EVALUATING THE IMPACT OF EXERGAMING ON THE EXERCISE BEHAVIOR OF PERSONS WITH SPINAL CORD INJURIES

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Individuals with spinal cord injuries (SCI) are at increased risk for cardiopulmonary and cardiovascular disease. The GameCycle^{TM} exercise system integrates arm-ergometry and video gaming with the goal of providing a fun and motivational exercise platform. For this thesis research, two studies were conducted to evaluate the design of the GameCycle^{TM} and its efficacy as an exercise platform.

The objective of the first study was to teach subjects how to safely and effectively use the GameCycle^{TM}, to determine if subjects are able to learn how to operate the GameCycle^{TM} in an acceptable time period, to learn whether they are able to reach their target heart rate zone using the GameCycle^{TM}, and to obtain feedback from new users regarding features of the new system. Participants included 14 subjects with SCI (11 men and 3 women, 37.5 +/- 6.5 years). Subjects were trained to use the GameCycle^{TM} and were required to complete a timed demonstration. Metabolic data were collected over a 14 minute exercise bout while playing the GameCycle^{TM}. All subjects were able to complete training successfully and 12 (86%) of the subjects were able to reach their target heart rate zones. All of the participants conveyed that the GameCycle^{TM} was easy to learn, operate, and has easily adjustable settings to suit their needs. 86% of participants found the GameCycle^{TM} to be enjoyable and that it was likely motivate

manual wheelchair users to exercise regularly. This study indicates that the GameCycle™ is easy to use and confirms previous findings that aerobic training zones can be reached.

The goal of the In-home Phase was to evaluate the effectiveness of the GameCycle™ as compared to standard ergometry. Nine persons with SCI (1 woman, 8 men, 36.2 +/- 5.5 years) completed a four-month in-home trial in which they were asked to exercise with the GameCycle™ for two months and a standard arm-ergometer for two months. Results indicate that subjects exercised for significantly longer durations ($p=0.035$) with the GameCycle™. This suggests that the GameCycle™ is more enjoyable and will increase exercise dosage for long-term exercise compared to standard arm-ergometry.

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PREFACE

I would like to thank my thesis committee, Dr. Rory Cooper, Dr. Shirley Fitzgerald, and Dr. Rakie Cham for all of their support throughout the project and my time at the Human Engineering Research Laboratories (HERL). I'm especially thankful to Dr. Cooper for providing me with many challenging and unique opportunities and Dr. Fitzgerald for being such an inspiring and supportive mentor. Additionally, I would like to thank all the students and staff at HERL who have helped me especially Erin Mishey, Garrett Grindle, Karl Brown, Emily Zipfel, Sara Sibenaller, Michelle Sporner, Harshal Mahajan, and Ana Souza. I would also like to thank all of the participants, who have helped me learn more than they could possibly ever know.

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1.0 INTRODUCTION

There are a number of studies that have investigated the impact of various interventions on physical activity practices in the able bodied population. Interventions range from physical activity programs (e.g., programs situated in the work place or community), internet and web-based interventions (e.g., email reminders for healthy practices), and mail based interventions. However, there are limited interventions and research studies geared toward persons with disabilities. With nearly 49 million Americans with disabilities in the United States and the fact that cardiovascular diseases is the leading cause of death in this population, research concerning ways to increase physical activity is sorely needed.

Recent developments in video gaming technology have brought about products that combine video gaming and physical activity, which are being referred to as "exergaming".[1] The most well known exergame is perhaps Dance Dance Revolution, in which players dance on a pad with a three by three matrix of switches and coordinate their steps to the arrows shown on the video screen.[2] By dancing through each level, the player is able to progress through stages of increased difficulty. Companies are marketing these technologies as a fun way to participate in physical activity.

