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Telehealth High-Intensity Interval Exercise and Cardiometabolic Health in Spinal Cord Injury

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TELEHEALTH HIGH-INTENSITY INTERVAL EXERCISE AND CARDIOMETABOLIC HEALTH IN SPINAL CORD INJURY

by

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A THESIS

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2022

TELEHEALTH HIGH-INTENSITY INTERVAL EXERCISE AND CARDIOMETABOLIC HEALTH IN SPINAL CORD INJURY

JACOB ADAMS

KINESIOLOGY WITH A CONCENTRATION IN EXERCISE PHYSIOLOGY

ABSTRACT

BACKGROUND: Recent studies have shown that high intensity interval training (HIIT) can improve cardiometabolic health in individuals with spinal cord injury (SCI). Individuals with SCI experience a wide array of barriers to participate in exercise such as lack of time, accessible equipment, and transportation. It is imperative to identify modes of exercise that provide effective health benefits and are accessible while requiring low time commitment. Studies have demonstrated that HIIT has similar positive improvements in cardiometabolic health with 20% of total time commitment compared to moderate intensity exercise (MIT) in short term studies.

OBJECTIVES: The purpose of this study is to assess changes in cardiometabolic health following 16-weeks of a home-based telehealth HIIT arm crank exercise program in individuals with long standing SCI.

METHODS: Participants were randomly assigned to 16 weeks of HIIT arm crank exercise training or a no-exercise control group. Body composition via DXA, resting energy expenditure (REE), blood lipids, fasting insulin sensitivity, blood pressure, aerobic capacity, and muscular strength and endurance were assessed at baseline and at 16 weeks post intervention. Qualitative interviews were conducted for the HIIT group upon completion of intervention.

RESULTS: Five participants (3 male, 2 female; n=3 in control, n=2 in HIIT exercise; mean age 53.5 ± 8.5) with longstanding SCI completed the exercise study. The preliminary data of this study shows significant group by time effects for gynoid % fat ($p=0.015$) and REE ($p=0.006$) showing improvement for body composition and REE in the HIIT group relative to control. Although not statistically significant, there were mean improvements in aerobic capacity and muscular endurance in HIIT group compared to control.

CONCLUSION: These preliminary data demonstrate that 16 weeks of telehealth HIIT may improve body composition and REE in individuals with SCI. The qualitative results demonstrate that the participants reported enjoying the remote aspect, increases in energy levels, and increases daily quality of life. These preliminary results suggest that a long-term telehealth HIIT program to individuals with SCI and may show improvements in overall health; however, a larger sample size is needed in order to confirm these observations. We hope to demonstrate that home-based telehealth HIIT program will improve cardiometabolic health, can yield high adherence, and be an enjoyable form of exercise for individuals with SCI.

Keywords: exercise, spinal cord injury, high-intensity interval training, cardiometabolic health, telehealth, remote training

DEDICATION

This thesis is dedicated to the people that have supported me throughout my education journey.
This is dedicated as a stepping stone of progress to better quality of life to all individuals with spinal cord injuries.

ACKNOWLEDGMENTS

This is a thank you for all the prayers and specifically to those listed below:

For my wife who has always pushed me every step of the way to never give up and always perform to the best of my abilities.
For my parents who raised me to not only to be patient and loving but also to strive for success and push through when times get tough.
To my family who were always there for me no matter the time or situation.
To my mentor, Gordon Fisher, who gave me this opportunity and has helped me every step of the way become a better student, a better researcher and a better person.
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To my committee for helping shape me into a better researcher and helping see things in a new perspective.
To Eric Plaisance who encouraged me to take steps even when the path is unclear.
To all my friends who helped me handle the stress of life.

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LIST OF ABBREVIATIONS

DXA	Dual-energy X-ray Absorptiometry
HIIT	High intensity interval training
VO_{2max}	Maximum aerobic capacity
MIT	Moderate intensity interval training
OGTT	Oral glucose tolerance test
REE	Resting energy expenditure
RMR	Resting metabolic rate
SCI	Spinal cord injury
UAB	University of Alabama at Birmingham

Introduction

Spinal cord injury (SCI) is damage to the bundle of nerves that transmit signal from the brain to the rest of the body.[1,2] The severity of a SCI varies based on the location of the injury and the intensity of nerve damage.[1] The American Spinal Injury Association (ASIA) created the ASIA Impairment Scale (AIS) to standardize documentation for SCI and categorize injuries.[3] The scale is separated into complete (A), sensory incomplete (B), motor incomplete with major loss of motor function (C), motor incomplete with limited loss of motor function (D), and normal (E).[3] Following the AIS, SCI injuries are separated into two categories: complete and incomplete.[1] A person with an incomplete injury will often still have nerve impulses past the injury location and will often have some sort of feeling or sensations past the injury; a person with a complete injury will have no nerve transmission beyond the location of the injury, resulting in no feeling or function past the injury.[1] Spinal cord injuries are often accompanied by numbness, tingling, loss of feeling, loss of motor function, difficulty breathing, pain in the head, neck and back, along with many others.[1]

The National Spinal Cord Injury Statistical Center estimated that as of 2021 there are 300,000 people living in the United States with a spinal cord injury, and that number increases by 18,000 each year.[4] The World Health Organization (WHO) estimates that as many as 500,000 people in the world are effected by a spinal cord injury each year.[2] The current leading cause of SCI is traumatic events, such as car crashes, followed by falls with 3 out of 4 reported instances occurring to males.[4]

Those living with SCI often face greater risks of developing chronic diseases compared to able-bodied individuals, and they often experience a lower life expectancy.[5] People with SCI have reduced mobility, which leads to a downward trend in metabolic health factors.[6] These trends often lead to secondary cardiometabolic health conditions, such as type-2 diabetes, obesity, insulin resistance, muscle atrophy, pain and lower aerobic fitness capacities.[7-12] WHO also reports that those living with chronic SCI face higher risks of developing deep vein thrombosis, pressure ulcers, cardiorespiratory issues and many more adverse health conditions.[2] In order to prevent these risks from developing or worsening, the WHO recommends that individuals with SCI adopt a health maintenance life style, incorporating increases in exercise and physical activity.[2]

