CALIFORNIA STATE UNIVERSITY, NORTHRDIGE

CARDIORESPIRATORY RESPONSE TO CONTINUOS PASSIVE MOTION EXERCISE IN PEOPLE WITH SPINAL CORD INJURY

A thesis submitted in partial fulfillment of the requirements
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By

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DEDICATION

To my family who always supported me
Sung Sik, Wee, Yeon Ok, Park, and Joo Yeon, Wee

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Abstract

Cardiorespiratory Response to Continuous Passive Motion Exercise in People with
Spinal Cord Injury

by

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PURPOSE: To investigate cardiorespiratory responses to continuous passive motion (CPM) exercises in individuals with spinal cord injury (SCI). Two different types of passive exercises were investigating the study purpose.

METHODS: A total of 11 individuals with SCI (age 40.72 ± 11.76) and 11 healthy controls (age 29.27 ± 11.36) participated in this study. All participants completed two different passive exercise modes; i) seated passive bike exercise (Flexicizer International corp. Inc., 2007) and ii) supine passive walking-like exercise (Cross-crawl brain pattern machine, Center of Achievement, 2001) and active arm cycling exercise (Monarch Inc. 2006). All research variables were collected while participants completed 20-minutes of passive exercises and of active arm cycling exercise. A telemetric metabolic system (Cosmed,Cosmed USA Inc., 2006) was used to obtain research variables including, oxygen consumption (VO_2, ml/kg/min), carbon dioxide production (VCO_2, ml/min), minute ventilation (VE, l/min), and heart rate (HR, beats/min). Blood pressure (BP, mmHg) was measured by wrist blood pressure monitor (Omron Healthcare, Inc, 2007) throughout the exercise session. Each exercise session was at least 24 hours apart to avoid the effect of previous exercise session. Participants were asked to avoid strenuous exercise within 24 hours prior to each exercise session that can affect the research variables. Collected data were reduced and processed using a Cosmed gas analysis program. A Multivariate analysis of variance (MANOVA) was used for statistical analysis. **RESULTS:** There were significant increase in VO_2 ($p<0.05$) and VCO_2 ($p<0.05$) level in both SCI and control groups during the seated cycling exercise, as well as in a supine walking-like exercise. There was no statistical difference in other variables. When the two passive exercise modes were compared, both supine position walking-like exercise and seated cycling exercise showed similar changes in VO_2 and VCO_2 in SCI group. ($p< 0.05$). Pulled statistical analysis showed that there are significant changes in VO_2 and VCO_2 during both seated cycling exercise. **CONCLUSION:** CPM exercise can promote cardiovascular response in both SCI population and able-bodied population. Our results indicate that both seated and

supine position passive exercises alter cardiovascular aspects such as VO2 and VCO2 that further can elicit cardiorespiratory improvement in people with SCI.

Introduction

Spinal cord injury (SCI) is the condition that are caused by traumatic incidents such as motor vehicle accidents, falls, sports accidents, or violence which cause fractures or dislocate of vertebrae (The National Institute of Neurological Disorder and Stroke, 2010). There are more than 300,000 individuals with SCI in the United States by 2007 and $9.7 billion dollars was spent to treat the conditions (University of Alabama, 2008).

SCI can cause secondary physical and psychological dysfunctions such as loss of motor function, muscular strength, and depression. These dysfunctions can further limit the physical activity of individuals with SCI. One of the most serious physical dysfunction among individuals with SCI is the decrease of cardiorespiratory capacity due to the loss of motor function and muscular strength.

Cardiovascular (CV) diseases were nominated as the primary cause of mortality among the individuals with SCI (Garshick et al., 2005). Furthermore, cardiovascular exercise is necessary for people with SCI in order to maintain their health and to reduce the risk of CV diseases. Krause, Carter, Pickelsimer, and Wilson (2008) investigated the mortality rate and multiple health conditions in individuals with SCI. The finding showed that the multiple health conditions including the cardiorespiratory diseases are closely related to the mortality rate of individuals with SCI. It is widely accepted knowledge that the risk of cardiovascular disease is inversely related to the aerobic exercise capacity of individual (Krause, Carter, Pickelsimer, & Wilson, 2008).

Different types of CV exercises such as active exercise, passive exercise, and passive exercise with Functional Electrical Stimulation (FES) are used in therapeutic and in research settings to study the effects of exercises on CV fitness in individuals with SCI. The most common type of active exercise for individuals with SCI is arm ergometer exercise since it is common that the individuals with SCI have limited mobility in their lower extremity. Several research studies examined the effects of arm ergometer exercise on CV fitness in individuals with SCI. It’s been documented that arm ergometer exercise increase maximum oxygen consumption and improve CV health of people with SCI. (Tawashy, Eng, Krassioukov, Miller, & Sproule, 2010; Schneider, Wing, & Morris, 2002)

FES is the method that is performed to elicit the muscular contraction using external electrical stimulation. Many research studies have been done in the area of FES and different modes of exercise in individuals with SCI. The study results suggested that there are significant changes in vascular characteristics, VO2 changes with FES intervention but no significant changes in passive exercise only group. (Johnston, Smith, Mulcahey, Betz, & Lauer, 2009; Thijssen, Ellenkamp, Smits, & Hopman, 2006)

Passive exercise is one of the most common exercise modes since individuals with SCI have immobilized limbs that limit their activity level. Thus, passive exercise can be used as an alternative mode of aerobic exercise mode. It is originally designed to enhance the range of motion (ROM) and mobility. However, these days it is been used in many therapeutic settings as an aerobic exercise mode. According to several research studies, passive exercise can induce the changes in HR, muscle contraction, venous return, VO2, BP and elicited muscle pump phenomenon.(Kawashima, Nakazawa, & Akai, 2005; Ogata, Higuchi, et al., 2009)

Currently, passive lower body or full body exercise machines are widely used in clinical and rehabilitation setting as a cardiovascular exercise mode for individuals with SCI. There are many research studies (Ballaz, Fusco, Cretual, Langella, & Brissot, 2007; Muraki, Ehara, & Yamasaki, 2000; Ter Woerds, De Groot, van Kuppevelt, & Hopman, 2006) investigated the effect of passive cardiovascular exercise on people with SCI. However, there still is controversy in significance of continuous passive exercises effect on cardiorespiratory health aspects in people with SCI. Thus, the purpose of this study is to investigate the effect of continuous passive exercise machine on the cardiovascular aspects in people with SCI.

Hypothesis

1. There will be significant changes in cardiorepiratory aspects during CPM exercise modes when compared to baseline values in individuals with SCI when compare to able-bodied individuals
2. Two different CPM exercises will have different level of effects on cardiorepiratory aspects.
3. There will be significant group interactions between two groups.

Definition of Terms

*** Heart Rate (HR)**: HR is the number of heartbeats per unit of time expressed as beats per minute (bpm). HR can vary as the body's need to absorb oxygen and excrete carbon dioxide changes, such as during exercise or sleep. It can be found on brachial and carotid arteries.

*** Blood Pressure (BP)**: BP is the pressure created by circulating bloodagainst the walls of blood vessels, and is one of the principal vital signs. Blood pressure usually refers to the arterial pressure.

*** Maximal Oxygen Uptake (VO_{2max})**:VO_{2max} is the maximum capacity of an individual's body to transport and use oxygen during incremental exercise, which represents the physical fitness of the individual.

*** Minute Ventilation (VE)**: VE is the volume of gas inhaled or exhaled from a person's lungs in one minute. It is an important parameter in respiratory medicine due to its relationship with blood carbon dioxide levels.

***Submaximal Exercise testing:** Diagnostic tool which is performed at a lower level of intensity due to the physical condition for diagnosing coronary artery diseases or assessing someone's physical fitness level.

*** RPM:** PRM is abbreviation of Revolution per minute. It is a measurement of the frequency of a rotation. It is defined as one full cycle or right and left leg movement of exercise machines in this study.

REVIEW OF THE LITERATURE

This section will discuss a summary of previous research studies that are related to the investigation of continuous passive exercise and cardiorespiratory response in individuals with spinal cord injury.

Spinal Cord Injury and Prevalence

Spinal cord injury (SCI) is the conditions that are caused by the traumatic incidents such as motor vehicle incidents, traumatic falls, sports incidents, or violence, which cause the fractures or dislocates the vertebrae ("NINDS", 2010). These fractures or dislocation of a vertebrae affects transfer of sensory and motor signals across the sites of lesions (DeVivo, Go, & Jackson, 2002). A study from the University of Alabama showed that there were about 300,938 spinal cord injuries in 2007 in the United States (Alabama UO, 2008).

Chiu et al. (2010) reviewed the previous research studies about the epidemiology of SCI among developed and developing countries. The results showed that the incident rate in developed countries was declining from 52.2 per million to 13.1 per million compare to developing countries that with inclining from 12.7 per million to 27.7 per million. In addition, the major cause of SCI in developed country was traffic accidents with the rate from 35% to 58.3% (Chiu et al., 2010).

Ho et al. (2007) showed that the major cause of SCI is motor vehicle accidents. A 50.4% of SCI between years 2000 and 2003 were due to the motor vehicle crashes. SCI from falls accidents have significantly increased from 16.5% to 23.8% among 60 years and older population between 2000 and 2003 (Ho et al., 2007). However, sports and violence related incidents were decreased from 14.4% to 9% and 21.8% to 11.2% respectively during the same period. SCI prevalence rate in female has increased compare to male prevalence rate (Ho et al., 2007). The study results suggested that there was significant increase in the average age of SCI from 28.7 years old in 1973 and 1979 to 37.6 years old in 2000 and 2003. In addition, racial prevalence in Caucasian has increased from 59.9% during 1973 – 1979 to 67.4% during 2000 to 2003 (Ho et al., 2007).

Classifications of SCI

According to Maynard et al. (1997), SCI has an effect on sensory or motor information transfer in the lesion of injury. SCI can be divided in to two classifications; complete and incomplete injury which are based on the location and the degree of penetration within the neural elements of the spinal canal. Incomplete injury is when partial sensory and motor function is remained below the lesion which includes sacral segment. Complete injury refers to when there is no sensory and no motor function below the lesion. SCI is also classified into paraplegia and quadriplegia or tetraplegia, which are based on the effected lesion and level. Paraplegia includes the motor or sensory impairment in thoracic, lumber, or sacral part of the spinal cord. In paraplegia, usually the arm function is remained. However, the involvement of the trunk, pelvic or legs depends on the level of injury Quadriplegia includes the motor or sensory impairment in the cervical segment of the spinal cord. Thus, it results in the functional impairments in arm, leg, trunk, or pelvic organs (Maynard et al., 1997).

SCI and health conditions

Spinal cord injury can cause many physical and psychological dysfunctions. Common physical conditions that followed by the SCI are the loss of motor function and of muscular strength below the affected lesion. These characteristics further limit the physical activity of SCI populations. Furthermore, these physical conditions are closely related to the mortality rate in SCI population. Krause, Carter, Pickelsimer, & Wilson (2008) longitudinally studied in 1389 traumatic SCI individuals about the mortality rate and multiple health conditions. The researchers were interested in looking at the two different comparisons; single health condition effect and multiple health condition effect on mortality rate. The results showed that the secondary health conditions from SCI such as pressure ulcers, urinary tract infections, amputations, secondary fractures, and depression were related to mortality rate of SCI individuals. Furthermore, multiple health conditions were more closely associated with the mortality rate (Krause et al., 2008).

Suzuki, Krahn, McCarthy, & Adams (2007) studied the secondary health outcomes of SCI. The questionnaire asked about the physical conditions that the SCI individuals experienced after the incident. The physical conditions that were included in the questionnaire were fatigue, circulation problems, extreme blood pressure, diabetes mellitus, contractures, muscle spasms, secondary injuries, osteoporosis, urinary tract infection bladder problems, yeast infections/vaginal infections, pneumonia, weight changes, chronic pain, stomach problems, and bowel problems (Suzuki, Krahn, McCarthy, & Adams, 2007). The results showed that 76% of SCI individuals suffered with poor circulation problem, 74% with rapid fatigue, 61% with weight management problem, and more than 50% of participants experienced blood pressure problem (56%) (Suzuki, Krahn, McCarthy, & Adams, 2007).

SCI and physical Rehabilitation

The major care of Spinal cord injury is acute care. Acute care includes the immobilization of the spine, maintaining the cardiovascular and other biological aspects (Yarkony, & Gittler, 2002). According to Yarkony, & Gittler, (2002), the most important purpose of acute treatment of SCI is to prevent the further damage to the spinal cord. Range of motion (ROM) exercise such as stretching exercise is essential for the SCI individuals in order to correct the contractures from the incident. In tetraplegic individual, since the patients cannot move their limbs, it is important to use proper equipment or assistant's help for their rehabilitation (Yarkony, & Gittler, 2002).

Spinal cord injury can cause many physical and psychological dysfunctions. One of the physical condition that followed by the SCI is the loss of motor function and muscular strength in the affected limbs. These characteristics further limit the physical activity of SCI populations.

SCI and Cardiovascular health

It is well known fact that the physical activity and cardiovascular disease are closely related. Due to these physical limitations, SCI population is at a higher risk for cardiovascular disease (CVD) compare to able-bodied population.