Examples of exergaming technology specifically developed for wheelchair users include GameWheels and the GameCycle^{TM}. The goal of the research efforts behind these devices is to increase the quality of life of individuals with lower extremity impairments, specifically wheelchair users, by improving overall physical activity levels. GameWheels is an interface between a personal computer and a roller system that allows a person to propel a manual wheelchair while controlling a video game. O'Conner, et. al have shown that an exercise training effect can be reached when exercising while engaged in a racing game, that with the video game component of the GameWheels participants are able to elicit a significantly ($p<0.05$) greater average ventilation rate and average oxygen consumption, and documented wheelchair user interest in such a device. [3-5] Participants felt that "playing a video game while exercising may help motivate manual wheelchair users to exercise longer and regularly."[5]

The GameCycle™ is an arm-ergometer that allows people to play video games by cranking the ergometer forward and backward, steering left and right, and using buttons and menus located on the top of the machine. [6] The resistance level of the GameCycle™ is controlled by a magnetic break that the user can set to a resistance of zero (0 N*m) through nine (7.91 N*m), incrementing by 0.88 N*m for every resistance level.

One of the first studies of the GameCycle™ compared exercising with the GameCycle™ to exercising with an arm ergometer and showed that subjects could reach target training zones and that they had significantly higher VO2 values when using the GameCycle™.[7] Guo, et. al, continued with further developing the exercise system and improving the functionality of the system.[8] The results of the focus group of wheelchair users and clinicians held to evaluate the GameCycle™ showed that 78% of participants thought the GameCycle™ was enjoyable to use, 83% agreed that the system was easy to learn and operate, and concluded that the GameCycle™ would encourage wheelchair users to exercise.

Few studies have researched the introduction of such technologies and the long term impact of exergaming however there is anecdotal evidence that people are losing weight and becoming more fit playing the games. There has been a study recently published concerning the GameCycle™ and adolescents with spina bifida (n=8) who participated in a 16 week training program.[9] The results of the study showed that training increased the maximum work capability of 87% of the study participants. Also, 87% agreed that the GameCycle™ was physically challenging, enjoyable, and comfortable to use and 75% agreed that the GameCycle™ would motivate them to exercise longer.

This study will expand upon these conclusions and investigate how exergaming can impact the physical activity practices of persons with spinal cord injuries in the context of extended in-home use. This research was conducted in two phases, the Training Phase and In-Home Phase. The first goal of the Training Phase was to use training sessions to demonstrate that the commercially available GameCycle™ was both functional and easy to use for persons with spinal cord injuries. The second goal of the Training Phase was to use training sessions to determine the user's ability to reach and maintain target aerobic training zones during 14 minute exercise trials, teach new users how to use the GameCycle™ Exercise System, and to obtain feedback from new users regarding perceived comfort, fit, and ease of use. The goal of the In-Home phase was to evaluate the effectiveness of the GameCycle™ Exercise System, as compared with a standard arm-ergometer, in the context of extended, in-home use.

2.0 SUBJECT TRAINING AND EVALUATION OF THE GAMECYCLE^{TM} EXERCISE SYSTEM

2.1 ABSTRACT

Background: Studies have suggested that simply performing activities of daily living and performing regular wheelchair propulsion is insufficient for providing adequate levels of physical strain and training for the cardiopulmonary system. As a result, individuals with spinal cord injuries are at increased risk for cardiopulmonary and cardiovascular disease. The GameCycle^{TM} is a commercially available upper body exercise system that integrates arm ergometry and video gaming with the goal of providing an enjoyable and motivational exercise platform. Objective: The objective of this study was to teach subjects how to safely and effectively use the GameCycle^{TM}, to determine if subjects are able to learn how to operate the GameCycle^{TM} in an acceptable time period, to learn whether they are able to reach their target heart rate zone using the GameCycle^{TM}, and to obtain feedback from new users regarding perceived comfort, fit, and ease of use of the new system. METHODS: Participants completed the following surveys: CESD-10, SF-36, barriers and self-efficacy and demographics. Subjects were trained to use the GameCycle^{TM} and required to complete a timed demonstration. Metabolic data, resistance settings, and rating of perceived exertion were collected during a 14 minute exercise bout. Participants also completed a survey in which they were asked to report their perceptions of the GameCycle™ exercise system. RESULTS: 14 subjects with spinal cord injuries, 11 men and 3 women, with an average age of 37.5 years (SD = 6.5) participated in the study. All subjects were able to complete training successfully and 12 (86%) of the subjects were able to reach their target heart rate zones during exercise. All of the participants found that the GameCycle™ was easy to learn and operate, with the majority finding the GameCycle™ enjoyable to use. This study indicates that the GameCycle™ is usable and confirms previous findings that aerobic training zones can be reached.