One major factor leading to these chronic diseases is a sedentary lifestyle created by the injury.[8,13] Due to the nature of the injury, those living with SCI exhibit up to a 27% lower basal metabolic rate and expend significantly less energy compared to age-matched able bodied individuals.[14] This reduced caloric expenditure coupled with lower metabolic rates places this population at higher risk of developing health conditions associated with sedentary behavior and obesity. The Centers for Disease Control and Prevention (CDC) has reported that less than 25% of the population in the US achieves the recommended levels of physical activity.[15,16] In individuals with SCI, this percentage drops down to 15%.[4] According to the US Bureau of Transportation Statistics, it can take up to four times longer for a person with SCI to enter and exit a vehicle compared to an able bodied individual.[17] This extended time commitment is often a large constraint to being able to travel for exercise. These factors compound and lead to low exercise participation and heighten the risk of cardiometabolic diseases seen in this population.

Physical inactivity has been shown to be the fourth leading cause of death worldwide.[16] Blair et al. reported that physical activity leads to reduced risks for heart disease, diabetes, and even some cancers.[18] Many surveys have reported lack of time as a primary barrier that prevents the adult population from engaging in physical activity.[19,20] Current American College of Sport Medicine (ACSM) guidelines suggest that all healthy adults should participate in aerobic activity for 30 minutes for five days a week or vigorous intensity activity for 20 minutes for 3 days a week.[21] These recommendations have been shown to lead to positive health outcomes and reduce the risk of developing cardiometabolic diseases.[19,21] Exercise training has been clinically shown to reduce or prevent, and in many cases, reverse health conditions that are associated with cardiometabolic health and diseases.[22,23]

Individuals with SCI often face low energy availability which leads to low bone mineral density, low desire to exercise, and lower quantities of exercise.[14] Low energy availability has been documented in individuals with spinal cord energy as the amount of energy available for optimal physiological processes after energy used during exercise is subtracted from energy intake.[24] This has been shown to be more prevalent in individuals with spinal cord injury.[14] Figel et al. report that those living with long standing SCI have shown decreases in energy availability which may be due to lower basal metabolic rates found within this population.[14] Chiu et al. found that the lower ventilation rates observed in cervical and thoracic spinal cord injuries were correlated to lower metabolic rates which lead to low energy availability within this population.[25] Given that lower ventilation rates and aerobic capacity have been correlated with lower metabolic rates, it is not surprising that studies have shown that increasing aerobic capacity in individuals with SCI may improve cardiometabolic health and decrease cardiometabolic diseases.[22,26,27]

Those living with spinal cord injuries often face severe mobility issues, which limit their ability to perform physical activity.[28] Additional services are needed in order to increase accessibility to participation in physical activities, sports, and recreational activities for those living with severe physical disabilities.[29] Many studies have utilized arm crank ergometers to perform aerobic exercise training in individuals with SCI.[23,26,30] A study by Vasiliadis et. al. compared able bodied individuals to participants with chronic SCI on an arm crank ergometer.[30] They found similar cardiometabolic and angiogenic responses between both SCI and able-bodied participants, demonstrating that this mode of exercise may improve metabolic and vascular health outcomes in SCI.[30] Jacobs et. al. reported that exercising in SCI populations leads to increased health outcomes and can be increased if the exercise is created specific to the level of injury for the individual.[31]

Many studies have assessed the efficacy of low volume high intensity interval training (HIIT) for improving cardiometabolic health, and have found that HIIT often shows comparable or superior improvements in cardiometabolic health factors in able-bodied individuals while requiring a significantly lower overall time commitment compared to traditional moderate intensity aerobic exercise programs.[23,32-35] In addition to the benefits shown from HIIT, studies have also shown that HIIT appears to be more enjoyable compared to traditional MIT, as the short duration and recovery periods offer rest that is not available with MIT.[36,37] Biddle et. al. found that HIIT may significantly benefit areas for prevention and treatment of type 2 diabetes and cardiovascular disease, especially in those that are sedentary.[38] These results have been corroborated in a vast number of recent studies in able bodied individuals.[23,32-34,39] However, whether or not these data translate into SCI populations have yet to be fully determined.

To date, there have only been a few studies to assess HIIT exercise in SCI. Brurok et. al. recruited six men with SCI to use an arm crank ergometer three times a week for seven weeks to test the effects on aerobic capacity; this study showed that HIIT significantly increased the peak stroke volume and the VO_{2peak} in individuals with SCI.[40] Graham et. al. showed that six weeks of HIIT in individuals with SCI could significantly increase cardiorespiratory fitness, decrease arm fat, improve insulin sensitivity, and increase strength measurements.[26] Astorino et. al. reported that eight 60 second bouts of HIIT was preferred over 25 min moderate intensity training (MIT) as well as showing potential for higher cardiometabolic health factors in individuals with SCI.[41] This supports one of the primary barriers referenced by the Department of Transportation report showing individuals with SCI prefer to engage in activities with shorter time commitments.[17] The study by Astorino et. al. performed 4 HIIT sessions over the course of 2 weeks and found that participants in the HIIT group showed a higher VO_{2peak} following the study.[41] Additionally, a study by Bakkum et. al. assessed a 16 week HIIT intervention incorporating arm crank ergometer combined with functional electrical stimulation hybrid cycle to determine if arm crank ergometer alone was sufficient to improve metabolic syndrome components, decrease body fat, and improve the inflammatory response in individuals with SCI.[42] They found no significant differences for fasting insulin, HOMA-IR, inflammatory markers, and waist circumference between the two groups.[42] The majority of studies have included smaller sample sizes and were performed for a short duration of training. Larger sample sizes and longer duration training studies are needed to confirm results from previous studies.