According to Garshick, et al. (2005), cardiovascular disease has been nominated as a leading cause of mortality in SCI population. The authors investigated the relationship between the secondary health conditions and mortality rate in 361 male SCI individuals with at least 1 year post injury between year 1994 and year 2000. Results showed that the most common cause of death was circulatory system diseases which were 40% of total mortality rate. Respiratory diseases were the next contributing factors of mortality with 24% (Garshick et al., 2005).

Groah et al. (2005) investigated that the cardiovascular diseases prevalence in 545 long term spinal cord injury survivors. Results showed that there was 16% higher risk for CVD and fivefold higher risk in cerebrovascular disease in quadriplegic SCI survivors. However, paraplegic participants showed 70% higher risk for coronary heart disease compare to quadriplegic population. In addition, more complete paralysis was related to 44% higher risk in all CVD (Groah, Weitzenkamp, Sett, Soni, & Savic, 2001).

According to Barfield, Malone, Collins, & Ruble, (2005), the level of spinal cord injury and the loss of various physiological functions are related (Barfield, Malone, Collins, & Ruble, 2005).

Damages of spinal cord injury depend on the level of lesion in the spinal cord. In addition, the level of spinal cord injury affects acute adjustment to peak exercise capacity and acute adjustment to activity (Schneider et al., 2002).

It is a widely accepted knowledge that the risk of CVD and aerobic exercise is inversely related. Since the SCI individuals have greater immobilization compare to able-bodied individuals, these individuals can be in greater risk for CVD. However, there are many alternative methods that are used to improve the cardiovascular conditions in this population.

(Tawashy et al., 2010) investigated the effect of aerobic exercise in early rehabilitation stage in C5 SCI individual on cardiovascular health. Participant asked complete the specially designed exercise training protocol which contained arm crank, boxing sliding motion and wheeling motion for 2 month period. The results showed that there was significant improvement in exercise tolerance which was measure by the exercise time and intensity. In addition, there was 20% increment of oxygen uptake observed. The research outcome suggested that the early rehabilitation aerobic exercise training was effective to improve the cardiovascular health of SCI individual (Tawashy et al., 2010).

Cardiovascular Exercises in SCI

Different types of cardiovascular exercises are applied in order to enhance the cardiovascular capacity of SCI individuals. The most common exercise modes are arm cycle exercise and leg cycle exercise. Valent et al. (2008) examined the effect of hand cycling on physical capacity in 162 participants with paraplegia and tetraplegia. Participants had a recent SCI population. Three time points of variables measurement were analyzed in order to investigate the effect of hand cycling. Results showed that there was 29% increase in peak oxygen consumption among paraglegia population during the intervention compare to control group ($p=0.00$). However, there was no cardiovascular benefit followed by the intervention among the tetraplegia ($p=0.32$). Results suggested that hand cycling had significant beneficial effect on aerobic physical capacity in paraplegia but not in tetraplegia (Valent et al., 2008).

Valent et al. (2009) investigated the training effects of hand cycling on physical capacity in 22 tetraplegic SCI individuals. Participants underwent 35 to 45 minutes of 8 to 12 weeks of hand cycling interval training either at home or rehabilitation center (Valent et al., 2009). The results showed that there was significant improvement in peak oxygen consumption (VO_{2peak}) with average of 114 ml/min post training. In addition, there was significant decrease in submaximal oxygen consumption with training (P= 0.04). The results suggested that adequately designed aerobic arm cycling exercise can improve the cardiovascular capacity of individuals with tetraplegic SCI (Valent et al., 2009).

Schneider, Wing, & Morris (2002) compared the effects of strenuous arm cranking and leg cycling on oxygen uptake and heart rate kinematics in ten untrained participants (Schneider, Wing, & Morris, 2002). Participants were asked to complete seven exercise sessions throughout three weeks period. Each exercise session included 7 min 15 sec exercise above the anaerobic threshold with arm crank and leg cycle exercise respectively. The study outcomes showed that there was greater increment in peak oxygen consumption during leg exercise compare to during arm crank exercise ($p<0.05$) (Schneider et al., 2002).

Another exercise mode that is commonly used for SCI individuals is the functional electrical stimulation (FES). According to the National Clinical FES Centre, FES is defined as a technique that use small electrical stimulation to produce the muscle contraction in paralyzed muscles in order to enhance the movement effect of the affected limbs followed by SCI, stroke, and other neuromuscular diseases (National Clinical FES Centre, 2010).

Thijssen, Ellenkamp, Smith, & hopman (2006) examined the effects of 25 minutes, 4 times per week for six weeks of cycling FES training and six weeks of detraining on the arterial adaptation on nine SCI participants. Plethysmography and echo Doppler was used to investigate the blood flow of thigh and diameter of the femoral artery and flow-mediated dilation respectively (Thijssen et al., 2006). The results showed that there were significant changes in baseline and peak arterial blood flow (P=0.078) and femoral artery diameter (P=0.057). Baseline thigh blood flow was significantly increased (P=0.03) after two weeks of training. In addition, there was decrease in vascular resistance after 2 weeks (P= 0.01) and 6 weeks (P=0.04) of training (Thijssen et al., 2006). The results suggested that there are significant changes in vascular characteristics after 2 weeks of cycling FES training. However, the changes disappeared after 1 week of detraining. Thus, the FES training should be maintained for longer period of the time (Thijssen et al., 2006).

Johnston, Smith, Mulcahey, Betz, & Lauer (2009) investigated the difference between the FES cycling and passive leg cycling on the cardiovascular and vascular health in children with SCI. Thirteen participants underwent 1 hour, 3 times per week, 6 month of exercise training in two different exercise modes (Johnston et al., 2009). Results showed that there was no difference in exercise effect on pre and post training between the groups (P>0.05). However, there was significant improvement in oxygen consumption in FES group (P= 0.035) where the passive exercise group did not show the improvement in oxygen consumption (Johnston et al., 2009).

In terms of different mode of exercise, passive exercise is one of the most important aerobic exercise modes. In many cases, individuals with SCI have immobilized limbs which limit their activity level. Thus, the passive exercise can be used as an alternative mode of aerobic exercise mode. There are many research studies that investigated the effects of passive exercise on cardiovascular aspects of SCI individuals.

Muraki, Ehara, & Yamasaki (2000) studied the cardiovascular responses of passive leg cycling exercise among five paraplegia and five able-bodied participants. Participants exercised for 6minutes on the passive leg cycle ergometer at 40 revolutions per minute (rpm). Pre, during, and post intervention measurements in cardiac output, stroke volume, and cardiac activity were collected. Results showed that there were significant difference in stroke volume and cardiac output during the passive leg cycle exercise (P<0.05) compare to the resting values. However, there was significant difference between able-bodied group and SCI group in cardiac output due to the difference in HR. The able-bodied group showed acute increase in HR and cardiac output within 20 sec of passive leg cycle exercise where the SCI group showed slow increase in these variables. These results suggested that SCI population need more time to see the effect of passive leg exercise than able-bodied population (Muraki et al., 2000).

Kawashima, Nakazawa, & Akai (2005) examined the effects of standing passive leg movement on the affected limb oxygenation and electromyography (EMG) activity in SCI (Kawashima et al., 2005). The participants were standing on the exercise machine that stabilize the trunk and lower limb while the researcher moved the hand lever which also moved the participant’s legs. The participant was exercising for eight to nine minutes. During passive leg exercise, oxygenation levels of the medial head of the gastrocnemius were measured by near-infrared spectroscopy (NIRS) and EMG and HR were also measured. The results showed that there was increased EMG activity in all participants during the passive leg exercise at the later stage of the exercise with higher movement frequency. However, there was no EMG activity shown in control group. According to the result, HR was elevated after exercise intervention in all participants. The results suggested that passive leg exercise can induce the muscular activity and muscle oxygenation which increased the HR due to the increment of venous return and muscle pump phenomenon in the legs. The researchers also suggested that there can be increased oxygen consumption due to the increment of the dependent variables (Kawashima et al., 2005).

Ogata, Higuchi, Ogata, Hoshikawa, Akai, & Nakazawa, (2009) conducted the study about the effects of passive standing walking–like exercise on blood pressure responses on twelve motor-complete SCI participants and twelve able-bodied participants. Participants were slowly moved from the seated position to standing position. Researcher put the participants in same position for 6 minutes in each seated and standing position in order to investigate the changes in the dependent variables. For the exercise session, participants performed 12 minutes of passive walking-like exercise at 1Hz. Results showed that there was significant increase in mean arterial blood pressure ($P<0.01$) in participants with SCI with lesion at or above thoracic level 6. In addition, VO_2 changed significantly from resting value of 190 ml/min to 207 ml/min ($P<0.01$). The study results suggested that the passive walking-like motion can induce the changes in blood pressure and oxygen consumption in people with SCI with the lesion level or above thoracic 6. The authors suggested that the passive walking-like movement can be used as a common rehabilitation mode for SCI population (Ogata, Higuchi, et al., 2009).

Israel, Campbell, Kahn, & Hornby, (2006) compared the difference in metabolic cost and lower extremity muscle activity during the robotic- and therapist-assisted treadmill walking. There were twelve participants with SCI. Five min prior to both robotic- and therapist-assisted treadmill walking, participants' metabolic rate was measured as a resting value. After the resting measurement, participants were asked to walk 10 minutes on the treadmill at a speed of 3.0 km/h. oxygen consumption during the standing and walking were measured in order to monitor the effect of exercise intervention on metabolic aspect. Results showed that the oxygen consumption in standing phase was significantly higher ($P<0.05$) than the oxygen consumption during the sitting phase in both robotic- and therapist-assisted conditions. In addition, results showed that the oxygen consumption during the therapist-assisted condition with feedback was significantly higher than robotic-assisted condition. These results suggested that the visual and verbal feedback can also an effect on the metabolic costs in SCI population (Israel, Campbell, Kahn, & Hornby, 2006).

Currently, passive full body exercise machines are widely used in clinical and rehabilitation setting as a cardiovascular exercise mode for SCI individuals. Many research studies investigated the effect of passive cardiovascular exercise on SCI population. However, there is some controversy whether CPM exercise has cardiorespiratory health benefits. Thus, the purpose of this study is to investigate the effect of CPM exercise machines on cardiorespiratory aspects in SCI population.

PURPOSE

The purpose of this study was to investigate the cardiorespiratory response of CPM exercise machines in individuals with spinal cord injury.

METHODS

1. Participants

A total of 22 individuals participated in this study. 11 people with SCI (4 male, 7 female, mean age 40.72 ± 11.76 years) and 11 able-bodied participants (7 male, 4 female, mean age 29.27 ± 11.36 years) were recruited from the Center of Achievement (COA)at California State University, Northridge (CSUN) and surrounding area. Detailed participant's information is summarized in Table 1.

There were two groups in this study; experimental group and control group. 11 individuals with spinal cord injury were assigned to the experimental group and 11 able-bodied individuals were assigned to the control group. Inclusion criteria for the SCI group were individuals with age between 18 and 80, diagnosed as spinal cord injury, minimum of 1 year from the injury, ability to exercise on passive exercise machines for 20 minutes and active arm ergometer exercise machine for 15 minutes. In addition, they had to be able to communicate in English. Exclusion criteria were individuals with recent orthopedic surgery within 6 month, any cardiovascular, pulmonary, metabolic, musculoskeletal, neurological diseases, mental disorder, or sever muscle spasm.

Table 1 Participant Characteristics Information

group	ID	Age	Gender	Weight	Injury Level
Control	1	25	1	71.76	N/A
	2	26	1	86.33	N/A
	3	22	2	58.27	N/A
	4	25	2	80.79	N/A
	5	21	2	110.57	N/A
	6	44	2	45	N/A
	7	27	2	78.3	N/A
	8	25	1	84.33	N/A
	9	24	2	67.67	N/A
	10	23	2	61	N/A
	11	60	1	80.25	N/A
SCI	12	25	1	65.37	T-12
	13	47	1	86	T-11
	14	33	2	64.53	T-11
	15	46	1	66.4	T-9
	16	51	2	67.22	T-11
	17	63	1	109	T-4,5
	18	61	2	65.47	T-7
	19	30	1	76	T-1,4
	20	47	2	65	C-8,T-1
	21	39	1	75.8	T-5,6
	22	19	1	71	T-12

SCI – Spinal Cord Injury, Control – Able-bodied control group

2. Research Variables

The independent variables for this study were modes of CPM exercise which were (i) seated position CPM exercise and (ii) supine position CPM exercise and two different groups (SCI group and able-bodied control group). Dependent variables for the study were cardiorespiratory aspects of participants which are oxygen consumption (VO_2, ml/min/kg), carbon dioxide production (VCO_2, ml/kg/min), minute ventilation (VE, l/min), heart rate (HR, beat/min), and blood pressure (BP, mmHg).

3. Instruments

Two CPM machine moved participants' limbs in seated and supine position while participants were comfortably in position. Flexiciser (Flexiciser Inc.) and CCBPM (Cross-crawl Brain motor Pattern generator Machine) were two CPM exercise machines. Monarc arm ergometer (Monarc Inc. Chicago 2006) ,active arm ergometer, was used in order to obtain estimated maximal oxygen consumption via previously proven submaximal exercise testing. A telemetirc metabolic system (K4b2, CosmedInc., Rome, Italy, 1998) was used to collect the respiratory gas variables during resting and exercise session. BP was monitored by the automatic wrist BP machine (Dinmap Pro 100^{th}, General Electric Inc., USA).