2.2 INTRODUCTION

Disability affects nearly 49 million Americans and has tremendous impact on the United States healthcare system.[10] Disability within this statement is defined as an impairment that limits one or more activities of daily living. Much is known about the benefits of regular physical activity in the general population; including improvement in levels of physical functioning (e.g., aerobic capacity) and numerous health benefits. There is evidence, though, that a significant proportion of the population of people with disabilities possesses a greater than average risk of acquiring cardiovascular disease. Finding ways to promote physical activity within this group has become a key challenge.[11]

The activity level of people tends to decrease after the occurrence of a spinal cord injury (SCI).[10,12,13] Sedentary individuals with SCI are not as fit as their physically active counterparts or the sedentary unimpaired population.[14] Sawka et al. studied the wheelchair exercise performance of young, middle-aged, and elderly subjects and reported that many middle-aged and elderly subjects demonstrated abnormal signs or symptoms that were suggestive of cardiovascular disease.[15] Janssen et al.[10] and Sedlock et al.[14] reported that daily wheelchair propulsion of an individual with a spinal cord injury (SCI) is not sufficient to maintain or improve his/her cardiovascular fitness level. As a result, cardiovascular diseases are an increasing health concern for wheelchair users and the SCI population.[15] Cardio Vascular Disease is the leading cause of death in populations with disabilities[17-20], with death occurring at a younger age than the general population. For individuals surviving more than 30 years after a spinal cord injury, cardiovascular disease is reported as the number one reason for death.[17]

Physical activity has been listed as one of the major modifiable CVD risk factors. The majority of benefits can be gained from moderate-intensity activities, which are more likely to be continued than high-intensity activities.[21] Physical activity protects against the development of CVD and also favorably modifies other CVD risk factors including high blood pressure, blood lipid levels, insulin resistance, and obesity.[22] The development of muscular strength and joint flexibility also is important and improves the ability to do occupational and recreational tasks and reduces the potential for injury.[23] In particular, people with disabilities may benefit from flexibility and resistance training to improve the ability to complete activities of daily living.[24] Psychosocial benefits of exercise have been supported in numerous studies in unimpaired populations including reduction of depression[25,26], stress[27,28], and anxiety[29]. It has been shown that people with spinal cord injuries who participate in sports or physical activity have a higher satisfaction with life and perceive sporting activity as beneficial.[30, 31]

2.2.1 Barriers to Exercise

Just as barriers to exercise exist in unimpaired populations, the same barriers plus others exist for individuals with SCI. These include but are not limited to physical barriers such as accessibility to facilities and equipment, attitudinal barriers, and transportation barriers. A regular exercise program may not be available or may be too difficult to participate in either physically and/or psychologically.[14] Many individuals who use wheelchairs have additional functional limitations with their cardio respiratory systems, which may decrease their desire and/or ability to exercise.[32]

Although people, in general, acknowledge the benefit of exercise, having them actually participate and change behaviors is challenging. Research studies examining exercise adherence shows that motivation is necessary for continued participation. Resnick et al[33] reported that 60% of participants in a walking program, did not adhere to the program. Possible reasons why individuals discontinue activity can range from lifelong exercise habits to what barriers exist regarding activity to individuals interest and their motivation to exercise. Motivation has been considered a modifiable factor that can elicit an increase in physical activity[34]. Techniques to motivate individuals has been studied in depth in unimpaired populations, but little has been examined in populations with SCI. Different modes of motivation have been examined including hanging signs by stairwells to encourage walking[35], cognitive and behavioral counseling[36], computer based systems that provide feedback and goal setting[37], and buddy systems of exercising with friends. Individuals with SCI have also reported that exercise programs using standard arm-crank or roller systems can be boring and no motivation is provided to maintain the exercise program.[14, 15]