There have been multiple barriers highlighted that limit exercise participation in individuals with disabilities; including physical barriers of the natural environment, monetary barriers, inadequate equipment, professional knowledge of the population, availability of resources and many more.[29] These coupled with the transportation issues faced by this population leads to the necessity of adding accessible options for physical activity and exercise. Several studies have shown increased participation in individuals with SCI by offering a remote telehealth session so that the training may occur at the individual's home to limit the need to travel.[43,44] Studies by Irgens et. al. and Van Straaten et. al. used remote video calls to offer a more accessible form of training sessions for this population which resulted in high subjective levels for enjoyment and higher adherence compared to traditional lab style sessions.[43,44] Due to the increased accessibility for individuals with SCI, more research needs to be focused on remote training. Therefore, the purpose of our study is to assess the effects of a home-based telehealth HIIT protocol on cardiometabolic health in individuals with SCI.

Objectives

The primary purpose of this study is to assess changes in cardiometabolic health following 16-weeks of a home-based telehealth arm crank HIIT intervention in individuals with long standing SCI.

Methods

Five participants (3 male, 2 female; n=3 in control, n=2 in HIIT exercise; mean age 53.5 ± 8.5) with longstanding SCI completed the exercise study. Individuals underwent an inclusion and exclusion checklist shown in **Table 1** and were considered eligible if they met the following criteria: (1) diagnosed with a traumatic SCI between C7 and T12 classified as A, B, C, or D on the AIS scale; (2) were between the ages of 19 and 65 at the time of the study; (3) at least 6 months post injury; and (4) void of any issues that would prevent them from being able to effectively operate an arm crank ergometer. Individuals with upper body orthopedic issues, cardiovascular disease, renal disease, currently pregnant or planning to become pregnant, or actively participated in structured daily exercise were considered ineligible for participation.

Recruitment

Participants were recruited using the University of Alabama at Birmingham (UAB) Spinal Cord Injury Database, Lakeshore Foundation Member Database, as well as online advertisements in SCI communities. 766 total individuals were contacted. 382 individuals did not answer or return the call or email. 384 individuals were screened and 379 were excluded based on the criteria in **Table 1** or refused to participate. The recruitment process is outlined in **Figure 1**.

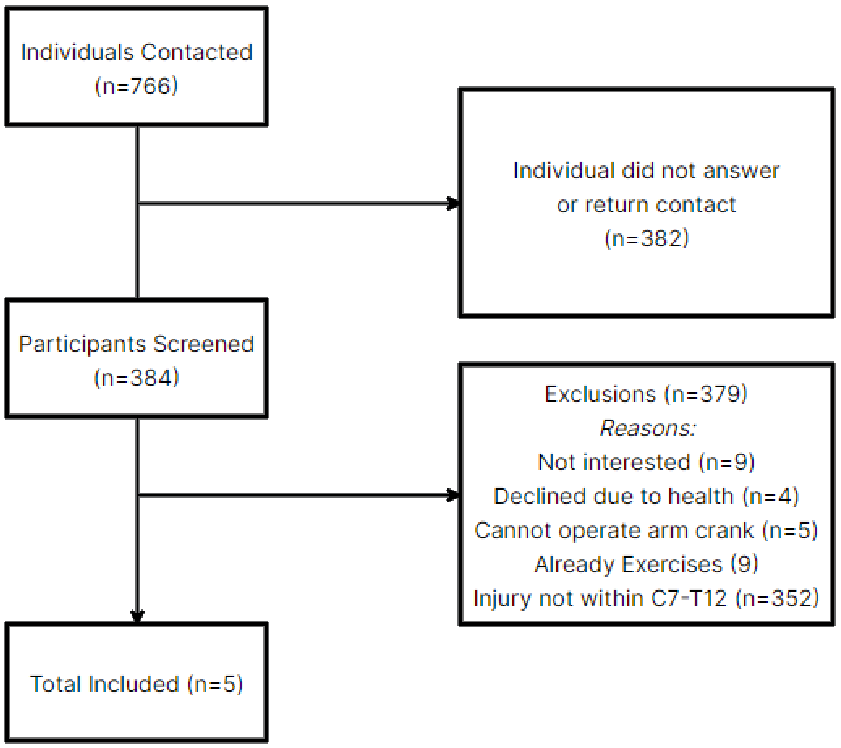


Figure 1. Recruitment

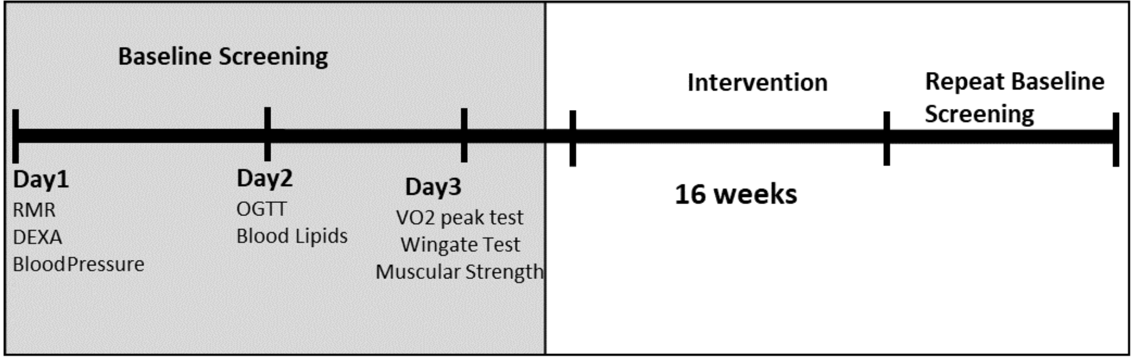
Table 1. Inclusion and exclusion criteria.