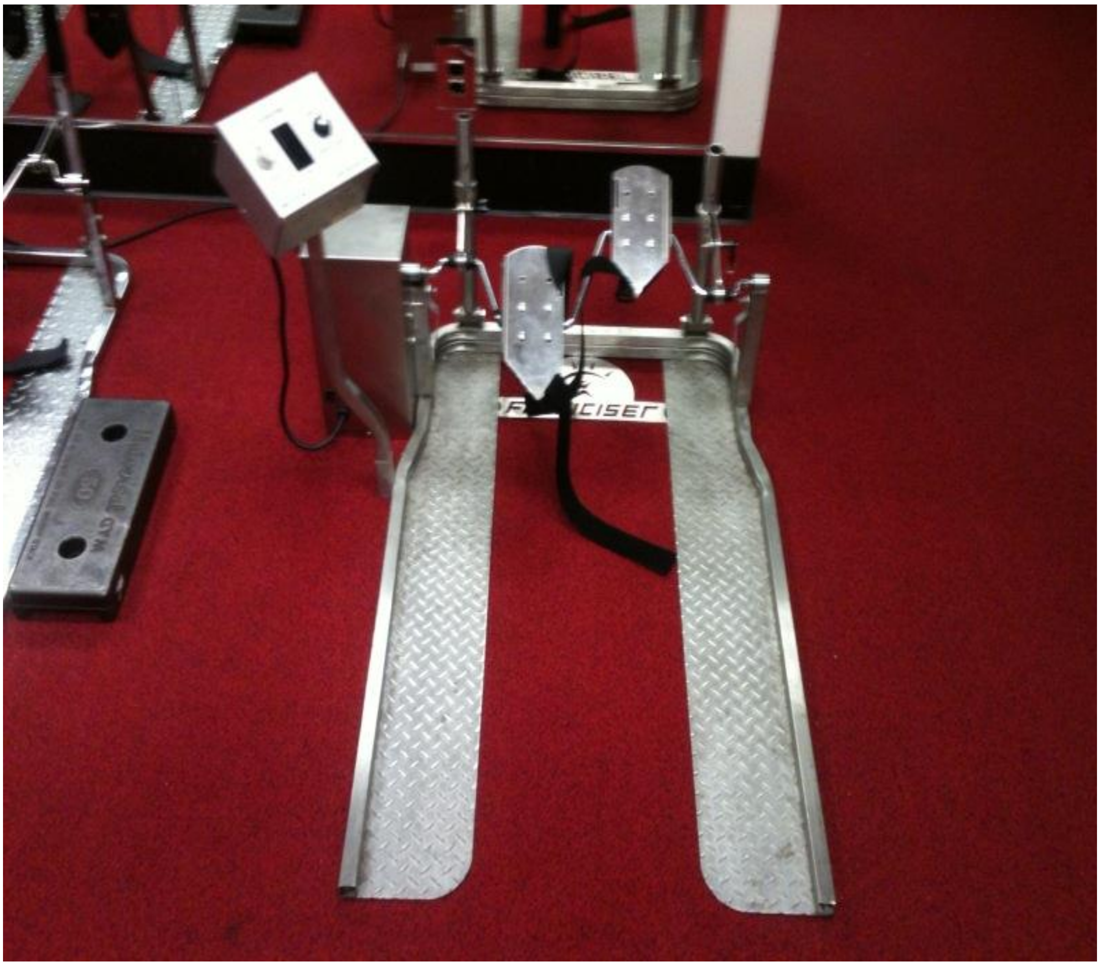

Figure 1. Flexiciser: Seated CPM exercise machine

Figure 2. CCBPM: Supine position CPM exercise machine

Figure 3. Monarc arm ergometer: Active arm cycle exercise machine

Figure 4. Cosmed: Metabolic Cart

4. Research setting

The experimental procedure for data collection took place in the therapeutic exercise room in the Center of Achievement (COA) at California State University Northridge (CSUN). Continuous passive exercises which include a) Flexiciser, b) Cross-crawl Brain Motor Pattern generator Machine (CCBPM) were performed at the therapeutic exercise room in separate occasions in randomly chosen order in order to investigate the cardiorespiratory response of each exercise. Active arm ergometer testing was performed to estimate each participant's maximum oxygen consumption at the same place. Each exercise was performed in different occasion.

5. Experimental Testing Procedures

There were total of 4 visits for each participant. At first visit, participants were asked to complete the informed consent form, and were explained about detailed procedure of research and data collection procedure. After agreeing to participate in the research study, baseline anthropometric data such as height, weight, HR, BP were collected on this day of meeting. Each Participant was asked to perform on each exercise machine including passive exercise machines and active arm ergometer exercise machine in order to perform familiarization session on passive exercise machines and to set an appropriate intensity for active arm ergometer. After setting up the intensity and familiarization session, all the participants received the directions for the study. All the participants were asked to avoid strenuous exercise at least 24 hours prior to each session and avoid caffeinated drink on the day of data collection. On the second, the third and the last visit, when a participant arrived at the COA, anthropometric data were collected. Telemetric metabolic cart was already calibrated before participant's arrival. After anthropometric data collection, participants were placed on either passive or active exercise machines which were selected in randomly chosen order to perform the continuous passive exercise or active arm ergometry exercise at a previously set intensity.

Active arm ergometer submaximal exercise testing was used to estimate maximal oxygen consumption (VO_{2max}) of each participant. Submaximal arm ergometer exercise testing was 6min testing on a constant resistance (Watts) which was set at the preliminary meeting. There were three minutes of warm-up at a lower resistance and five minutes of recovery period. This method was used to estimate VO2max by using Watts and exercise HR during exercise. Followed by three minutes of low intensity warm-up, participants were asked to pedal at rpm between 60 and 70 at a previously set resistance which puts participant's HR between 60 to 80% of their age calculated maximal HR. During the six minutes exercise testing, HR, and RPE were measured every minute. If the HR did not fall into the target range (60-80% of Max HR), the resistance was adjusted accordingly until HR stabilized within the target range for 3 minutes. After the exercise testing, each participant's VO_{2max} was calculated based on average of last three minutes HR and average of six minutes resistance (Watts).

CPM exercise sessions were performed in different days. After participants arrived at COA, same instruction was given for baseline data collection. HR monitor and wrist BP machine were attached to participants to collect the research data. Heart rate was recorded manually and automatically at the baseline, five minutes, ten minutes, 15 minutes and 20 minutes. BP was measured every five minute throughout the exercise. After 20 minute of exercise, recovery data, HR and BP were collected for three minutes. If participants HR and BP did not return to normal range (10 beats/min, 10mmHg), recovery data collection was elongated until they were stabilized. Between the each visit, there were at least 24 hours of wash out period in order to avoid the previous exercise effect on the next exercise data. During this wash out period, participants were asked not to perform any strenuous aerobic exercise. Also, participants were asked to keep their regular diet. Throughout the study, Participants were asked to dress properly with T-shirt and comfortable pants to perform the exercises.

Table 2. Experimental Procedures

Pre-test Preparation	1. Informed Consent and medical release collection 2. Familiarization session and Instructions 3. Equipment preparation 2. Telemetric Metabolic cart Calibration
Participant Preparation	1. Arrival to COA 2. Anthropometric data collection
Data collection for Arm ergometer testing	1. 5 minutes seated resting 2. Attach K4b2, Face mask, HR monitor, Wrist BP monitor on participant in seated position 3. Baseline data collection (HR, BP, Respiratory Gas) 4. 3 minutes warm-up at 25 rpm and 5 watts 5. 6 minutes exercise testing at 60 to 70 rpm and preset resistance 6. Data collection: HR (60 – 80% of HR max), BP and respiratory gas every minute 7. 3 minutes recovery (1 minutes and 3 minutes recovery data collection)
Data collection for CPM exercise session	1. 5 minutes seated resting 2. Attach K4b2, Face mask, HR monitor, Wrist BP monitor on participant in seated position 3. Baseline data collection (HR, BP, Respiratory Gas) 4. 5 minutes warm-up at low intensity 5. 20 minutes of CPM exercise at pre-set rpm (Flex – 45 rpm, CCBPM – 75 rpm) 6. Data collection: HR, BP, RPE, and respiratory gas every 5 minute 7. 3 minutes recovery (1 minutes and 3 minutes recovery data collection)

6. Data Analysis

Collected respiratory gas data and other variables' data were stored in K4b2 unit (Cosmed USA Inc., Chicago, IL). Respiratory gas data were averaged in five minutes intervals and filtered by using Cosmed computer software. All the filtered data were converted to Excel data format for further analysis. Repeated measures multivariate analysis of variance (MANOVA) was used to for difference between CPM exercises. It is also used to analyze the group interaction between SCI group and able-body group. Repeated measure of analysis was used to analyze BP changes throughout the exercise session. Independent T-test was used to analyze the group difference. SPSS 19.0 (SPSS software, version 19, SPSS Inc. Chicago, IL) was the statistical program which was used to analyze all the variables data. Significance level for all the data analysis was set at $P < 0.05$.

7. Human Subjects Institutional Review Board

The study was approved by the Human Subjects Institutional Review Board (IRB) of California State University Northridge. The potential risks to participation in the study were a) Heart attack, b) muscle spasm, c) muscle fatigue, d) sudden heart rate and e) blood pressure changes. In order to avoid these risks, physician's medical clearances were obtained from all the participants prior to the participation. In addition, participants' physical condition was continuously monitored throughout the exercise session by properly trained researchers. There were first aid and CPR/AED certified staff members from Center of Achievement (COA) in order to assist the experimental procedures. In case of an emergency, a procedure to contact the campus emergency and police service was provided. All procedures, risks and benefits of the study were explained to all participants prior to their participation in the study. Inform consent (Appendix A) was obtained from each participant and participants were explained about Will of right.

Results

A total of 11 individuals with SCI and 11 able-bodied individuals completed research study. Among the SCI group, four participants had an injury level above T-6 and seven participants had an injury level below T-6. The summarized participants' profile data are presented in Table 4.

The main hypothesis of the study was looking if the passive exercises increase any of the dependent variables. There were two mixed model 2x2 MANOVAs executed one for each machine. The first factor was the difference between the baseline and the exercise condition (within same group repeated measures), whereas the second factor was the group difference between the control group and the SCI group. The 2x2x2 MANOVA that also included the differences between the two machines did not showed any differences between the machines, so the two simpler MANOVAs are presented here.

The two different CPM exercise modes which are Flexiciser in a seated and CCBPM in a supine exercise mode were performed in separate occasion for both SCI group and control group. Summarized physiology data and information are presented in Table 4.

Flexiciser

The 2x2 mixed model MANOVA statistical analysis showed that there was statistically significant difference in one of the variables with a *Wilk's* λ = .567, an $F_{(4,17)}$ =3.835, *p*=.021. The univariate analysis showed that the difference is explained because there were statistically significant differences on the VO2 and VCO2 variables.

There were statistically significant differences between baseline oxygen consumption (VO2) and exercise oxygen consumption (VO2) during the Flexiciser exercise with an *F* = 13.587, *p*= 0.001 pooling the main effect in both SCI and control groups. There were statistically significant differences between baseline VCO2 and exercise VCO2 during the Flexiciser exercise with an *F* = 16.175, *p*= 0.000 pooling the main effect in both SCI and control groups.

The statistical data analysis for the research variables for the Control group and SCI group are presented in Table 5 and Table 6 respectively. There was a strong trend (p<.10) for minute ventilation (VE) to be different, but not strong enough (p<.05) to be statistical different. There were also a strong trend (p<.10) but not statistical significance (p<.05) for the interaction of the two variables VO2 and VCO2 that were statistically different on the main effect. The main effect baseline to exercise was significantly different for both groups as indicated but the control group contributed more into these differences (both on VO2 and VCO2) see Figures 5 and 6.

There was a statistically significant difference between the two groups on VO2 as a main effect, with an F=5.214, p=.033. Looking the individual t-tests between the two groups on VO2, there was no difference in the baseline (t=.413, p=.684) but there was a statistical difference during the exercise effect (t=2.810, p=.011). In other words, the control group had a significant higher rate of VO2 increase than the SCI group to create such difference, which was also noted by the trend for interaction. When paired t-tests are executed for each group from baseline to exercise, there is no significant difference on VO2 for the control group alone, and there is no significant difference on VO2 on the SCI group alone. However, when both groups are together on the main effect on the VO2 from baseline to exercise within the MANOVA the differences shows significant.

There was no statistically significant difference between the two groups on VCO2 as a main effect but a strong trend, with an F=3.130, p=.092. Looking the individual t-tests between the two groups on VCO2, there was no difference in the baseline (t=.579, p=.569) but there was a statistical difference during the exercise effect (t=2.197, p=.04). In other words, the control group had a significant higher rate of VCO2 production increase than the SCI group to create such difference, which was also noted by the trend for interaction. When paired t-tests are executed for each group from baseline to exercise there is no significant difference on VCO2 for the control group alone, and there is no significant difference on VCO2 on the SCI group alone. However, when both groups are together on the main effect on the VCO2 from baseline to exercise within the MANOVA the differences shows significant.

Individual groups cannot demonstrate statistically that the passive exercises affect the two variables but pooling them together it does on the main effect. The statistical explanation is that the paired t-test include only 11 people per group (10 degrees of freedom); whereas the main effect includes all 22 people in the calculation (20 degrees of freedom), thus increasing the statistical power. So the Flexerciser increased both the VO2 and VCO2 consumption of the whole group with the results suggesting that the control group contributed more into those changes.