We seek to examine an aerobic exercise alternative for wheelchair users that provides an aerobic workout and incorporates the use of video games for motivation. Because wheelchair users are limited to exercise they can perform with their upper body, arm ergometry is the most common low-impact, non-weight bearing cardiovascular exercise performed. Arm ergometry consists of shoulder extension and flexion, scapular and clavicular protraction and retraction, and elbow extension and flexion.[38]

2.2.2 Previous Research

Through previous research we have developed an interface between a Nintendo GameCube™ and an arm ergometer called the GameCycle™.[7, 8] Cranking the arm cycle, allows one to control and play a video game. Videogames are controlled by cranking and steering, similar to hand-cycling. This allows the user to play racing style video games while participating in a simultaneously challenging and entertaining workout. Cranking the GameCycle™ forward and backward, and steering left and right replace the up/down/left/right arrows on the traditional controller. The GameCycle™ is designed with six large buttons on the top of the machine. These buttons are defaulted to "A", "B", and "Start," buttons found on a traditional controller, and to "↑" (which increases the resistance), "↓" (which decreases the resistance), and "Menu." The resistance level of the GameCycle™ is controlled by a magnetic break that the user can set to a resistance of zero (0 N*m) through nine (7.91 N*m), incrementing by 0.88 N*m for every resistance level. The "Menu" button allows the user to access a series of menus that contain the remainder of the buttons that can be found on a traditional GameCube™ controller.

Figure 1. The GameCycle™ Exercise System

The GameCycle™ can be adjusted to the user by pulling a pin to adjust the height to allow the user to set the crank at a comfortable height for exercise (Figure 2). Finally, different grips are available for the GameCycle™; crank handles allow comfortable use, and alternatively, gloves (Bike-On.com, Coventry, RI) that snap into the handles ensure ease of use for limited gripping ability (Figure 3).

Figure 2. Height Adjustment

Figure 3. Grip Alternatives

In order to design a device that would meet the needs and preferences of wheelchair users a participatory design methodology was used. Once a proof of concept prototype was built wheelchair users evaluated the prototype and performed exercise testing with the prototype to show that wheelchair users were able to reach target aerobic training zones and end user interest in the device.[7] An improved prototype was then created and a focus group of end users (wheelchair users and clinicians) evaluated the GameCycle™ and suggested improvements.[8] The culmination of these studies is the commercial GameCycle™ Exercise System (Three Rivers Outfront, Mesa, Arizona).

An important study conducted using the commercially available prototype as an exercise intervention was conducted by Widman, et. al. with eight adolescent subjects with spina bifida.[9] Results of their study show six of the eight subjects were able to reach 50% of their VO2 reserve and seven of the eight subjects reached 50% of their heart rate reserve. Seven subjects increased their maximum work capability after training with the GameCycle™ for 16 weeks. They conclude that the GameCycle™ was an adequate exercise device that subjects felt was fun and enjoyable.

The long-term goal of our GameCycle™ study was to improve the overall activity level of individuals who use wheelchairs and increase their general well being. The overall study had a training phase and an 'in-home' phase. The specific objectives for this paper, which discuss the training phase, were to:

1. teach individuals who use wheelchairs how to safely and effectively use the GameCycle™ Exercise System
2. determine if subjects were able to learn how to operate the GameCycle™ in an acceptable time period
3. determine whether subjects were able to reach and maintain their target aerobic training zone during 14 minute exercise trials, and
4. to obtain feedback from the subjects regarding perceived comfort, fit, and ease of use of the system.

The purpose in training participants to use the GameCycle™ is two fold. Training participants to set up the exercise system will ensure their safety while exercising during testing as well as during a future study in which they will be asked to use the GameCycle™ in their homes. Training to use the system will also decrease the likelihood that the system will be abandoned due to frustration in the learning process. A system that is easily taught to users has a greater viability as a commercial product. To show that past studies were effective in helping to create a product that is useful and desired by wheelchair users, the survey that has been given in previous GameCycle™ studies was repeated. In addition, an exercise test was conducted to verify that the final product allowed users to reach their target heart rate training zones.