Inclusion Criteria	**Exclusion Criteria**
1. Men and women, 19-65 years of age. 2. Confirmed diagnosis of traumatic SCI at the cervical or thoracic level (C7-T12), classified as A, B, C, or D (motor and sensory complete or incomplete) on the AIS scale. 3. At least 6 months post-injury. 4. Able to independently operate an arm ergometer. 5. Have access to a wireless internet connection. 6. Medically stable, able to provide informed consent.	1. Cardiovascular or renal diseases 2. Pregnant women 3. Orthopedic conditions that prevents arm ergometry 4. Upper extremity musculoskeletal conditions that prevents arm ergometry. 5. Neurological disorder that prevents arm ergometry 6. Participation in a structured exercise program currently or in the past 3 months. 7. Unable to perform exercise interventions

Study Design

This study is a 16-week randomized controlled trial within a cohort of individuals with longstanding SCI. Baseline testing consisted of three separate visits. Day one included a Dual-energy X-ray absorptiometry (DXA) scan, assessment of resting energy expenditure (REE), and systolic and diastolic blood pressure measurements. Participants also completed three surveys on day one: the 2nd version of the Short Form-36 item survey (SF-36v2), Spinal Cord Independence Measure (SCIM) survey, and a general life satisfaction survey. Day two consisted of an oral glucose tolerance test (OGTT). Day three included a peak oxygen uptake test (VO_{2peak}), a Wingate arm cycle test for peak power and fatigue rate, and assessment of muscular strength using arm curl exercise, seated pushups, and grip strength. Participants were then randomly assigned to a no exercise control group or a HIIT intervention group. The HIIT group performed 2 HIIT sessions per week for 16 weeks for a total of 32 sessions. The HIIT protocol was determined based on peak anaerobic power measures obtained from the arm crank Wingate Cycle test. The HIIT session consisted of 20 minutes of continuous exercise with four cycles in which they alternated between a 4-minute recovery session at 5% of peak anaerobic power and 30 seconds at 30% of peak anaerobic power before concluding the workout with a 2-minute cooldown. After 16 weeks, both groups returned to repeat the three days of assessments. **Figure 2** is a timeline that shows the participant schedule throughout the study.

Figure 2. Study Participant Timeline



Assessments

Dual-energy X-ray Absorptiometry (DXA): The total body composition was measured in sections using DXA (Lunar Radiation Corp, Madison WI) to determine the fat mass, lean body mass, and bone mineral density. Whole body data was analyzed, in addition to anatomical regions (arms, legs, trunk, gynoid and android).

Resting Energy Expenditure (REE): REE was measured following a 12 hour fast between 8:00 and 10:00 a.m. Participants reamined awake and at rest in a quiet, well-ventilated, temperature-controlled environment. This was measured with the participant laying supine on a bed with a plexiglass enclosure around the head. The participant underwent a 15-minute rest period before testing began. The test included a 30-minute measurement period using an open circuit, computerized, indirect calorimetry system (ParvoMedics) connected to the plexiglass enclosure placed over the participant's head. The first 10 minutes of the test was omitted and the average of the remaining 20 minutes was used to calculate REE.

Oral Glucose Tolerance Test (OGTT): An OGTT was performed by trained medical personnel at the Clinical Research Unit of UAB. This test was administered between 7:00 and 9:00a.m., at least 48 hours after the last session and following a 12 hour, overnight fast. At time 0, the participant consumed 75g of glucose orally within 5 minutes. Blood samples were collected via intravenous catheter and stored in BD Vacutainer tubes. Two baseline blood samples were collected at 10 and 20 minutes prior to administration of the oral glucose solution to calculate basal insulin and glucose. Blood samples were then collected at 30, 60, 90 and 120 minutes following ingestion of the 75g of glucose to measure plasma glucose and plasma insulin. The collected blood was centrifuged at 3000 revolutions per minute, separated into 0.5cc aliquots, and frozen at -80°C until being transported for serum analysis.

Serum Analysis: Serum glucose assays were analyzed using an automated glucose analyzer to determine concentrations of each factor. Serum insulin was analyzed using an immunofluorescent method using an AIA-600 II analyzer with manufacturer's instructions. Insulin sensitivity was calculated using the Matsuda Index.[45] Insulin sensitivity was also measured using the Quantitative Insulin Sensitivity Check Index (QUICKI).[46] QUICKI was calculated as 1/[log(fasting insulin(mg/dL)) + log(fasting glucose(mg/dL))]. Insulin resistance was calculated using Homeostasis Model of Assessment of Insulin Resistance (HOMA-IR).[47] HOMA-IR was calculated as [fasting insulin (μU/L) x fasting glucose (nmol/L)]/22.5. HDL, triglycerides and total cholesterol were measured using a Sirrus analyzer. LDL was measured using the Friedewald method.[48]

Blood Pressure: Blood pressure was obtained using an automated blood pressure cuff and manual cuff testing performed by a trained researcher. Blood pressure was taken from the left arm while the arm was rested at approximately 145 degrees.

Peak Oxygen Uptake (VO_{2peak}): All subjects underwent a graded exercise test using arm crank ergometry and indirect calorimetry to determine VO_{2peak}. Participants were instructed to use an arm crank ergometer (Lode) at 10W for 2 min. Every 2 min thereafter, power output was increased by 10W until voluntary fatigue. Peak aerobic power was defined as VO_2 at the point of failure to maintain 60-65 rotations per minute (rpm)[49]. Minute ventilation, oxygen uptake and carbon dioxide production were continuously analyzed and recorded by an open-circuit spirometry system (ParvoMedics). Heart rate was continuously assessed using a polar heart rate monitor. Rating of perceived exertion (RPE) during exercise was assessed using the 6-20 BORG scale.