CCBPM

The 2x2 mixed model MANOVA statistical analysis showed that there was statistically significant difference in one of the variables with a *Wilk's* λ = .353, an $F_{(4,17)}$ =7.803, *p*=.001. The univariate analysis showed that the difference is explained because there were statistically significant differences on the VO2 and VCO2 variables.

During CCBPM exercise, MANOVA statistical analysis showed that there was statistically significant difference between baseline VO2 and exercise VO2 with an $F = 23.524$, $p = 0.000$. In addition, VCO2 was significantly different from the baseline value with an $F = 19.324$, $p = 0.000$ in both SCI and control groups pooled together in the MANOVA analysis.

There were no interaction effect between the exercise and group effect under the CCBPM machine condition according to the *p*-values. Even looking Figures 7 and 8 clearly the rate of increase of VO2 and VCO2 is parallel in both groups, and also there were no statistical t-test differences between the two groups on each condition. So on both VO2, the two groups were equal during baseline measurements, as well as during exercise condition measurements.

According to statistical analysis, only CCBPM exercise showed statistically significant changes in BP between baseline SBP and certain exercise time points. There was significant SBP difference between baseline SBP and at five minute SBP ($F= 6.200$, $p=0.022$) and 20 minute SBP ($F= 8.079$, $p=0.01$) respectively.

Flexiciser exercise did not alter either systolic or diastolic blood pressure. The summary of mean and standard deviation in systolic BP during Flexiciser condition is presented in Table 10. There was no statistically significant change in HR and VE during CPM exercise.

Table 3. Summary of Participants' information

Group	N	Gender (M/W)	Age	Injury level (AboveT6/Below T6)	Weight (kg)
Control	11	4/7	29.27±11.36	N/A	74.93±15.79
SCI	11	7/4	40.72±11.76	4/7	73.80±12.17

SCI- Spinal Cord Injury group, Control – Able-bodied Control group

Table 4. Means of Cardiorespiratory variables for CONTROL groups in Flexiciser condition

	CONTROL (n=11)	
	FlexicizerBaseline	Flexicizer Exercise
VO2 (ml/kg/min)	3.01±1.02	4.67±1.38
VCO2 (l/min)	198.0±95.7	325.1±112.7
VE(l/min)	8.5±3.6	12.1±3.6
HR (bpm)	76.64±9.47	78.33±9.00

Table 5 . Means of Cardiorespiratory variables for SCI groupsin Flexiciser condition

	SCI (n=11)	
	FlexicizerBaseline	Flexicizer Exercise
VO2 (ml/kg/min)	2.84± 0.96	3.35±0.80
VCO2 (l/min)	178.7±55.0	225.6±99.2
VE(l/min)	9.4±7.3	9.5±3.2
HR (bpm)	76.09±9.77	77.18±11.78

Table 6. MANOVA P values of Flexiciser condition Cardiorespiratory variables for main effect

	SCI+ CONTROL(n=22)		
	FlexicizerBaseline	Flexicizer Exercise	P value
VO2 (ml/kg/min)	2.93± 0.90	**4.02±1.09****	**0.001****
VCO2 (l/min)	188.36±75.35	**275.33±105.95****	**0.001****
VE(l/min)	9.0±5.5	10.8±3.4	0.061
HR (bpm)	76.36±9.62	77.76±10.39	0.235

Significance level *p*=0.05
** Statistically Significant, p <0.05

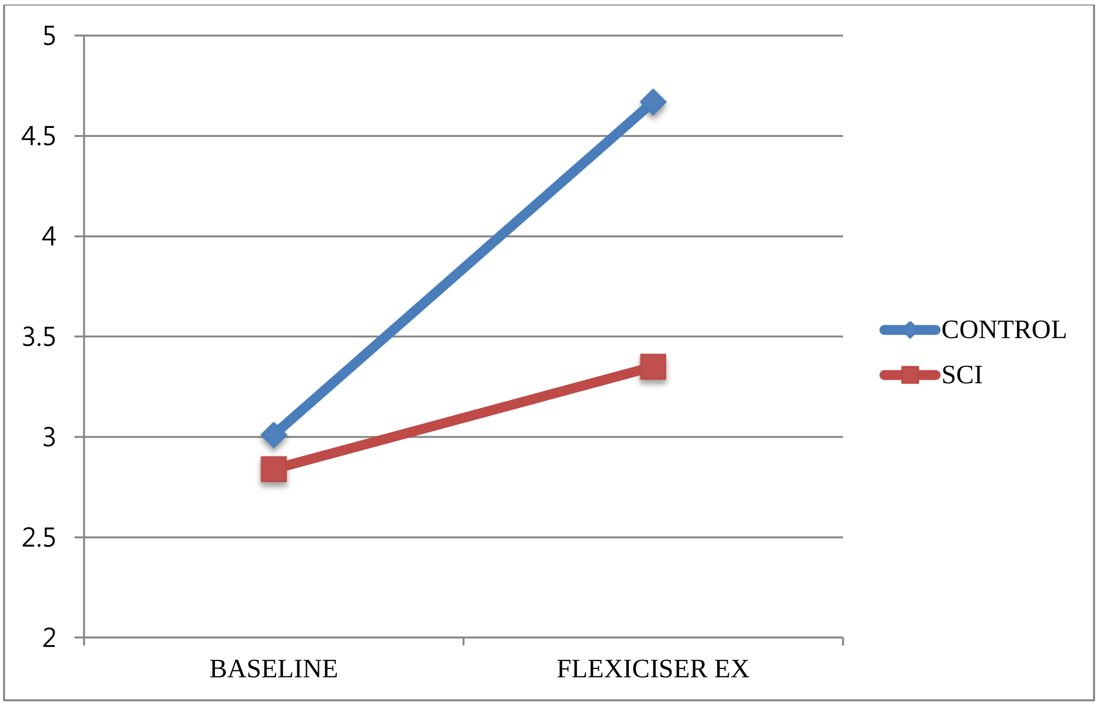

Figure 5.VO2 Comparison of BASELINE and Exercise Conditions using Flexiciser (ml/kg/min)

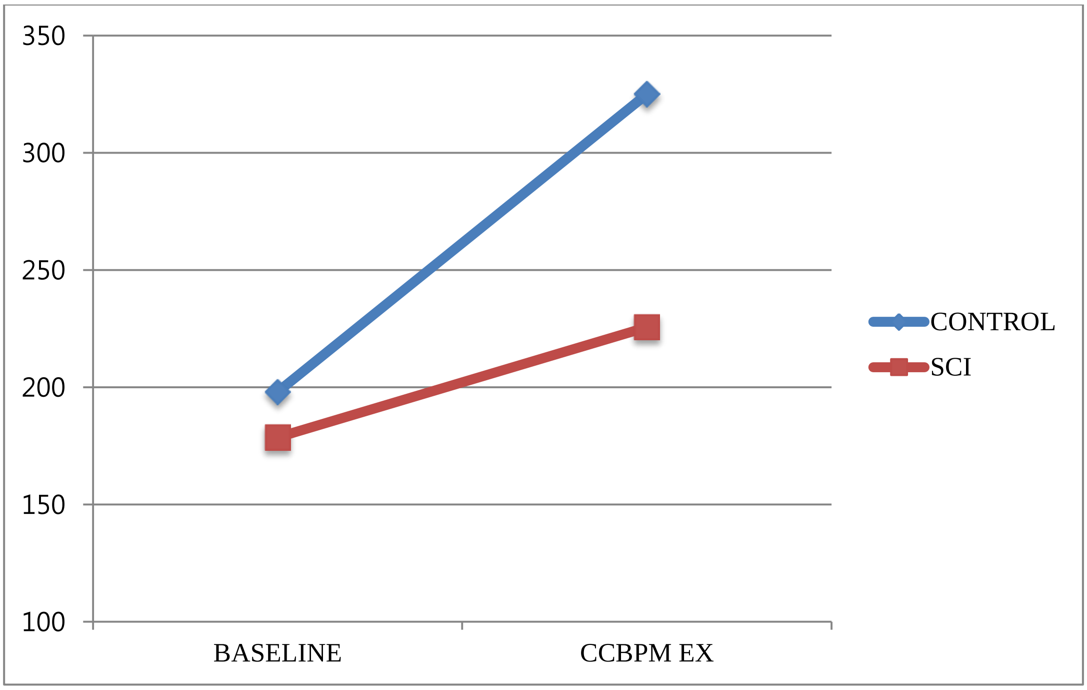

Figure 6. VCO2 Comparison of BASELINE and Exercise condition using Flexiciser (L/min)

Table 7.MANOVA P values of CCBPM condition Cardiorespiratory variables for CONTROL groups

	CONTROL (n=11)	
	CCBPMBaseline	CCBPMExercise
VO2 (ml/kg/min)	3.74±1.43	4.88±1.13
VCO2 (l/min)	256.2±123.5	331.0±114.1
VE(l/min)	9.9±4.1	12.4±3.6
HR (bpm)	81.00±6.93	80.56±11.08

Table 8. MANOVA P values of CCBPM condition Cardiorespiratory variables for SCI groups

	SCI (n=11)	
	CCBPMBaseline	CCBPMExercise
VO2 (ml/kg/min)	2.73±1.01	3.96±1.07
VCO2 (l/min)	184.6±92.9	258.5±110.6
VE(l/min)	7.3±2.9	27.4±30.4
HR (bpm)	78.45±8.97	76.73±10.00

Table 9. Between-Within Comparison of CCBPM condition Cardiorespiratory variables for SCI groups

	SCI+CONTROL (n=22)		
	CCBPMBaseline	CCBPMExercise	P value
VO2 (ml/kg/min)	3.24±1.01	**4.418±1.10****	**0.000****
VCO2 (l/min)	220.4±92.9	**294.7±112.4****	**0.000****
VE(l/min)	8.5±3.5	19.9±57.2	0.203
HR (bpm)	79.73±7.95	78.65±10.54	0.489

Significance level *p*=0.05
** Statistically Significant, p <0.05

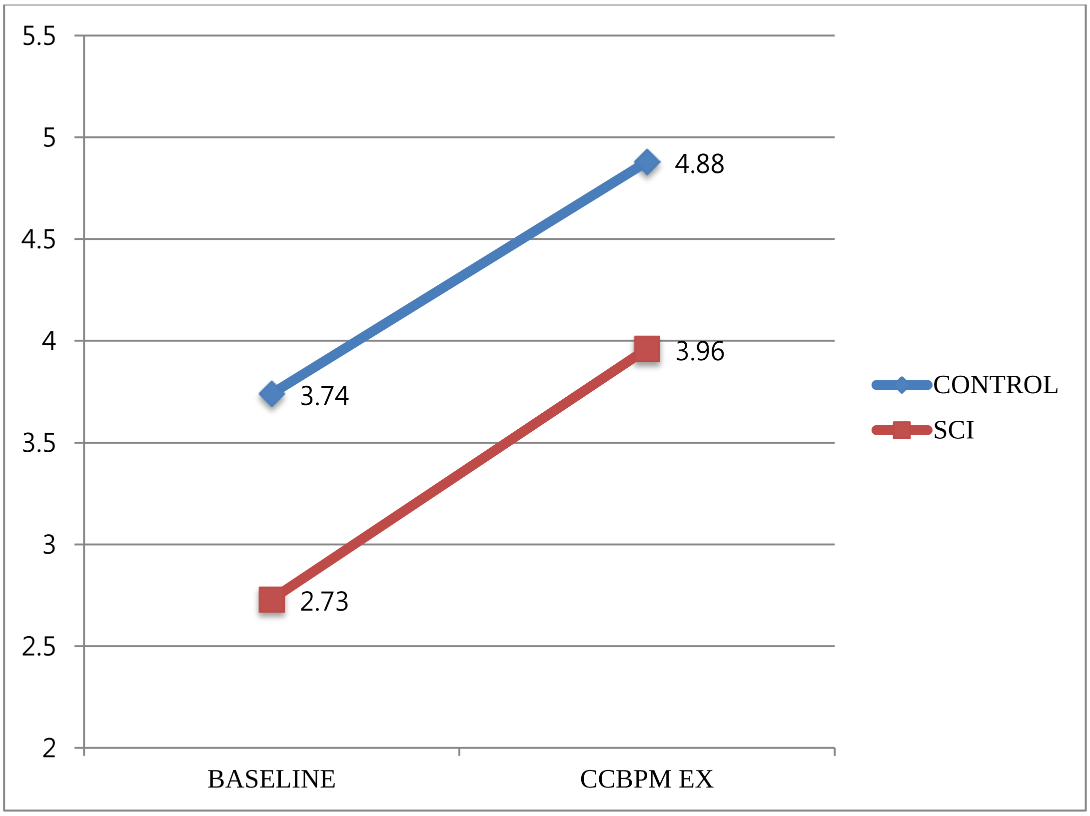

Figure 7.VO2 Comparison of BASELINE and Exercise condition using CCBPM (ml/kg/min)