2.3 METHODS

2.3.1 Protocol

The study was conducted under a protocol approved by both University of Pittsburgh and the Pittsburgh VA Health Care System. Recruitment was conducted through an IRB approved registry of wheelchair users maintained by the Human Engineering Research Laboratories (HERL) as well as through postings on the HERL website and newsletter. Persons interested in the study contacted the study's researchers and initial screenings were conducted over the phone.

Eligibility requirements included full time wheelchair (manual or power) of more than 20 hours per week, an age between 18 and 50 years, and the ability to use an arm-ergometer. Participant exclusion criteria included any history of cardiovascular or cardiopulmonary disease (CVD) in self or participant's family (defined as death of parents, grandparents and siblings from CVD before the age of 55). Subjects, who contacted the investigators and expressed interest, were asked questions regarding eligibility criteria. Those who met the inclusion/criteria during the telephone screening were required to obtain physician's consent to participate in the study. Upon the initial visit, eligibility criteria were confirmed after informed consent was obtained.

2.3.2 Surveys

Participants completed a demographic survey to collect age, sex, education, race, injury level, and years of injury. They were also asked whether or not they had experience playing video games. Because exercise interventions have the potential to impact participants' quality of life and other psychosocial variables the following surveys were used to measure these variables.[39]

Participants completed the 10 item Center for Epidemiologic Studies Depression Scale (CES-D 10) which is used to screen for a depressive mood and has been shown to be both reliable and valid.[40,41] To measure health status participants were asked to complete the Medical Outcomes Study Short Form (SF-36) (Medical Outcomes Trust, Boston, MA) a 36 question survey that measures eight health concepts: limitations of physical functioning because of health problems (PF), limitations in usual activities because of physical health problems (role-physical: RP), bodily pain (BP), general health perception (GP), vitality (energy and fatigue: VT), limitations on social functioning because of physical or emotional problems (SF), limitations on usual activities because of emotional problems (role-emotional: RE), and general mental health (psychological stress and well-being: MH).[42, 43]

The third questionnaire collected was the Exercise Barriers and Self-Efficacy questionnaire (Appendix A). The questionnaire rated participants' responses to questions on an 11 point ordinal scale, incrementing from 0% to 100% by 10%. Participants were asked how confident they were (0% not at all confident, 50% moderately confident, 100% highly confident) that they could continue to exercise if they encountered the following barriers: bad weather, boredom, vacation, lack of interest, pain or discomfort, exercising alone, exercise was not fun or enjoyable, exercise location was difficult to get to, etc.

2.3.3 GameCycle™ Training

Training was conducted in the laboratory setting. The Training phase was divided into three parts: 1) subject training 2) a 14 minute exercise bout and 3) GameCycle™ evaluation. In order to meet the first objectives of the study, all subjects were trained to use the GameCycle™ system. The training consisted of a) researchers reading a script to the subjects (Appendix B), b) a practice session of playing the GameCycle™ and c) subject completion of a timed demonstration (Figure 3). Three time points were recorded during this Training Phase: time point 1 (T1) at the start of subject training, time point 2 (T2) at the beginning of the timed demonstration and time point 3 (T3) at the end of the demonstration. Subjects were encouraged to ask questions at any time during training and unaware that they were being timed.

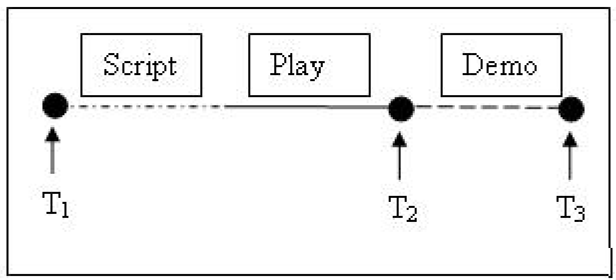

Figure 4. Subject Training Sequence

To promote subject safety and independence while using the GameCycle™, subjects were shown how to fit the GameCycle™ to them. To ensure the consistency of training given to all subjects a script was used that introduced subjects to the GameCycle™ and its features, and described how to setup and use the GameCycle™. All training was completed by the same investigator. Subjects were shown how to comfortably position themselves to insure that the center of the crank was in line with their shoulders, their hands placed comfortably at shoulder width. Adjustments for height and fore-aft positioning were made to insure that the motion about the shoulder remained about the neutral position. Finally, subjects were given the option of using either the horizontal grips or gloves (Figure 3).