Wingate Test: All subjects performed the Wingate Anaerobic Power test using a Lode arm ergometer at Lakeshore Foundation. Subjects sat in their wheelchair or a provided chair and remained seated throughout the entire test. The arm crank was adjusted so that the crank position on the opposite side to the body and the hand grasping the handles, allowing the elbow joint to almost fully extend (165-175°) and the shoulders in line with the center of the ergometer's shaft. A fly wheel braking force corresponding the 5% of the participants body weight was used. Prior to each test, participants completed a 5-minute warm up at 10W, which included 3 short sprint efforts followed by a 5 min recovery period. Following the warm up participants were instructed to hand cycle as fast as possible, verbal encouragement was given to all participants to maintain their highest possible cadence throughout the test. Peak power, mean anaerobic power, fatigue rate, and relative peak power was assessed following each test. The physiological data obtained from this test was used to calculate exercise intensity corresponding to 30% of peak power for the exercise intervals.

Muscle Strength Assessment: A muscle strength assessment was performed to determine participant strength measurements. This included arm curls, wheelchair pushups, and hand grip strength.

Arm curls was assessed using a 5-25lb weight determined by age, gender and body weight. Participants performed the arm curl from a seated position to the beat of a metronome. This test was performed on both arms, starting with the participant's dominant arm. Total number of repetitions were counted until the participant was fatigued.

Wheelchair seated pushups were conducted by the participant pushing up on the arm rest of a chair or wheel of their chair. One repetition included full extension so that the elbows were straight and the buttocks were separated from the chair, followed by the elbows bending so that the buttocks returned to the chair. Total number of repetitions were counted until the participant was fatigued.

Grip strength was tested using a Jamar hand dynamometer. This test was administered three times per hand with an additional practice run before beginning. The average of the three tests was taken per hand.

Analysis

Qualitative

The post intervention interviews were conducted by a researcher that was uninvolved with data collection and had no participant interaction prior to the interview. Researchers analyzed the qualitative interviews using a case narrative analyses. The qualitative data was then analyzed descriptively using the constant comparative method to code emergent themes from the qualitative data[50]. Themes were coded and compared between both participants within the HIIT intervention group. Utilizing the participants' interview data, themes were coded and combined into universal themes. The resulting universal themes were used to create a case narrative analyses for each participant.

Results

Cardiometabolic health and body composition date are shown in **Table 2**. There were no significant differences between groups in any of the baseline measurements. There were significant time effects found for android fat (p = .042), gynoid fat (p = .035) and REE (p = .027). There was also significant group by time effects for gynoid fat (p = 0.015) and REE (p = 0.006) showing that the HIIT group lead to greater improvements in gynoid fat and REE compared to the control. Individual REE responses are showing in **Figure 3**. There were no other significant differences between groups for body composition and cardiometabolic health markers. There was a trend for an overall time effect for percent fat (p = 0.081) and percent arm fat (p = 0.089). Changes in aerobic capacity, anaerobic power, muscular strength, and muscular endurance are shown in **Table 3**. There were no significant improvements, however, there were mean overall improvements in VO_{2peak}, muscular endurance, peak power and relative peak power for the HIIT group.

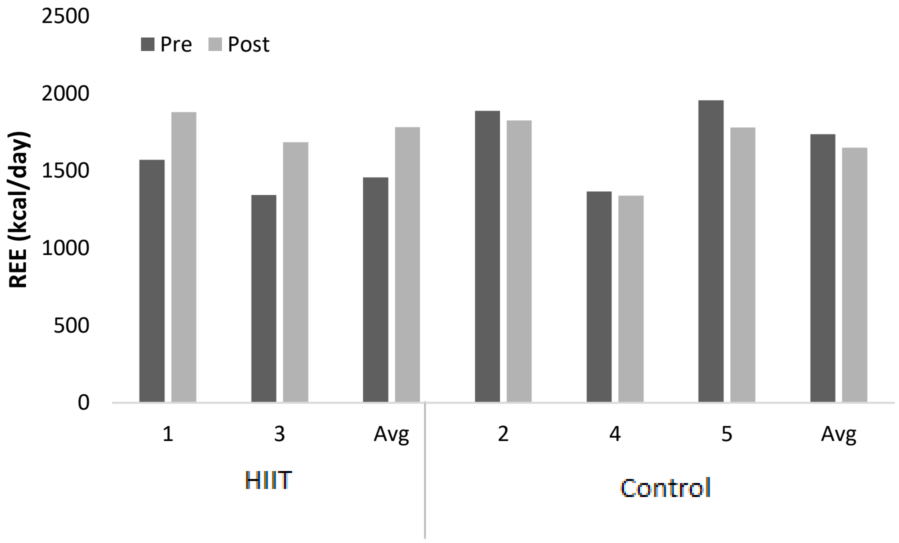


Figure 3. Individual resting energy expenditure response following 16 weeks of intervention.

