak RPE can be seen throughout the duration of the study (Table 7). Between session change shows that as subjects progressed through training, there was a decreased in perceived exertion while performance improved. This reinforces the results found for first to last session peak RPE change. Median time to peak RPE remained relatively constant throughout the course of this study.

Peak feeling though statistically significant was found to have increased (3.13 ± 1.46 to 4.38 ± 0.92). It is important to note that improvements in peak feeling may be associated with improved affective and perceptual response to HIIT. Following with current literature, a possible reason for improvement may be as subjects became more trained, they understood the benefits of the exercise program thus an increase in feeling. By having a positive perceptual response to the training program, an increase subject's likelihood to continue exercise following the intervention may be seen because of the reported enjoyment. Pervious research has shown that a positive response in feeling, can lead to increased adherence to an exercise program.[13,25] Time to peak to feeling remained exactly the same (90.00 ± 84.85 to 90.00 ± 55.55), and no significance was observed. A possible reasoning for this may be because subjects understood the benefits of the exercise program and were excited and hopeful to participate. It is important to note that feeling scale ranges from negative to positive values thus when only looking at the peak value, it does not provide a full understanding of subject's perceived response to the entire HIIT program. Peak value was observed with the first two HIIT bouts of exercise for each session, thus this does not provide a good representation of how subjects may have felt as they progress and became more fatigued.

Referencing Table 7, a positive trend in peak feeling can be observed throughout the duration of the study. Figure 4 details change in median peak feeling for all subjects, individuals with tetraplegia, and paraplegia over the course of this study. Between session change aligns the improvements seen for all domains of pre-to post change in peak feeling; further signifying the overall positive response to the exercise program. Median time to peak feeling remained exactly the same for each session (60.00sec), for all subjects, and varied slightly for subgroups. Showing that from the first session subjects felt a positive affective response, and quickly towards to the exercise program.

When assessing perceptual variables among injury sub-groups, several interesting trends were observed. Both sub-groups reported a decreased in peak RPE (17.60 ± 1.82 to 16.00 ± .71) and (20.00 ± 0 to 17.33 ± 2.52), tetraplegia and paraplegia, respectively. Similarly, both tetraplegia and paraplegia subjects saw improvements in their peak feeling scores (3.20 ± 1.48 to 4.40 ± .89) and (3.00 ± 1.73 to 4.33 ± 1.16), respectively. Again, though inferential statistics were not calculated for these variables among injury sub-groups, there were positive response seen from the HIIT program. Comparable to all subject results, both sub-categories were able to identify and understand the purpose of this study, and enjoyed the program. Further research can be done in the area to further support this claim.

4.2 Limitations

This study has several limitations. Human and technological error can be reduced, but will always present a challenge. Some data was lost for one participate during one training session, resulting in incomplete data set for their twelve supervised HIIT training sessions. This was a result of equipment and technology error. Also, not all subjects completed the minimum 12 sessions, causing a varying amount of data per subject. Two subjects withdrew after six sessions, while one subject completed 15 sessions. This wide range in training duration may have affected the results. All twelve sessions were expected to take place over the course of six weeks (two sessions per week), may be a potential reason for why limited improvements were observed. Extending the study to twelve weeks, two-three sessions per week, could potentially elicit better results. Studies have shown that, improvements in aerobic capacity can take about eight to twelve weeks.[1] Having subjects reach and train at their true aerobic capabilities will allow for a better representation of their physiological and perceptual responses.

Level of physical activity (PA) prior to the start of the study may have affected subject's response to the exercise program. All subjects completed an exercise participation evaluation during initial testing. Of the eight subjects, six reported to have been active several times per week prior to the start of training. This study's purpose was to implement HIIT training for individuals with SCI with low fitness levels. This subject population may not have been representative of the purpose of this study due to pervious levels of PA.

Despite recruiting efforts, this study had an extremely small sample size. A total of eight subjects were included in the analysis of this study, whereas the initial power analysis deemed ten subjects would allow for adequate analysis with alpha set to 0.05. With a limited sample size, a reduction in the power of the study and an increase in type II error may have occurred.