Subjects were then permitted a practice session to learn how to play the GameCycle™ which entailed playing Need for Speed Underground™ for approximately two laps at a self-determined pace and resistance. They were encouraged to experiment with different resistance levels to find a comfortable resistance for exercise purposes. Afterwards subjects were asked to complete a timed demonstration to demonstrate that training was successful. During the timed demonstration subjects were asked to demonstrate or describe how to a.) turn on the GameCycle™ and GameCube™ and load a videogame, b.) position themselves and adjust the GameCycle™ for use, c.) adjust the resistance of the GameCycle™ and finally, d.) set up a game for play. Participants who were unable to reach the GameCube™ or perform a task due to physical limitations were allowed to verbally instruct the researchers on how to perform them.

2.3.4 Exercise Testing

Subjects were required to complete 14 minutes of exercise with the GameCycle™ system while playing Need for Speed™. They were fit with a Polar Heart Rate Monitor (Polar Electro Inc., Lake Success, NY) worn on their chest for two minutes to determine a baseline heart rate. Metabolic data was collected using an Aerograph VO2000 portable gas analyzer (Medical Graphics Corporation, St. Paul, MN) and a laptop. The target aerobic training zone was defined as when the individual's measured heart rate was at or above 60% of their predicted maximum heart rate for arm work. The following equation was used to calculate maximum heart rate, adjusted for arm work: HRmax = (220 – age) - 13.[44]

The starting resistance for all subjects was a setting of 4 (3.52 N*m) on the GameCycle™. One exception to the starting resistance was made for a subject who could not exercise at the resistance and was started at a resistance of 1 (0.88 N*m). Resistance was incremented every two minutes, as long as subjects felt they could continue exercising. Participants whose HR was above or below 60% - 80% max HR were asked to either increase/decrease cadence and/or resistance in order to remain within this range. Ratings of perceived exertion using the Borg scale, which rates exercise intensity on a scale of 6 (very ,very light) to 20 (very, very hard)[45], and the resistance setting were collected every 2 minutes during the exercise trial. One subject was unable to complete the entire fourteen minutes of exercise due to trunk instability. We were able to accommodate him in future studies by providing him with a custom vinyl pillow to place between the GameCycle™ and his chest to help him stabilize his trunk.

2.3.5 GameCycle™ Evaluation

Following completion of the exercise session research participants were asked to complete a questionnaire in which they were asked to report their perceptions of: 1) the stability of the GameCycle™ System, 2) goodness of fit to the user, 3) comfort and ease of use, and 4) the extent to which they think it would motivate them and others to exercise. This questionnaire (Appendix C) has been used in the previous GameCycle™ development studies to guide prototype design and to show that a user centered design process used by researchers resulted in a product that end users found easy to use and functional.[8]

2.3.6 Statistical Analysis

All data were analyzed using SPSS 14.0 statistical software. Significance for all tests was set at $p < 0.05$. The CES-D and SF36 were scored according to their standardized scoring procedure. Responses to the Exercise Barriers and Self-Efficacy questionnaire were tallied and frequency percents are reported. Because of the small cell sizes, ratings of strongly agree and agree were combined as well as strongly disagree and agree. Descriptive statistics were calculated and reported for these surveys.

The time to complete the entire training process (Ttot = T3 – T1) was calculated as well as the time of the demonstration (Demo = T3 – T2). Descriptive statistics were calculated for these variables. A Kruskal Wallis was run to see if there was a relation between the highest degree earned by participants and the total time they required to complete training. A Spearman Rho correlation was run to see if there was a correlation between age and total training time and years of education and total training time.

A repeated measured analysis estimated that steady state for the group of subjects began at approximately four minutes, therefore heart rate and oxygen consumption data was averaged from four to fourteen minutes of the trial. Participants were identified as meeting and maintaining their training zone, if their predicted 60% maximum heart rate was equal to or less than their average heart rate. Maximum and mode resistance and BORG ratings were calculated for the exercise session.