Table 2. Cardiometabolic health markers

	Control		HIIT		G	T	GxT
	Baseline	16 Weeks Post	Baseline	16 weeks post	*p*	*p*	*p*
Body Weight (kg)	95.77 ± 28.6	97.15 ± 29.0	100.05 ± 9.06	95.52 ± 3.31	.955	.399	.161
Fat (%)	47.37 ± 6.54	46.83 ± 7.18	41.775 ± 1.73	39.7 ± 3.39	.315	.081	.223
Lean Mass (kg)	48.72 ± 13.92	49.59 ± 14.29	56.01 ± 5.74	56.06 ± 4.53	.571	.394	.448
Fat Free Mass (kg)	51.36 ± 14.61	52.18 ± 14.986	59.17 ± 5.96	59.30 ± 4.60	.559	.415	.538
Android Fat (%)	51.73 ± 5.96	50.82 ± 4.85	52.1 ± 5.52	49.15 ± 4.85	.908	**.042**	.170
Gynoid Fat (%)	50.93 ± 10.25	51.37 ± 9.81	41.85 ± 1.63	39.15 ± 2.61	.254	**.035**	**.015**
Arm Fat (%)	37.95 ± 12.6	37.43 ± 11.83	31.5 ± 0.14	29.85 ± 0.92	.498	.089	.285
BMI (kg/m^2)	33.47 ± 13.89	35.17 ± 14.61	30.8 ± 2.69	29.4 ± 0.85	.719	.838	.105
REE (kcal/day)	1737.3 ± 321.6	1650 ± 268.5	1458 ± 159.8	1783 ± 137.2	.774	**.027**	**.006**
SBP (mm Hg)	149.3 ± 6.658	132.0 ± 18.0	152.0 ± 1.41	149.0 ± 1.41	.140	.335	.478
DBP (mm HG)	94.33 ± 0.577	92.33 ± 0.577	99.5 ± 9.19	95.5 ± 2.12	.117	.388	.759
Glucose (mg/dL)	148.3 ± 85.6	84 ± 25.7	95 ± 5.66	96.5 ± 7.78	.442	.501	.483
Insulin (uU/mL)	7.6 ± 4.10	41.7 ± 57.59	10.15 ± 7.0	8.5 ± 1.84	.528	.508	.469
Cholesterol (mg/dL)	178 ± 4.36	188 ± 25.36	176.5 ± 50.21	194.5 ± 86.97	.951	.361	.779
Triglyceride (mg/dL)	126.33 ± 30.09	102.33 ± 44.28	137 ± 82.02	132.5 ± 61.52	.659	.572	.694
HDL (mg/dL)	51.67 ± 0.58	57.67 ± 8.02	41 ± 4.24	46.5 ± 0.707	.041	.175	.944
LDL (mg/dL)	101.07 ± 8.01	109.67 ± 22.05	108.1 ± 38.04	121.1 ± 73.4	.788	.392	.852

Note: **Bold values** indicate statistical significance (p < .05). T = time; GxT = Group x Time interaction

Table 3. Aerobic capacity, anaerobic power, muscular strength, and muscular endurance changes.

	Control		**HIIT**		**G**	**T**	**GxT**
	Baseline	16 Weeks Post	Baseline	16 weeks post	*P*	*p*	*p*
VO_{2peak} (mL/kg/min)	10.05 ± .998	9.99 ± .937	9.95 ± 3.32	12.5 ± 2.05	.220	.436	.418
Peak Power (watts)	281.67 ± 55.5	244.67 ± 101.9	308.0 ± 14.1	345.5 ± 37.5	.261	.996	.45
Mean Power (watts)	108.6 ± 10.3	113.1 ± 12.14	96.65 ± 10.83	122.3 ± 6.80	.666	.202	.333
Relative Peak Power (watts)	3.03 ± .447	2.65 ± .999	3.09 ± .127	3.61 ± .280	.341	.864	.324
Fatigue Rate (%)	52.87 ± 46.19	80.11 ± 9.10	94.13 ± 8.305	90.61 ± .91	.163	.606	.511
Arm Curl Reps (Right)	13 ± 11.5	12.67 ± 11.02	41.5 ± 13.4	47.0 ± 2.83	**.037**	.605	.562
Arm Curl Reps (Left)	11.3 ± 9.81	13.33 ± 11.72	34.0 ± 1.41	85 ± 55.86	.063	.175	.200
Wheelchair Pushup Reps	10.33 ± 17.90	8.67 ± 15.01	31.0 ± 19.80	44.5 ± 12.02	.108	.534	.436
Grip Strength Mean (Right)	28.78 ± 8.57	27.99 ± 13.13	2.33 ± 0	2.33 ± 0	.165	.931	.931
Grip Strength Mean (Left)	34.22 ± 10.06	28.77 ± 5.10	29.0 ± 0	14.67 ± 0	.381	.087	.292

Note: **Bold values** indicate statistical significance ($p < .05$). T = time; GxT = Group x Time interaction.

Participants showed no significance for insulin sensitivity as shown in **Figure 4** with the exception of participant 05 who has been diagnosed with diabetes which may explain the unusual response to the OGTT. Due to the outlier of participant 05, if this participant is excluded from results, the differences shown in fasting measurements are eliminated.