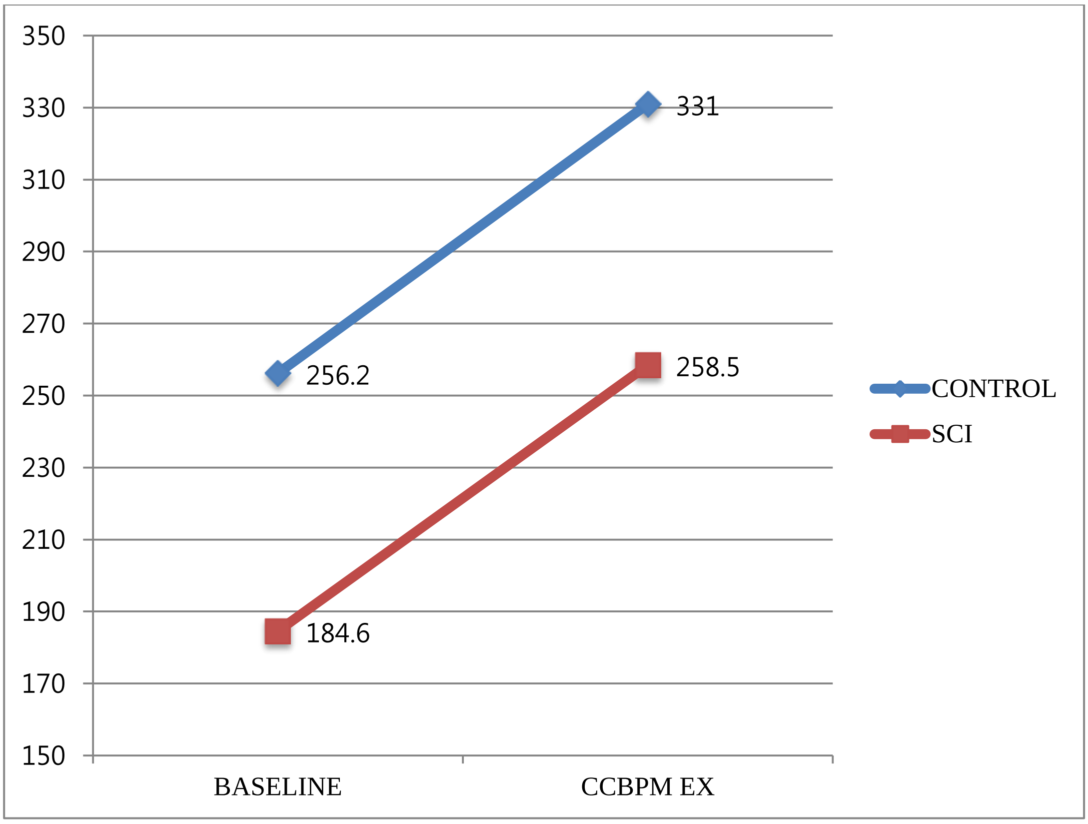

Figure 8.VCO2 Comparison of BASELINE and Exercise condition using CCBPM (L/min)

Discussion

The primary objective of this study was to investigate cardiorespiratory responses to CPM exercise in individuals with SCI. The comparisons were made between baseline condition and CPM exercise condition. There were three hypotheses in this study. The main hypothesis was that the CPM exercise would elicit beneficial changes in cardiorespiratory aspects; HR, BP, VO_2, VCO_2 and VE in SCI group when compared to able-bodied control group. In addition, it was hypothesized that there would be statistically significant group interaction between two groups.

According to the statistical analysis, not all the hypothesis was supported by the study results. Results demonstrated significant increases in VO2, VCO2 when the two groups were combined as a main effect. In addition there were significant changes in BP in certain time points when it was compared to baseline BP. There was no statistically significant change in HR, VE, and BP in certain time points.

Oxygen consumption (VO2) (ml/kg/min)

Statistical analysis showed that there was significant increment during the CPM exercises in SCI group and control group ($p<0.05$). The increment of VO2 could be explained by increased stroke volume followed by higher venous return due to increased muscle movement by passive motion exercise (Muraki et al., 2000; Ogata, Higuchi, et al., 2009). The study results indicated that there were statistically significant changes in VO2 when both SCI group and control group were combined as a main effect. Note that both groups were pooled together by MANOVA to show the difference, but individual groups did not have statistical power to have significance. There was 4.25% increase in VO2 with Flexiciser exercise and 3.03% increase with CCBPM respectively. The changes in VO2 can be due to increased stroke volume and cardiac output which is supported by previous study(Astorino, Tyerman, Wong, & Harness, 2008a). However, the magnitude of increments in VO2 (1.66ml/kg/min for Flexiciser and 1.18ml/kg/min for CCBPM) was small. Therefore, this means that the effect of the passive exercise is statistically significant but small. The cardiorespiratory changes are typically due to the intensity of exercise. Thus, the long term cardiovascular fitness benefits of CPM exercise in people with SCI is questionable, if the exercise is not prolonged.

Carbon dioxide production (VCO2) (L/min)

There was a statistically significant change in VCO2 when both groups were pooled together by MANOVA to show the difference during CPM exercise same as VO2 change. The results supports previous study results (Astorino & Harness, 2009) that showed significant changes in VCO2 after passive leg cycling exercise. The results showed that VCO2 level during CPM exercises changed from 118.36 L/min to 275.33 L/min during Flexiciser exercise and from 220.4 L/min to 294.7 L/min during CCBPM exercise with statistical significance. This results indicated that there was carbon dioxide production while CPM exercise followed by oxygen consumption.

Heart Rate (HR) (beats/min)

There was no statistically significant change in HR during CPM exercises when compared to baseline HR. The study results support the previous studies with passive leg cycling exercise which reported increased cardiac output and stroke volume without increased heart rate (Muraki et al., 2000). However, there are conflicting results that are not supporting the study results (Ballaz et al., 2007; Kawashima et al., 2005; Muraki et al., 2000) which showed statistically significant changes in HR during passive motion exercise. However, there is evidence that indicated that the changes in HR in these studies could be caused by additional stimulation such as FES or resistance on the limbs (Astorino et al., 2008a; Chi et al., 2008).

Blood pressure (BP) (mmHg)

There was no statistical significance in BP during Flexiciser exercises when compared to baseline SBP and DBP. However, there was statistically significant difference in SBP and DBP during each exercise time point when compared to baseline SBP and DBP. However, the changes in BP was caused by positional change from seated position to supine position since the baseline data was collected in seated position and CCBPM exercise is performed in supine position. If the baseline BP data is eliminated for statistical analysis, there is no statistical significance among the exercise time points. This finding is supported by the previous research (Ter Woerds et al., 2006) which found out that passive movement intensity is not enough to create arterial leg blood flow and blood pressure change (Ter Woerds et al., 2006). On the other hand, this result is conflicting to the previous study (Astorino, Tyerman, Wong, & Harness, 2008b) which stated that passive leg exercise increased SBP during exercise. However, this study applied extra resistance to legs while they are performing the passive exercise. This addition resistance may be the stimulating aspect of blood pressure alteration.

Minute ventilation (VE) (l/min)

The results in ventilation in present study were similar to those in other studies (Ogata, Nakahara, et al., 2009; Ogata et al., 2010). These studies suggested that the magnitude of change in VE was related to the magnitude of changes in arterial blood pressure. Since there was no significant BP change found in this study during CPM exercise, the study results are going along with previous study results.

Limitations

There were several limitations that could effect on the study results. The first limitation is the small sample size**.** The sample size in this study was not big enough (SCI n = 11, Control n=11) to generalize the study results. The MANOVA analysis pooled both CONTROL group and SCI group together to show the statistical significance. The bigger sample size is suggested for future research to have greater power.

Secondly, the supporting research methods can be beneficial to investigate the effects of CPM exercise. The study results was unable to confirm if there is physiological benefits during the CPM exercises even though they showed statistically significant changes in VO2 and VCO2. The study results were conflicted with previous researches in terms of other physiological aspects such as HR, BP and VE which indicated statistically significant difference in other studies. Such as EMG activity or vascular activity should be examined with the study variables in order to support the significance of study.

Another limitation for this study was the collection procedure for BP measurement. During CCBPM BP data collection procedure, baseline BP was collected in seated position. However, the CCBPM exercise was supine position exercise. This positional change might alter the SBP and DBP values. The results showed that there was statistical significance between baseline and certain exercise time points. However, if we eliminate the baseline condition, there is no statistical significance in BP. Thus, the detailed study design will be needed for the future study.

Clinical Implications

The study results showed that there was statistically significant cardiorespiratory response during CPM exercises. This is suggesting that CPM exercise can be prescribed as cardiorespiratory exercise for people with SCI. In addition, these results can help clinicians and exercise specialists to prescribe proper exercise to enhance cardiovascular fitness of people with SCI.

Future Research

There was no independent study in CPM exercise on cardiorespiratory aspects of people with SCI. The study results can guide future CPM research study to investigate the in depth cardiorespiratory response in SCI population. In addition, the results of this study suggested that further research in cardiorespiratory response of CPM exercises in people with SCI is needed. Further study can investigate that Cardiorepiratory responses in this study is solely due to the CPM exercise by investigating EMG activity of muscle, vascular activity, and cognitive responses followed by CPM exercises. Furthermore, this study included all the level of SCI (C1- T12) which could cause different cardiorespiratory responses due to the autonomic reflexia. Future research study can be done with specific level of injury.

References

Alabama UO.(2008). Spinal cord injury facts and figures at a glance. *Journal of Spinal Cord Medicine, 31*, 357-358.

Astorino, T. A., & Harness, E. T. (2009). Substrate metabolism during exercise in the spinal cord injured. *Eur J Appl Physiol, 106*(2), 187-193. doi: 10.1007/s00421-009-1005-x

Astorino, T. A., Tyerman, N., Wong, K., & Harness, E. (2008a). Efficacy of a new rehabilitative device for individuals with spinal cord injury. *J Spinal Cord Med, 31*(5), 586-591.

Astorino, T. A., Tyerman, N., Wong, K., & Harness, E. (2008b). Efficacy of a new rehabilitative device for individuals with spinal cord injury. *J Spinal Cord Med, 31*(5), 586-591.

Ballaz, L., Fusco, N., Cretual, A., Langella, B., & Brissot, R. (2007). Acute peripheral blood flow response induced by passive leg cycle exercise in people with spinal cord injury. *Arch Phys Med Rehabil, 88*(4), 471-476.

Barfield, J. P., Malone, L. A., Collins, J. M., & Ruble, S. B. (2005). Disability type influences heart rate response during power wheelchair sport. *Med Sci Sports Exerc, 37*(5), 718-723.

Chi, L., Masani, K., Miyatani, M., Adam Thrasher, T., Wayne Johnston, K., Mardimae, A., . . . Popovic, M. R. (2008). Cardiovascular response to functional electrical stimulation and dynamic tilt table therapy to improve orthostatic tolerance. *J Electromyogr Kinesiol, 18*(6), 900-907. doi: S1050-6411(08)00126-0 [pii] 10.1016/j.jelekin.2008.08.007

Chiu, W. T., Lin, H. C., Lam, C., Chu, S. F., Chiang, Y. H., & Tsai, S. H. (2010). Review paper: epidemiology of traumatic spinal cord injury: comparisons between developed and developing countries. A*sia Pac J Public Health, 22(*1), 9-18. doi: 10.1177/1010539509355470

Coupaud, S. ,Gollee, H. , Hunt, K. , Fraser, M. , Allan, D. , et al. (2008). Arm-cranking exercise assisted by functional electrical stimulation in c6 tetraplegia: A pilot study. *Technol Health Care*, *16*(6), 415-427.

DeVivo, M. J., Go, B. K., & Jackson, A. B. (2002). Overview of the national spinal cord injury statistical center database. J *Spinal Cord Med, 25(*4), 335-338.

Dolbow, D., Miller, J., Hanish, C., Poarch, H., Gorgey, A., et al. (2010). Arm crank exercise increases v[o.sub.2]peak and reduces body fat mass in older adult with chronic paraplegia. *Clinical Kinesiology: Journal of the American Kinesiotherapy Association, 64*(4), 51

Garshick, E., Kelley, A., Cohen, S. A., Garrison, A., Tun, C. G., Gagnon, D., & Brown, R. (2005). A prospective assessment of mortality in chronic spinal cord injury. S*pinal Cord, 43(*7), 408-416. doi: 10.1038/sj.sc.3101729

Groah, S. L., Weitzenkamp, D., Sett, P., Soni, B., & Savic, G. (2001). The relationship between neurological level of injury and symptomatic cardiovascular disease risk in the aging spinal injured. S*pinal Cord, 39(*6), 310-317. doi: 10.1038/sj.sc.3101162

Ho, C. H., Wuermser, L. A., Priebe, M. M., Chiodo, A. E., Scelza, W. M., & Kirshblum, S. C. (2007). Spinal cord injury medicine. 1. Epidemiology and classification. A*rch Phys Med Rehabil, 88(*3 Suppl 1), S49-54. doi: 10.1016/j.apmr.2006.12.001

Israel, J. F., Campbell, D. D., Kahn, J. H., & Hornby, T. G. (2006). Metabolic costs and muscle activity patterns during robotic- and therapist-assisted treadmill walking in individuals with incomplete spinal cord injury. P*hys Ther, 86(*11), 1466-1478. doi: 10.2522/ptj.20050266

Johnston, T. E., Smith, B. T., Mulcahey, M. J., Betz, R. R., & Lauer, R. T. (2009). A randomized controlled trial on the effects of cycling with and without electrical stimulation on cardiorespiratory and vascular health in children with spinal cord injury. A*rch Phys Med Rehabil, 90(*8), 1379-1388. doi: 10.1016/j.apmr.2009.02.018

Kawashima, N., Nakazawa, K., & Akai, M. (2005). Muscle oxygenation of the paralyzed lower limb in spinal cord-injured persons. M*ed Sci Sports Exerc, 37(*6), 915-921.