Subject responses to the survey regarding GameCycle™ features were tallied and frequency percents are reported. Because of the small cell sizes, ratings of strongly agree and agree were combined as well as strongly disagree and agree. Results of the survey for the GameCycle™ were compared to results found for a previous GameCycle™ prototype reported by Guo et. al.[8]

A secondary analysis compared results between participants with quadriplegia and paraplegia. Tetraplegia was defined as an injury to the cervical region of the spinal cord and paraplegia was defined as an injury to the thoracic, lumbar or sacral region of the spinal cord. A Fisher's Exact test was used to compare gaming experience (yes/no) and whether or not the participants reached their target training zones (yes/no). A Mann-Whitney test compared training times (Phase I, timed demonstration, and total training time), years of education, years living with a disability and age between the groups. Finally an exact Chi-squared test compared the highest degree completed (high school diploma/GED, associates degree, bachelor's degree and master's degree), CESD-10 scores, SF-36 scores, maximum and mode resistance, and maximum and mode BORG ratings between the groups. A one-way ANOVA was run to compare average HR and VO2 between the participants with quadriplegia and paraplegia.

2.4 RESULTS

2.4.1 Participants

Fourteen individuals with spinal cord injuries, mean age 37.5 years (+/- 6.5), were recruited for the study (Table 1). Subjects had injury levels ranging from T12 to C4, with six having an injury level at or above C7. Eleven subjects were male and three were female; eleven subjects were Caucasian and three were African American. Participants had been living with a spinal cord injury for an average of 11.7 (+/- 9.7) years.

Table 1. Characteristics of the Study Sample (n=14)

	Age	37.5 (+ 6.5) years
Sex	Male	11 (79%)
	Female	3 (2%)
Race	African American	3 (21%)
	Caucasian	11 (79%)
	Years Living with Disability	11.7 (+ 9.7) years

2.4.2 Psychosocial Results

Table 2 summarizes the SF-36 and CESD-10 scores for all study participants. The results of the SF-36 suggest that the majority of study participants have problems with work or other daily activities as a result of their physical health (Role Physical Median = 0) and emotional problems (Role Emotional Median = 0). However results also suggest that the majority of participants have no limitations performing physical activities (Physical Functioning Median = 73), see their personal health as excellent (General Health Median = 80), are not limited due to pain (Bodily Pain Median = 84), and that physical and emotional problems do not interfere with normal social activities (Social Functioning Median = 88). Vitality results (Median = 55) suggest that participants can feel tired or worn out and Mental Health results (Median = 41) suggest that participants do have feelings of nervousness or depression. The Physical Component Summary (Median = 54) suggests that there is some limitation in self-care and the Mental Component Summary (Median = 33) suggests that emotional problems cause psychological distress.

The results for the CESD-10 were skewed to the right (skewness = 2.561) and responses ranged from 1 to 19. The median was a CESD-10 score of 4 and the scores showed two modes, 3 and 4. One subject scored above a 10, indicating the presence of depression. He/she was notified of the score. Subject number 14's response was determined to be an outlier and the data summary with this score removed resulted in a skewness of 0.296, a mean of 4.31, and a standard deviation of 2.016. The results of the independent samples t-test comparing CESD-10 results between participants with quadriplegia and paraplegia were not significant ($p = 0.064$).