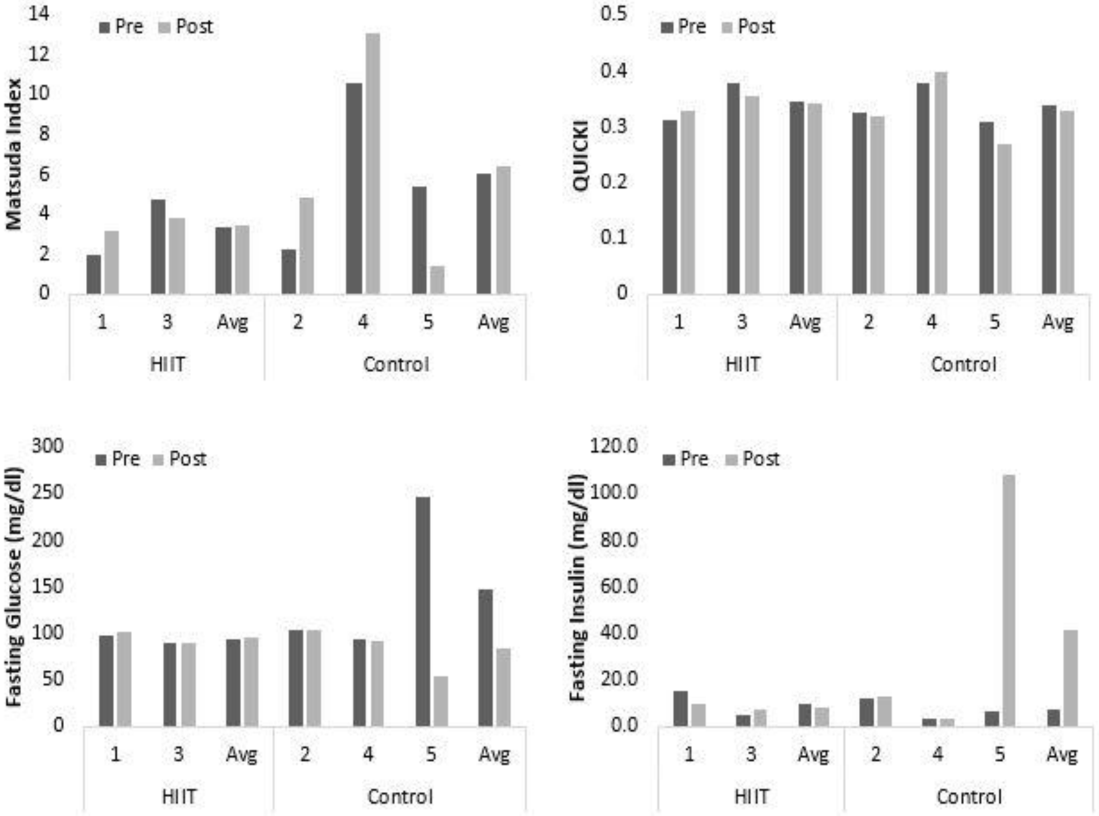


Figure 4. Individual blood glucose and insulin responses of HIIT and control group before and after 16-week intervention.

Table 4 shows the survey results completed by the participants. While no statistical significance was observed, the participants in the HIIT group showed an average increase in the SF-36v2 Health survey which correlates to overall quality of life measurements as well as the Life Survey which depicts the participant’s opinion on his or her quality of life. This was also evident in the post intervention interviews in which the HIIT group participants reported higher quality of life upon concluding the intervention.

Table 4. Surveys

	Control		**HIIT**		**G**	**T**	**GxT**
	Baseline	16 Weeks Post	Baseline	16 weeks post	*p*	*p*	*p*
SF-36v2 Health Survey	100 ± 0	100 ± 4.36	102.5 ± 7.78	110.5 ± 3.54	.151	.136	.136
SCIM	72.0 ± 12.53	69.67 ± 13.01	72.0 ± 4.24	71.50 ± 2.12	.930	.174	.334
Life Survey	25.33 ± 4.16	26.67 ± 5.51	24.0 ± 7.07	29.5 ± .71	.861	.217	.412

Note: **Bold values** indicate statistical significance (p < .05). T = time; GxT = Group x Time interaction.

HIIT Group

Participant 1 has a C6/C7 incomplete injury. Following the 16 weeks of intervention, this participant saw the following physical changes; an 8% decrease in overall body weight, a 3.25% decrease in percent body fat, a 3.9% decrease in android fat percent, a 3.4% decrease in gynoid fat and a 2.7-point decrease in BMI. Participant 1 also saw a significant increase in REE (19.7% increase). This was correlated with the participants reported higher energy levels during the intervention. Participant 1 showed a significant increase in VO_{2peak} from 7.6 mL/kg/min to 14 mL/kg/min at the conclusion of the intervention period. Participant 1 drastically increased in both the arm curl test and wheelchair pushup increasing 53% on the right arm curl, 279% on the left arm curl, and 212% on the wheelchair pushups. He also had an 11-point increase in the SF-36v2 Health Survey which tracks the participants ability to perform basic functions with or without aid showing an increase in quality of life reported. This participant reported an overall enjoyment for the study and said he looked forward to each session as he could see the improvements.

In an interview with participant 1, he mentioned an overall enjoyment for the HIIT intervention group. Shortly after beginning the intervention, the participant contracted Covid-19 which caused a hospitalization visit in which he was admitted to the ICU for 9 days. He contributes the exercise sessions, both before and after the illness, to how quickly he was able to recover, noting that his doctors were extremely surprised of his progress in his follow-up visit. He also reported that the exercise program pushed him to lead a healthier lifestyle and change other lifestyle habits. Upon completing the study and looking back over the 16 weeks, his favorite thing was the structure and the staff that were part of the project. By creating the relationship by meeting remotely twice a week, the participant was more eager to complete each session and reports that he was more likely to push himself instead of doing the minimum. An important remark is that the participant admitted that he would likely have skipped sessions or cut them short had there not been a trainer present for each session which reinforces the positive impact it was to have a live trainer for each session. The participant reported issues with the technology, specifically the heart rate monitor and the TeleRehab connection, not always working which did cause some stress when trying to troubleshoot. Overall, this participant thoroughly enjoyed being part of the study, reports better energy levels and a higher overall health and wellness, and has continued training even after finishing the study.

Participant 3 has a T5 complete injury. Following the 16 weeks of intervention, this participant saw the following physical changes; a 0.9% decrease in percent body fat, a 2% decrease in android fat percent, a 2lb increase in lean mass and 1% decrease in arm fat. While these findings were not statistically significant, they do show positive and healthy trends following the intervention. Participant 3 also saw a significant increase in REE (25% increase). Participant 3 showed a slight decrease in VO_{2peak} from 12.3 mL/kg/min to 11.1 mL/kg/min; however, this is likely due to the participant contracting covid-19 during the 15th week of the intervention which effected his aerobic capacity. While the changes were not statistically significant, he did show positive trends for muscular strength and muscular endurance results. This participant also showed increases in survey categories for overall quality of life and ability to care for oneself.

In an interview with participant 03, he mentioned a general enjoyment for the HIIT intervention group. His main objection to the study was the time commitment, both in reference to the amount of time needed for in person assessments and for the 16-week time frame. While he understood the need for the extended period to gather data, he felt the time frame could be a deterrent for many people in the SCI community. During the study he experienced a variety of different technical issue with the equipment reporting that the tablet was not user friendly and often had connection issue which was a source of frustration and stress. He also reported the heart rate monitor was often inaccurate which led to additional frustration during training. The trainers were reported as exceedingly positive and were able to guide through the troubleshooting process to get the session back in order. When asked about the main positive of the study, the participant reported enjoying the remote aspect of the training as transportation is often an obstacle for him with regards to exercise. The largest negative factor was related to the paperwork and timing associated with compensation for being part of the study in that it was not streamlined and took an excessive amount of time in his instance. Participant said the study would have been more enjoyable if the process was more streamline and was easier on the participants involvement. While there was frustration associated with the study, he reported higher energy levels and noticed an overall increase in general health and wellbeing.