Krause, J. S., Carter, R. E., Pickelsimer, E. E., & Wilson, D. (2008). A prospective study of health and risk of mortality after spinal cord injury. A*rch Phys Med Rehabil, 89(*8), 1482-1491. doi: 10.1016/j.apmr.2007.11.062

Maynard, F. M., Jr., Bracken, M. B., Creasey, G., Ditunno, J. F., Jr., Donovan, W. H., Ducker, T. B., . . . Young, W. (1997). International Standards for Neurological and Functional Classification of Spinal Cord Injury. American Spinal Injury Association. S*pinal Cord, 35(*5), 266-274.

Muraki, S., Ehara, Y., & Yamasaki, M. (2000). Cardiovascular responses at the onset of passive leg cycle exercise in paraplegics with spinal cord injury. E*ur J Appl Physiol, 81(*4), 271-274. doi: 10.1007/s004210050042

National Clinical FES Centre.(2010). Retrieved from http://www.salisburyfes.com/. 04/18/2011.

Ogata, H., Higuchi, Y., Ogata, T., Hoshikawa, S., Akai, M., & Nakazawa, K. (2009). Pressor response to passive walking-like exercise in spinal cord-injured humans. C*lin Auton Res, 19(*2), 113-

122. doi: 10.1007/s10286-008-0504-x

Ogata, H., Nakahara, M., Sato, T., Hoshikawa, S., Ogata, T., & Nakazawa, K. (2009). Hyperventilation during orthostatic challenge in spinal cord-injured humans. C*lin Auton Res, 19(*6), 327-334. doi: 10.1007/s10286-009-0023-4

Ogata, H., Ogata, T., Hoshikawa, S., Ogawa, T., Uematsu, A., Saitou, S., . . . Nakazawa, K. (2010). Hypoventilation during passive leg movement in spinal cord-injured humans. C*lin Auton Res, 20(*2), 101-103. doi: 10.1007/s10286-009-0042-1

Schneider, D. A., Wing, A. N., & Morris, N. R. (2002). Oxygen uptake and heart rate kinetics during heavy exercise: a comparison between arm cranking and leg cycling. E*ur J Appl Physiol, 88(*1-2), 100-106. doi: 10.1007/s00421-002-0690-5

Suzuki, R., Krahn, G., McCarthy, M., & Adams, E. (2007). Understanding health outcomes: Physical secondary conditions in people with spinal cord injury. *Rehabilitation Psychology*, *52*(3), 338-350.

The National Institute of Neurological Disorder and Stroke.(2010). Retrieved from http://www.ninds.nih.gov/disorders/sci/sci.htm.03/12/2011

Tawashy, A. E., Eng, J. J., Krassioukov, A. V., Miller, W. C., & Sproule, S. (2010). Aerobic exercise during early rehabilitation for cervical spinal cord injury. P*hys Ther, 90(*3), 427-437. doi: 10.2522/ptj.20090023

Ter Woerds, W., De Groot, P. C., van Kuppevelt, D. H., & Hopman, M. T. (2006). Passive leg movements and passive cycling do not alter arterial leg blood flow in subjects with spinal cord injury. P*hys Ther, 86(*5), 636-645.

Thijssen, D. H., Ellenkamp, R., Smits, P., & Hopman, M. T. (2006). Rapid vascular adaptations to training and detraining in persons with spinal cord injury. A*rch Phys Med Rehabil, 87(*4), 474-481. doi: 10.1016/j.apmr.2005.11.005

Valent, L. J., Dallmeijer, A. J., Houdijk, H., Slootman, H. J., Janssen, T. W., Post, M. W., & van der Woude, L. H. (2009). Effects of hand cycle training on physical capacity in individuals with tetraplegia: a clinical trial. P*hys Ther, 89(*10), 1051-1060. doi: ptj.20080340 [pii] 10.2522/ptj.20080340

Valent, L. J., Dallmeijer, A. J., Houdijk, H., Slootman, H. J., Post, M. W., & van der Woude, L. H. (2008). Influence of hand cycling on physical capacity in the rehabilitation of persons with a spinal cord injury: a longitudinal cohort study. Ar*ch Phys Med Rehabil, 89(6*), 1016-1022. doi: 10.1016/j.apmr.2007.10.034

Yarkony, G. M., & Gittler, M. (2002).Spinal cord injury rehabilitation.InLee, B. Y., & Ostrander, E. O. (Eds). The spinal cord injured patient (pp. 358-380). Retrieved from http://books.google.co.kr/books?hl=ko&lr=&id=5nDQEnX9yssC&oi=fnd&pg=PA358&dq=spinal+cord+injury+rehabilitation&ots=zJKcWtXqzy&sig=STnQMu2ZD_8v2uwGNZL753GtXpc#v=onepage&q=spinal%20cord%20injury%20rehabilitation&f=false, 4/06/2011

Appendix A

California State University, Northridge
Cardiorepiratory Response to Continuous Passive Motion Exercise
in People with Spinal Cord Injury

INFORMED CONSENT

Project Title:

You are invited to participate in a study titled “Cardiorepiratory Response to Continuous Passive Motion Exercise in People with Spinal Cord Injury”, conducted by Sang Ouk, Tommy, Wee, a graduate student in the Department of Kinesiology. The study will take place at the Brown Center, California State University Northridge (CSUN) under the supervision of Dr. Konstantinos Vrongistinos

Introduction:

There are about 300,000 spinal cord injuries in the United States by 2007 and $ 9.7 billion dollars was spent to treat the spinal cord injury (SCI) (University of Alabama, 2008). SCI can cause many secondary physical and psychological dysfunctions such as loss of motor function, muscular strength, and depression. These dysfunctions can further limit the physical activity of individuals with SCI. One of the most serious physical dysfunction is the decrease of cardiovascular capacity due to the loss of motor function and muscular strength.

Currently, passive full body exercise machines are widely used in clinical and rehabilitation setting as a cardiovascular exercise mode for individuals with SCI. There are many research studies investigated the effect of passive cardiovascular exercise on individuals with SCI. However, there is no current research study on full body passive exercise on cardiovascular health aspects. Thus, **the purpose of this study is to investigate the effect of full body passive exercise machine on the cardiovascular aspects in population with SCI.**

You are invited to participate in this study if you meet the inclusion criteria a)age between 18 and80 years old, b) diagnosis of Spinal Cord Injury, c) ability to perform 20 min of passive and active exercise, d) ability to communicate in English, e) no recent orthopedic surgery within 6 months, f) no surgery within the past six months, g) no cardiovascular, metabolic, pulmonary, musculoskeletal, neurological, disease, h) no mental disorder, and i) no severe muscle spasm.

Description of Research:

In this study, you will perform 3 different exercises,include arm ergometer, flexicizer, and CCBPM, which will have an emphisis on cardiorespiratory aspect of your fitness. There will be total of 4 visits for this research study. Between the each exercise session, there will be minimum of 2 day of wash out period in order to avoid the previous exercise effect on the next exercise session. You will be assigned to perform all 3 exercise in randomly chosen order.

General Procedures will include 1) baseline data collection.; 2) arm ergometer exercise for predicting VO2max, 3) 2 different 20 min exercise on passive exercise machines on separate date ; 3) post-exercise data collection.

Data collection proceedures

1. You will sign the informed consent form.
2. The testing procedures will be explained to you with a written summary.
3. You will be asked to remove shoes and socks for data collection.
4. Your height and weight will be measured and your age will be documented.
5. Youre blood pressure and heart rate will be recorded in a seatedand supine position after 5 min of resting based on your exercise condition.
6. At the first meeting, you will be asked to try all 3 exercise machines in order to set the target intensity.
7. At the second, thrid and forth meeting, you will be asked to wear a mouth piece, heart rate monitor, and blood pressure machine prior to start the exercise session.

8. You will position or assited to be positioned for the exercise session
9. Resting data which includes blood pressure, heart rate,and respiratory gas will be collected after 5 min quiet resting.
10. After the resting data collection, You will start the exercise session at 50% of you target intensity for warm up for 5 min.
11. After 5 min warm up, you will perform 20 min of exercise session at the preset intensity.
12. Through out the exercise session, blood pressure, heart rate and respiratory gas will be constantly collected.
13. After the 20 min exercise session, recovery data will be collected at 1min and 5 min post exercise in order to check your recovery condition.

The entire data collection will take approximately 1 hour.

Risks:

The study may have potiential for risks including heart attack, muscle spasm, muscle fatigue, and sudden heart rate and blood pressure changes. Physician clearance will be obtained to ensure that partcipants do not have any contraindications for any of the three exercise protocols. In addition, participants' condition and physical condition will be continuously monitored throughout the exercise session by properly trained researchers. There will be first aid and CPR/AED certified staff members from Center of Achievement in order to assist the experimental procedures. If a participants shows any signs or symptoms of abnormality, the procedure will be terminated and follow the first aid procedure to treat the condition of the participants. In case of emergency, emergency services (911) will be contacted and participants will be referred to their primary care physician.

Confidentiality:

Any information and digital photographs collected in this study will remain confidential and will be disclosed only with your written permission or if required by law. The cumulative results of this study will be published, but your name will be replaced by numeric code for confidentiality. All documentation/ data/digital photographs will be secured in a locked file cabinet located in the center's main office up to three years and after three years they will destroyed. Only Sang Ouk, Tommy, Wee, the primary researcher, and Dr. Konstantinos Vrongistinos, research advisor will be allowed to access the data and the digital photographs.

Benefit of participation:

You may not receive any benefit from taking part in this study. However, your participation in this study may help us in better understanding of the effects of passive and active continuous motion exercise on cardiorespiratory outcomes in people with spinal cord injury.

Concerns:

If you wish to express a concern about the research, you may direct your question(s) to Research and Sponsored projects, 18111 Nordhoff Street, California State University, Northridge, CA91330-8232, or phone no. 818-677-2182. With specific questions and concerns about this study, you may contact Dr. Konstantinos Vronginostins, research advisor, at the Department of Kinesiology, 18111 Nordhoff Street, Northridge, CA 91330-8287, or call (818) 677-7567. You will get the copy of the consent form.

Voluntary Participation & Rights:

You should understand that participation in this study is completely volountary and you may withdraw from the study at anytime, for any reason without jeopardy including but limited to any of the following reasons: If you develop any serious side effects, you fail to meet the inclusion criteria for participation in the study, or your physical condition gets worse.

Digital Photographs:

During the course of the data collection, photographs will capture you during balance testing.Your face may or may not be captured. Your initials here_________________ signify your consent to bephotographed. All photographs collected as part of this study will be kept in a locked cabnet, located at the Center of Achievement.I have read the above and understand the conditions outlined for participation in the described study. I have been provided with the copy of this consent form to keep and I give the informed consent of myself to participate in the study.

CONSENT:

Name ____
Last First MI

Sex M F (circle one)
Address____

City________________________State__________Zip_________

Signature____________________________________Date_____

Witness/P.I. signature_____________________________Date____________

If you have signed this form, please return one copy in an envelope by mail to:
Dr. KonstantinosVrongistinos
Department of Kinesiology
California State University, Northridge
18111 Nordhoff Street
Northridge, Ca, 91330 mail box 8287
Or return to: Sang Ouk, Tommy, Wee
Keep a copy of this consent form for your personal records

CALIFORNIA STATE UNIVERSITY, NORTHRIDGE

EXPERIMENTAL SUBJECTS
BILL OF RIGHTS

The rights below are the rights of every person who is asked to be in a research study. As an experimental subject I have the following rights:

1) To be told what the study is trying to find out,

2) To be told what will happen to me and whether any of the procedures, drugs, or devices is different from what would be used in standard practice,

3) To be told about the frequent and/or important risks, side effects or discomforts of the things that will happen to me for research purposes,

4) To be told if I can expect any benefit from participating, and, if so, what the benefit might be,

5) To be told the other choices I have and how they may be better or worse than being in the study,

6) To be allowed to ask any questions concerning the study both before agreeing to be involved and during the course of the study,

7) To be told what sort of medical treatment (if needed) is available if any complications arise,

8) To refuse to participate at all or to change my mind about participation after the study is started. This decision will not affect my right to receive the care I would receive if I were not in the study.

9) To receive a copy of the signed and dated consent form.

10) To be free of pressure when considering whether I wish to agree to be in the study.

If I have other questions I should ask the researcher or the research assistant, or contact Research and Sponsored Projects, California State University, Northridge, 18111 Nordhoff Street, Northridge, CA 91330-8232, or phone (818) 677-2901.