Furthermore, some subjects reported feeling muscular fatigue prior to reaching aerobic fatigue, which is the primary goal when performing HIIT. Though there was no true measurement to this, several subjects stated that their arms become tired prior to feeling out of breath. Thus, being limited by upper extremity strength and endurance may have inhibited subjects from performing high aerobic workload activity. Incorporating an upper extremity strengthening and stretching program along with the HIIT intervention could potentially reduce any limitation that may have resulted from muscular strength as opposed to aerobic conditioning.[22]

4.3 Study Significance

This study is one of few existing investigations of individuals with tetraplegia during an exercise intervention. Pervious research has excluded individuals with tetraplegia due to various reasons such as poor to limited upper extremity function and grip strength. This study was unique in that it allowed for subjects with "enough" grip strength to participate, as well as allowed for wrist and hand straps to assist with training. Furthermore, subjects were allowed to use either a handcycle or an add-on hand crank attached to their wheelchair. The add-on hand crank allowed for the inclusion of subjects who did not have the functional capability to transfer from a wheelchair to a lower surface. The results from this study indicate that high intensity interval training is safe, effective, and promotes health benefits for individuals with spinal cord injuries. Research has shown that individuals with SCI, are more prone to developing secondary health problems due to physical inactivity.[1,7,12] This study has shown that individuals with SCI, regardless of injury level, can participate in higher level training as long as it is modified to the capabilities of the individual. HIIT utilizes a decrease in frequency and duration, and an increase in intensity of exercise to elicit aerobic health benefits, which can be observed to cause improvements and overcome several pervious perceived barriers within this population.

4.4 Future Directions

This study provides more insight into the capabilities of, and the need for exercise programs, for individuals with SCI. This study used multiple physiological and perceptual variables to establish a better understanding of individuals with SCI response to HIIT exercise. Researchers found that when classifying subjects broadly, i.e. having as spinal cord injury, there was a positive response to exercise training. However, when looking further into spinal cord injury type, there were different trends among injury sub-groups and further research is needed in this area. Based on the limited data, there does appear to be a relationship between SCI type and exercise response, in that exercise response is different depending on injury. Potentially examining these variables within a larger sample could show a significant relationship between exercise response and injury type. Furthermore, this could be replicated across multiple sites to allow for greater recruitment, as well as more personnel and equipment to train subjects.

Future research has the ability to move forward in many directions. One instance could be the addition of a strength training program to the HIIT protocol. As stated previously, several subjects reported muscular fatigue prior to aerobic fatigue during the invention. Previous studies have shown that strength and circuit training can effectively increase muscular strength, aerobic capacity, and decrease anaerobic fatigue and risk of overuse injuries.[18] Developing a resistance training program for subjects, either prior to or during the HIIT intervention, could reduce confounding factors such as muscular fatigue. This would allow researchers to ensure that the response to the HIIT protocol is from an aerobic capacity standpoint.

Furthermore, lengthening the duration of study may be another opportunity to further understand the physiological and perceptual responses to HIIT. Having increased the length of the study may allow for subjects to become more familiar with the protocol, thus limiting some potential risk for familiarization period being a large portion of the intervention timeframe. Pervious literature by Harnish et al. has shown that a twelve-week HIIT intervention protocol on a 42-year old man with SCI elicited a large increase in peak aerobic power. Though this study was of just one subject and may be a unique case, it may be beneficial to develop a study that is of the same timeframe, but involves a larger sample in order to understand proper HIIT duration for individuals with SCI.

4.5 Conclusion

This study found that over the course of a six-week HIIT exercise intervention, physiological and perceptual changes occurred within individuals with spinal cord injuries. Furthermore, significant improvements were seen when comparing subjects' first and last session. While the differences between sub-groups based on injury level during HIIT remains unclear, the results do provide insight into the importance of including individuals with spinal cord injuries of various types and severity. The outcomes of this study help guide future research by supporting the claim that HIIT training is safe, beneficial, and practical for individuals with SCI. HIIT training was seen to provoke positive improvements within subjects' physiological and perceptual responses. Clinicians and practitioners should promote HIIT training for individuals with spinal cord injuries due to its similarity in benefits to moderate intensity aerobic exercise, and reduction in requirement duration. Researchers should continue to investigate HIIT intervention durations, to determine what time period (weeks), frequency (days per week), and ratio (work: rest) would best serve this population.

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