Control Group

There were no statistically significant changes for the control group. On average, the participants in the control group remained constant for all measurements of fat mass and muscle mass. The control group showed an average BMI increase of from 33.47 kg/m2 to 35.17 kg/m^2. The control group did not see any statistical changes in blood lipids, glucose or insulin sensitivity, with the exception of participant 05's bout with diabetes that caused a large effect on her insulin sensitivity levels. The mean peak power for control which decreased from 281.67 watts to 244.67 watts and the fatigue rate increased from 52.87% to 80.11%. Overall, the control group remained constant in most categories while some categories showed slight decreases in physical health shown with increased BMI, decreased peak power and increased fatigue rates.

Discussion

Compared to the general population, people with SCI are at a greater risk of developing chronic diseases and higher risk for cardiometabolic health issues.[51] Many of the secondary health conditions that individuals with SCI face may be preventable with appropriate lifestyles modifications, which include exercise. A previous pilot study showed that exercise was able to significantly improve areas of insulin sensitivity, muscular strength, and cardiovascular fitness.[26] It is reported that the SCI population often has high levels of physical inactivity, which has been attributed to obstacles such as accessibility to appropriate facilities, transportation barriers, and lack of time.[4,17] Astorino et. al., demonstrated that HIIT is a preferred form of exercise and it leads to increases in cardiometabolic health in individuals with SCI.[41] HIIT has also been shown to elicit higher responses in cardiometabolic health while only requiring as little as 20% of time commitment compared to other recommended interventions.[23,32-34,39,52]. The preliminary findings of this study support previous studies. We found that 16-weeks of remote home-based telehealth HIIT training displayed improvements in (a) percent body fat, (b) cardiovascular fitness, and (c) resting energy expenditure in individuals with SCI.

Overall, this study found that HIIT improved cardiometabolic risk factors within individuals with longstanding SCI. Even with a small sample size, the data shows a positive trend in the HIIT group while showing the control group remained constant. The qualitative data from the interviews suggests that HIIT was an enjoyable form of exercise that did not require a major weekly time commitment. However, future studies with larger cohorts of participants are still needed to further observe the results of HIIT within the SCI population.

This study also demonstrated that a home-based exercise may be effective in eliminating many of the exercise barriers that individuals with SCI face. Participants attended all exercise sessions over the 16-week period showing a 100% adherence. Participants in the HIIT intervention group reported enjoying the remote training method and that the remote aspect allowed them to participate. Studies have already shown that remote training methods have been successful in increasing participation and accessibility in the SCI population.[43,44] Showing that a remote form of HIIT training can be effective allows for more accessible remote options to be created, allowing for accessibility for individuals with SCI. Utilizing remote training allows this population to receive improvements in their cardiometabolic health without obstacles such as accessibility to appropriate facilities, transportation barriers, and lack of time.

While other studies have shown that HIIT may decrease blood lipids in obese and sedentary populations, the data in this study does not show any significant changes in blood lipids in the HIIT group.[23,53] This may be due to the small sample size, which has also been shown in other pilot studies following HIIT training.[54] However, other studies have shown positive trends for blood lipids.[26] More research is needed to show the effects of HIIT on blood lipids in individuals with SCI.

Maximum aerobic capacity has been shown to be a strong predictor for all-cause mortality, thus it is important to identify modes of exercise that can increase VO_{2peak}.[55] We found a 25.6% increase in VO_{2peak} for participants in the HIIT group. However, we found large variability in our two participants; participant 01 showed a 6.4 mL/kg/min increase, whereas participant 03 showed no change which may be attributed to his bout with a cardiorespiratory illness just before the conclusion of the intervention period. Studies have shown that exercise within this population has been shown to increase VO_{2peak} values as our pilot study showed an average increase of 7.2% in the HIIT group after only 6 weeks of training.[26]

To our knowledge, this is one of the first studies to assess a long-term (16 week) week HIIT training study in individuals with SCI. While this study is currently underpowered in participants, we are seeing trends for improvements that are additive to those seen in our recent pilot study.[56] These data demonstrate the potential to deliver a home based, long term, HIIT program that is safe and may improve markers of cardiometabolic health in individuals with long standing SCI. However, the small sample size of this study limits the ability to provide statements that may apply to the entire SCI population. Future research is still needed to infer the effects of HIIT training within the SCI population.

Study Limitations

There were a few limitations of this study. First, the small sample size of this study limits the ability to provide statements that may apply to the entire SCI population. Secondly, participants had to be both sedentary and willing to participate in structured exercise which limited the available population.

Future Recommendations

There are a number of ways in which further research could extend and further test the preliminary data shown in this study:

1. Future studies with a larger sample size are necessary to infer the effects of remote HIIT exercise within the SCI population. One way to address recruitment would be to utilize multiple institutions. This would allow for more accessible pre- and post-intervention assessment locations as well as additional resources for recruitment.
2. Many studies have shown larger or more conducive trends by implementing HIIT exercise three times a week in able bodied individuals. It would be beneficial to conduct three sessions a week to further quantify the impact within the SCI population.
3. Potential participants responded negatively to having three days of testing pre- and post-intervention. Determining a way to reduce in-person assessments to two days without sacrificing efficacy would potentially increase the number of willing participants.

Conclusion

Individuals with SCI experience a wide array of barriers to participate in exercise such as lack of time, accessible equipment, and transportation. This exercise intervention shows the potential to utilize a remotely monitored, home based, HIIT program that is both feasible and safe that may improve markers are cardiometabolic health in individuals with SCI. Participants reportedly accepted the intervention due to the ease of accessibility, convenience of being remote, and the associated positive physical benefits that developed over the course of the program. The preliminary data of this study show improvements for this population and merits future research in larger clinical trials.

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