X ____

Signature of Subject Date

APPENDIX B

TABLES AND GRAPHS OF OTHER VARIABLES

Table 10. Descriptive statistics for SBP during Flexiciser exercise

	group	Mean	Std. Deviation	N
FLEXbaselineSBP	0	117.80	15.761	10
	1	114.09	13.232	11
	Total	115.86	14.245	21
flexSWarmSBP	0	111.70	15.326	10
	1	112.91	12.357	11
	Total	112.33	13.507	21
flex5minSBP	0	109.30	13.166	10
	1	119.27	13.260	11
	Total	114.52	13.855	21
flex10minSBP	0	111.70	14.553	10
	1	120.18	16.123	11
	Total	116.14	15.625	21
flex15minSBP	0	111.00	13.679	10
	1	116.82	10.255	11
	Total	114.05	12.068	21
flex20minSBP	0	111.90	16.428	10
	1	121.27	11.909	11
	Total	116.81	14.675	21
flex1minReSBP	0	110.30	17.095	10
	1	115.91	8.837	11
	Total	113.24	13.371	21
flex5minReSBP	0	113.50	14.714	10
	1	113.73	5.746	11
	Total	113.62	10.675	21

Group 0 – Control group, Group 1 – SCI group

Table 11. Comparisons for SBP during Flexiciser exercise

SBP	df	Mean Square	F	Sig.
Baseline vs. warm-up	1	277.749	2.479	.132
Baseline vs. 5 min	1	57.673	.315	.581
Baseline vs. 10 min	1	.000	.000	.999
Baseline vs. 15 min	1	86.885	.611	.444
Baseline vs. 20 min	1	8.606	.079	.782
Baseline vs. 1 min rec	1	169.102	1.420	.248
Baseline vs. 5 min rec	1	113.926	.940	.344

Table 12. Descriptive statistics for DBP during Flexiciser exercise

	group	Mean	Std. Deviation	N
FLEXbaselineDBP	0	70.64	12.933	11
	1	70.73	9.880	11
	Total	70.68	11.231	22
FLEXWarmDBP	0	67.00	14.422	11
	1	67.45	7.019	11
	Total	67.23	11.071	22
FLEX10minDBP	0	67.45	14.215	11
	1	70.55	8.454	11
	Total	69.00	11.522	22
FLEX15minDBP	0	67.27	12.354	11
	1	74.09	10.922	11
	Total	70.68	11.902	22
FLEX20minDBP	0	69.36	12.524	11
	1	70.82	9.590	11
	Total	70.09	10.910	22
FLEX1minReDBP	0	67.18	13.963	11
	1	72.27	5.798	11
	Total	69.73	10.753	22
FLEX5minReDBP	0	70.82	12.172	11
	1	73.09	5.029	11
	Total	71.95	9.162	22

Group 0 – Control group, Group 1 – SCI group

Table 13. Descriptive statistics for SBP during CCBPM exercise

	group	Mean	Std. Deviation	N
CCBPMbaseline SBP	0	109.27	14.616	11
	1	107.73	15.831	11
	Total	108.50	14.889	22
CCBPM5minSBP	0	102.55	13.374	11
	1	100.36	12.940	11
	Total	101.45	12.890	22
CCBPM10minSBP	0	102.09	11.467	11
	1	105.27	14.451	11
	Total	103.68	12.834	22
CCBPM15minSBP	0	106.55	15.546	11
	1	104.36	14.514	11
	Total	105.45	14.719	22
CCBPM20minSBP	0	99.64	12.556	11
	1	100.18	7.782	11
	Total	99.91	10.198	22
CCBPM1minReSBP	0	103.82	13.144	11
	1	102.09	10.616	11
	Total	102.95	11.692	22
CCBPM5minReSBP	0	97.00	8.888	11
	1	101.36	8.958	11
	Total	99.18	8.990	22

Group 0 – Control group, Group 1 – SCI group

Table 14. Comparisons for SBP during CCBPM exercise

SBP	df	Mean Square	F	Sig.
Baseline vs. 5 min	1	1092.045	6.200	.022
Baseline vs. 10 min	1	510.727	2.292	.146
Baseline vs. 15 min	1	204.045	1.560	.226
Baseline vs. 20 min	1	1623.682	8.079	.010
Baseline vs. 1 min rec	1	676.545	4.159	.055
Baseline vs. 5 min rec	1	1910.227	13.027	.002

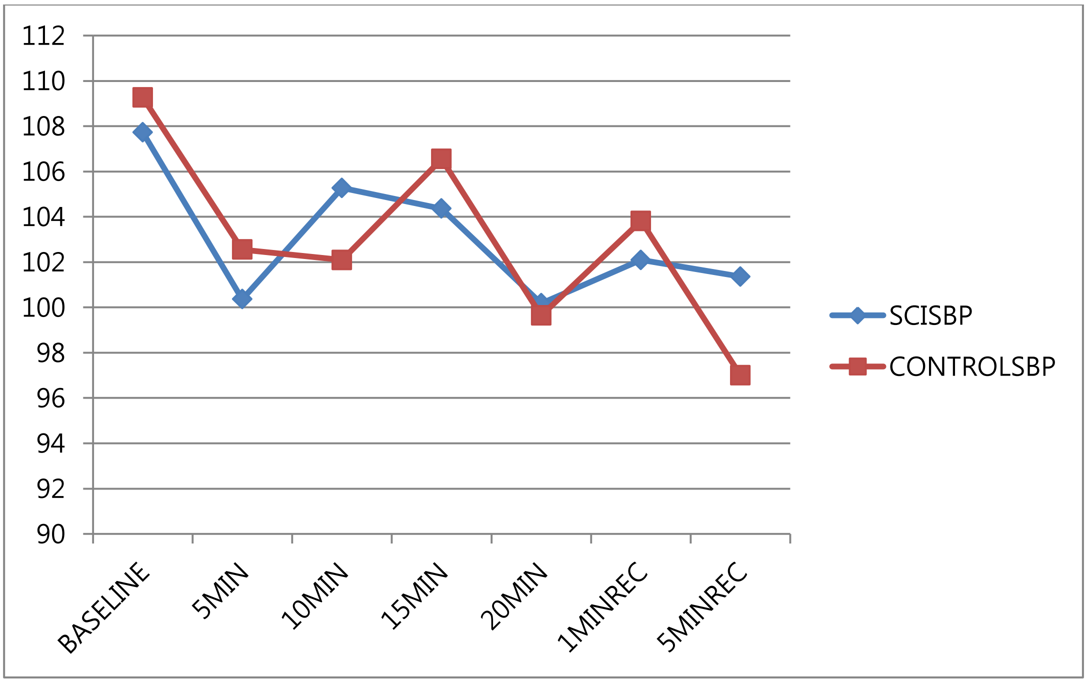

Figure 9. CCBPM SBP changes

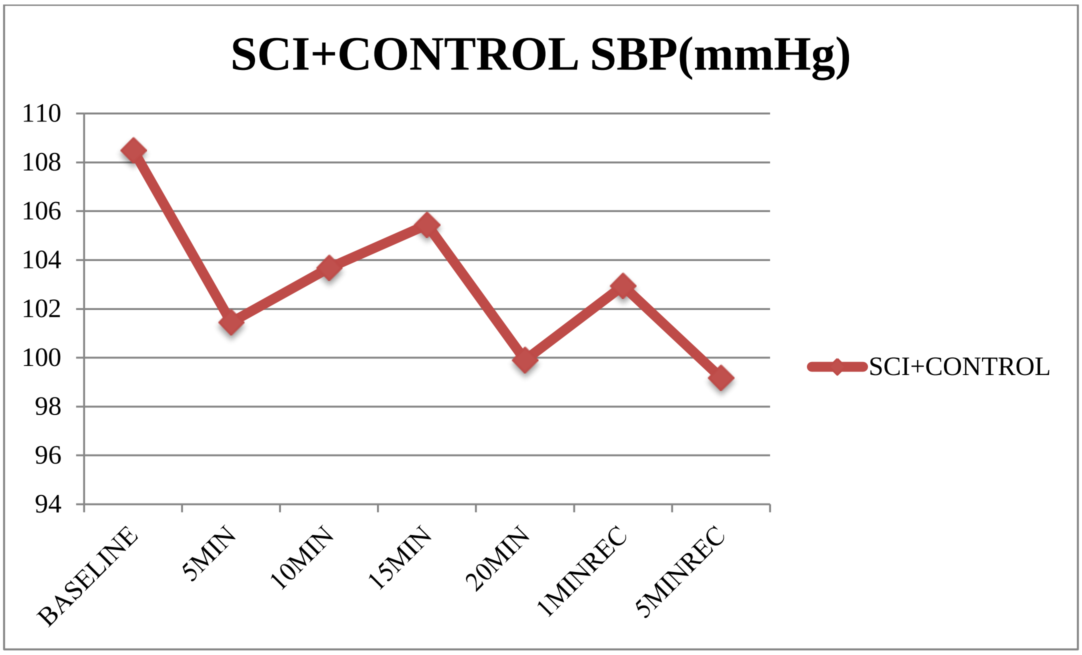

Figure 10. SCI + Control group CCBPM SBP changes

Table 15. Descriptive statistics for DBP during CCBPM exercise

	group	Mean	Std. Deviation	N
CCBPMbaseline DBP	0	66.18	13.519	11
	1	67.82	13.303	11
	Total	67.00	13.115	22
CCBPM5minDBP	0	60.27	11.385	11
	1	57.82	8.316	11
	Total	59.05	9.810	22
CCBPM10minDBP	0	58.64	13.109	11
	1	58.55	10.903	11
	Total	58.59	11.766	22
CCBPM15minDBP	0	60.73	10.928	11
	1	61.18	10.088	11
	Total	60.95	10.265	22
CCBPM20minDBP	0	58.64	9.014	11
	1	60.82	8.565	11
	Total	59.73	8.653	22
CCBPM1minReDBP	0	59.64	12.176	11
	1	58.00	8.473	11
	Total	58.82	10.271	22
CCBPM5minReDBP	0	56.73	8.320	11
	1	58.36	5.608	11
	Total	57.55	6.974	22

Group 0 – Control group, Group 1 – SCI group

Table 16. Comparisons for DBP during CCBPM exercise

SBP	df	Mean Square	F	Sig.
Baseline vs. 5 min	1	1392.045	10.143	.005
Baseline vs. 10 min	1	1555.682	10.587	.004
Baseline vs. 15 min	1	804.045	6.254	.021
Baseline vs. 20 min	1	1163.636	5.572	.029
Baseline vs. 1 min rec	1	1472.727	8.190	.010
Baseline vs. 5 min rec	1	1966.545	15.549	.001

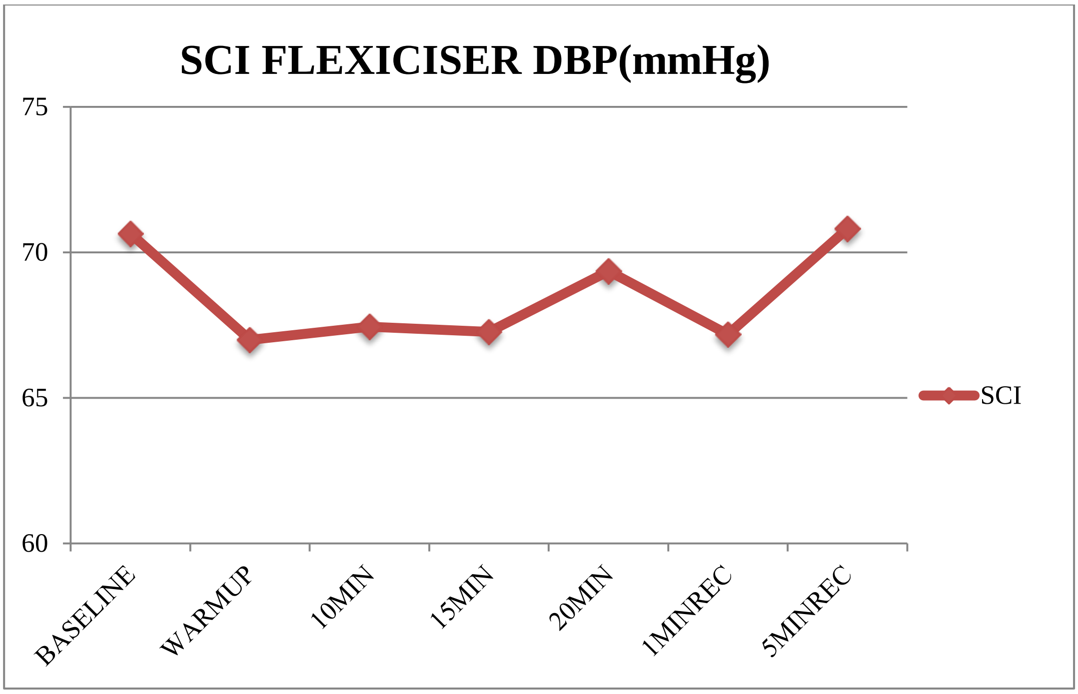

Figure 11. SCI group Flexiciser DBP changes

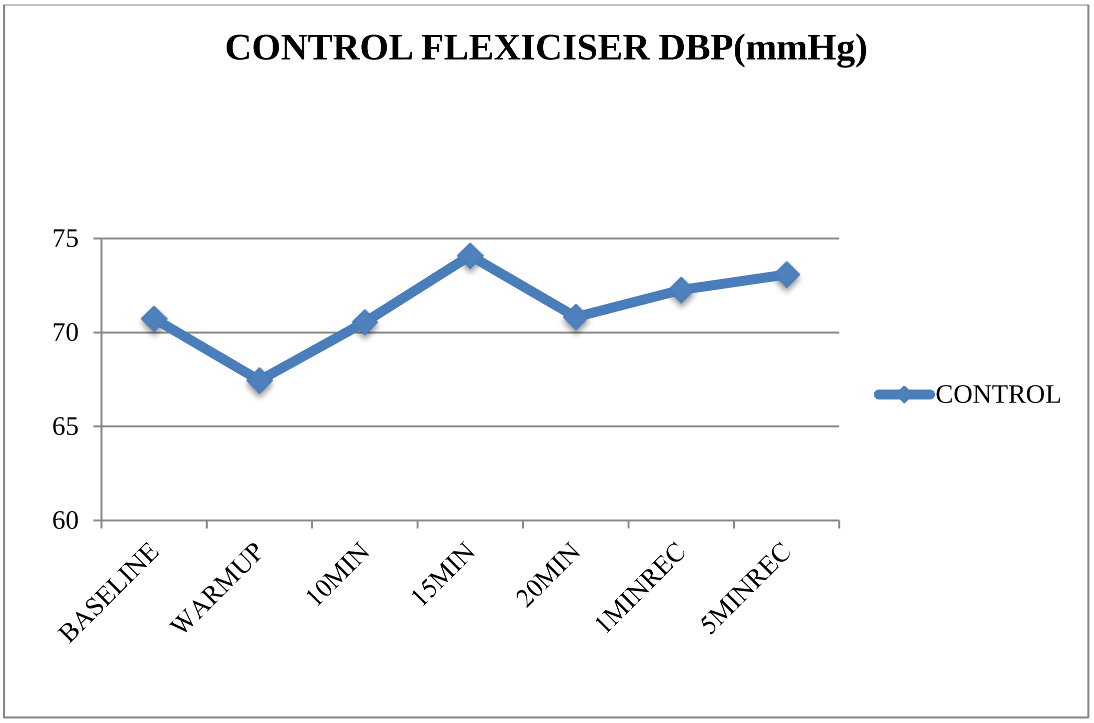

Figure 12. Control group Flexiciser DBP changes

APPENDIX C

RAW DATA SPSS

VO2 – Oxygen consumption
VCO2 – Carbon Dioxide production
HR – Heart Rate
VE – Minute Ventilation
SBP – Systolic Blood Pressure
DBP – Diastolic Blood Pressure
FLEX – Flexiciser
Rec - Recovery
S – Subject
G-Group

MANOVA VO2 changes in SCI group and CONTROL group

subject	group	FLEXbaselineVo2	FLEXVo2	CCBPMBASELINEVO2	CCBPMVO2
1	1	3.07584079	3.089503	4.751056082	5.629429
2	1	3.308166	3.55396	4.34239055	5.198435
3	1	2.327844976	3.005549	1.653352971	3.142725
4	1	1.119755344	1.876748	2.968529769	2.528867
5	1	2.3238566	4.024314	2.168022612	3.609314
6	1	3.340967194	2.567611	2.276505239	3.666058
7	1	3.91664383	4.77952	2.462478879	5.103204
8	1	2.702709496	2.991972	1.710532724	3.182399
9	1	3.45418463	3.574976	2.717223186	3.466465
10	1	3.964571684	3.229216	1.934980334	2.995629
11	1	1.727711219	4.136857	3.052032541	5.013052
12	0	4.939113846	4.548815	2.566950837	4.613425
13	0	3.86500419	5.09637	5.657801506	7.451857
14	0	1.530417338	3.971462	5.19233824	4.894784
15	0	3.133229107	4.41515	3.977779823	5.167212
16	0	2.645045228	3.412727	5.473676039	4.639171
17	0	4.381403254	4.506343	4.62460508	3.859506
18	0	2.921891432	3.061611	3.004185127	3.549099
19	0	2.809947611	4.599475	2.980002932	3.62212
20	0	2.037009306	3.763503	2.080928855	4.944951
21	0	2.27417845	6.473827	1.392563155	4.782867
22	0	2.586718357	7.850223	4.17113556	6.127098

Group 0 – Control group, Group 1 – SCI group

MANOVA VCO2 changes in SCI group and CONTROL group

subject	group	Flexbaseline VCO2	FlexVCO2	CCBPMBASELINE VCO2	CCBPMVCO2
1	1	189.371	187.0323	250.5524	250.5524
2	1	261.9604	289.0709	371.5493	435.3582
3	1	127.9782	159.8624	78.63782	171.3687
4	1	89.47442	141.1318	234.5139	157.6415
5	1	224.3664	432.4933	191.6811	382.3452
6	1	126.8198	95.11861	67.38828	133.8282
7	1	247.2738	315.3894	247.2738	369.3746
8	1	195.9908	203.4489	117.7658	230.214
9	1	189.7	193.725	150.5265	183.5212
10	1	186.4787	154.7749	94.41115	155.9874
11	1	126.6433	309.53	226.3813	372.9504
12	0	245.6566	314.3566	118.5327	253.8681
13	0	307.1127	378.1374	481.5004	626.875
14	0	96.96723	245.7613	394.2166	319.1412
15	0	173.5752	306.7217	308.9251	367.7377
16	0	128.173	213.6998	231.3104	241.9514
17	0	425.2459	415.3295	368.9781	361.4473
18	0	163.6945	182.5364	175.448	211.0074
19	0	188.8142	292.9654	217.1165	251.3462
20	0	124.7994	218.5734	149.2651	315.2925
21	0	183.3943	492.4018	90.42364	296.8962
22	0	140.5154	515.278	282.2184	395.3049

Group 0 – Control group, Group 1 – SCI group

MANOVA Heart Rate (HR) changes in SCI group and CONTROL group

subject	group	FlexbaselineHR	FlexHR	CCBPMBaselineHR	CCBPMHR
1	1	68	79	85	80
2	1	86	87	93	84
3	1	96	95	83	79
4	1	73	64	70	68
5	1	81	93	69	80
6	1	72	69.8	75	69.6
7	1	73	73.6	70	75.2
8	1	73	76.2	80	75.4
9	1	65	62.8	73	64.4
10	1	65	63	72	68
11	1	85	85.6	93	100.4
12	0	87	88	76	74
13	0	72	79	79	86
14	0	68	66	80	81
15	0	76	79	84	102
16	0	77	72.8	80	79.4
17	0	82	79.6	88	84.4
18	0	82	83.8	98	95.6
19	0	72	72	77	66.8
20	0	71	70.8	74	66.2
21	0	95	97.6	80	73.8
22	0	61	73	75	77

Group 0 – Control group, Group 1 – SCI group

MANOVA Minute Ventilation (VE) changes in SCI group and CONTROL group

subject	group	FlexBaseline VE	FlexVE	CCBPMBaselineVE	CCBPMVE
1	1	10.30225	9.416784	10.44747	10.31069
2	1	30.53731	16.2409	13.42923	16.97164
3	1	6.910816	7.58559	4.775695	8.200898
4	1	4.158941	5.802285	8.170097	199.7805
5	1	6.863973	12.8505	6.902936	11.21204
6	1	6.332873	5.381632	5.628723	7.333777
7	1	9.785324	10.64377	9.785324	11.26688
8	1	9.398088	9.650865	4.936302	9.480279
9	1	8.644775	9.052295	3.956433	7.805039
10	1	6.394696	6.961574	4.954592	6.576557
11	1	4.256811	10.76255	7.111968	12.3549
12	0	9.060778	11.78705	7.99799	8.946225
13	0	9.462874	14.85718	18.05542	21.45733
14	0	6.766893	11.54416	14.69684	14.18094
15	0	9.075279	11.30935	8.192915	10.77309
16	0	6.323679	8.757063	9.948038	10.28351
17	0	18.70432	19.02497	13.331	14.98361
18	0	6.702904	7.402918	7.524798	9.276641
19	0	6.745764	9.92567	8.273965	9.276641
20	0	6.985469	8.902226	3.827574	12.10996
21	0	8.343693	13.21092	6.217524	11.26282
22	0	5.528594	16.69248	10.3251	13.30052

Group 0 – Control group, Group 1 – SCI group

Repeated Measure for SBP during Flexiciser

S	G	FLEX baseline SBP	FLEX Warm-up SBP	FLEX 5min SBP	FLEX 10min SBP	FLEX 15min SBP	FLEX 20min SBP	FLEX 1min RecSBP	FLEX 5min RecSBP
1	1	137	130	134	154	120	120	118	117
2	1	102	97	110	103	114	110	104	110
3	1	100	101	108	111	110	106	105	112
4	1	101	103	102	107	105	107	104	111
5	1	117	110	127	115	114	122	122	109
6	1	110	130	145	147	134	146	132	127
7	1	127	116	121	122	126	131	119	119
8	1	117	114	119	109	115	119	117	108
9	1	107	127	128	115	130	124	121	108
10	1	104	98	106	120	100	117	112	115
11	1	133	116	112	119	117	132	121	115
12	0	134	134	.	117	129	126	124	124
13	0	105	113	115	110	113	109	111	115
14	0	97	93	98	97	96	89	92	99
15	0	115	102	101	103	113	111	106	110
16	0	113	95	99	95	94	102	101	104
17	0	145	133	128	136	130	138	143	141
18	0	97	92	95	95	93	90	88	91
19	0	126	115	94	115	105	105	96	105
20	0	121	124	125	113	115	121	124	124
21	0	136	121	120	129	124	132	122	125
22	0	123	129	118	124	127	122	120	121

Group 0 – Control group, Group 1 – SCI group

Repeated Measure for DBP during Flexiciser

S	G	FLEX baseline DBP	FLEX Warm-up DBP	FLEX 5min DBP	FLEX 10min DBP	FLEX 15min DBP	FLEX 20min DBP	FLEX 1min RecDBP	FLEX 5min RecDBP
1	1	82	70	87	86	76	76	75	71
2	1	61	63	67	69	72	68	67	67
3	1	61	67	70	73	61	63	68	70
4	1	62	57	63	65	64	47	64	67
5	1	68	67	72	72	63	73	68	72
6	1	61	75	83	72	68	76	69	75
7	1	80	71	74	77	77	76	74	84
8	1	82	76	81	72	82	75	75	71
9	1	73	75	73	51	93	75	80	74
10	1	63	55	58	68	68	67	72	74
11	1	85	66	68	71	91	83	83	79
12	0	78	78	.	62	81	69	76	84
13	0	56	65	69	84	66	71	70	70
14	0	54	49	56	46	49	47	53	51
15	0	53	52	58	57	60	65	62	64
16	0	72	58	59	54	59	69	63	72
17	0	91	85	93	87	82	89	83	91
18	0	60	51	55	57	52	54	54	56
19	0	80	57	56	60	58	60	40	60
20	0	73	74	79	72	74	77	77	75
21	0	83	81	76	80	80	83	79	79
22	0	77	87	74	83	79	79	82	77

Group 0 – Control group, Group 1 – SCI group

Repeated Measure for SBP during CCBPM

S	G	CCBPM Baseline SBP	CCBPM WARM-UP SBP	CCBPM 5min SBP	CCBPM 10min SBP	CCBPM 15min SBP	CCBPM 20min SBP	CCBPM 1min RecSBP	CCBPM 5min RecSBP
1	1	108	108	114	127	124	107	106	103
2	1	109	84	91	93	99	90	100	96
3	1	118	103	100	100	99	102	105	100
4	1	97	94	98	87	90	104	94	97
5	1	109	92	97	90	99	90	95	106
6	1	119	126	124	134	135	101	127	122
7	1	117	110	110	109	107	110	103	100
8	1	134	104	91	106	107	106	105	100
9	1	110	106	108	105	109	108	107	108
10	1	77	89	77	107	87	94	85	86
11	1	87	123	94	100	92	90	96	97
12	0	114	.	105	106	105	96	101	94
13	0	88	84	84	83	77	81	91	83
14	0	93	92	95	96	96	100	106	98
15	0	121	94	96	100	123	89	91	94
16	0	93	88	90	94	91	89	86	83
17	0	130	99	106	111	120	104	113	102
18	0	97	94	96	86	92	95	93	93
19	0	113	124	129	120	125	127	131	100
20	0	107	104	95	108	115	104	108	109
21	0	126	124	118	106	113	98	113	110
22	0	120	98	114	113	115	113	109	101

Group 0 – Control group, Group 1 – SCI group

Repeated Measure for DBP during CCBPM

S	G	CCBPM Baseline DBP	CCBPM WARM-UP DBP	CCBPM 5min DBP	CCBPM 10min DBP	CCBPM 15min DBP	CCBPM 20min DBP	CCBPM 1min RecDBP	CCBPM 5min RecDBP
1	1	74	62	76	81	72	70	66	66
2	1	73	58	46	62	49	64	55	58
3	1	67	55	63	53	52	59	51	60
4	1	59	52	55	48	52	64	55	56
5	1	64	43	55	41	55	48	42	53
6	1	71	64	63	72	81	73	68	61
7	1	78	60	62	57	63	56	55	53
8	1	92	67	55	59	67	46	64	65
9	1	73	57	59	61	64	65	62	64
10	1	42	54	47	53	52	57	51	48
11	1	53	91	55	57	66	67	69	58
12	0	75	.	56	61	61	56	56	55
13	0	43	44	46	42	40	42	48	42
14	0	54	51	50	44	49	53	56	59
15	0	73	49	53	51	69	49	42	50
16	0	53	52	57	50	55	55	50	49
17	0	76	60	73	64	71	67	65	57
18	0	54	58	50	49	56	58	57	55
19	0	67	80	81	84	79	74	82	74
20	0	67	60	57	62	57	62	62	62
21	0	87	71	72	76	67	66	79	62
22	0	79	65	68	62	64	63	59	59

Group 0 – Control group, Group 1 – SCI group