Table 2. SF-36 Norm-based Scale and Component Scores and CESD-10 Scores

Scale	Median, range, skewness	Subject #													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Physical Functioning	73, 0 – 100, -1.10	100	50	75	100	40	100	0	100	100	65	55	65	100	75
Role Physical	0, 0–100, 1.14	25	0	75	0	75	0	100	0	0	0	0	25	0	50
General Health	80, 37– 100, -0.85	77	62	67	95	77	100	42	87	92	82	87	62	87	37
Vitality	55, 45 – 65, -0.19	45	60	45	55	55	50	60	60	55	50	65	60	55	45
Social Functioning	88, 38– 100, -1.41	63	75	88	100	75	88	88	100	100	100	100	75	100	38
Mental Health	41, 24 – 80, 1.35	28	56	48	36	40	28	56	36	44	28	24	40	28	80
Role Emotional	0, 1 – 100, 2.78	0	0	33	0	100	0	0	0	0	0	0	0	0	33
Bodily Pain	84, 41 –100, -0.44	100	84	100	74	51	84	62	100	84	52	100	41	100	41
Physical Component Summary	54, 38 – 61, -0.32	61	42	56	56	42	59	38	59	56	46	52	44	60	38
Mental Component Summary	33, 22 – 47, 0.214	22	39	35	31	47	27	43	31	33	33	33	34	28	42
CESD-10	4 (1 – 19)	4	5	7	1	6	4	3	3	3	6	8	4	2	19

2.4.2.1 Barriers to Exercise

Majority of responses (>85%) were highly confident that they could continue to exercise 3 times per week for the next 3 months if the weather was bad or if they had to exercise alone (Table 3). The majority of participants responded that they were highly confident that they could continue to exercise 3 times per week for the next 3 months for the following conditions, however there were at least 4 participants that were less than highly confident: bored by the activity or program (NC: 1(7%), MC: 3(21%), HC: 10(71%)), not interested in the activity (NC: 2(14%), MC: 5(36%), HC: 7(50%)), self-conscious about appearance during exercise (NC: 3(21%), MC:

2(14%), HC: 9(64%)), instructor not offering encouragement (NC: 1(7%), MC: 3(21%), MC: 10(71%)). This suggests that bad weather, exercising alone, boredom with the activity, interest in the activity, self-consciousness about appearance, and the lack of instructor encouragement are not barriers to exercise for the majority of the study's participant population.

Table 3. Exercise Barriers and Self-Efficacy Results

Barrier	Not at all Confident	Moderately Confident	Highly Confident	N
I believe that I could continue to exercise 3 times per week for the next 3 months if:				
The weather was very bad (hot, humid, rainy, cold)	2 (14%)	0 (0%)	12 (85%)	14
I was bored by the program or activity	1 (7%)	3(21%)	10(71%)	14
I was on vacation	2 (14%)	7(50%)	4(29%)	13*
I was not interested in the activity	2 (14%)	5(36%)	7(50%)	14
I felt pain or discomfort when exercising	4(29%)	5(36%)	5(36%)	14
I had to exercise alone	0 (0%)	2 (14%)	12 (85%)	14
It was not fun or enjoyable	2 (14%)	5(36%)	7(50%)	14
It became difficult to get to the exercise location	5(36%)	6(43%)	3(21%)	14
I didn't like the particular activity program that I was involved in	2 (14%)	8(57%)	4(29%)	14
My work schedule conflicted with my exercise session	3(21%)	5(36%)	6(43%)	14
I felt self-conscious about my appearance when I exercised	3(21%)	2 (14%)	9(64%)	14
The instructor did not offer any encouragement	1 (7%)	3(21%)	10(71%)	14
I was under personal stress of some kind	2 (14%)	6(43%)	6(43%)	14
I am able to continue to exercise three times per week at moderate intensity, for 40+ minutes without quitting for the NEXT				
Week	0 (0%)	1 (7%)	13 (92%)	14
2 Weeks	0 (0%)	1 (7%)	13 (92%)	14
3 Weeks	0 (0%)	1 (7%)	13 (92%)	14
4 Weeks	0 (0%)	1 (7%)	13 (92%)	14
5 Weeks	0 (0%)	1 (7%)	13 (92%)	14
6 Weeks	0 (0%)	1 (7%)	13 (92%)	14
7 Weeks	0 (0%)	2 (14%)	12 (85%)	14
8 Weeks	0 (0%)	2 (14%)	12 (85%)	14

*Missing data point

43% to 57% of participants only felt moderately confident that they could continue exercising if they were on vacation (NC: 2(14%), MC: 7(50%), HC: 4(29%)), it was difficult to get to the exercise location (NC: 5(36%), MC: 6(43%), HC: 3(21%)), or if they didn't like the particular activity program (NC: 2(14%), MC: 8(57%), HC: 4(29%)). While 7(50%) of participants were highly confident that they could continue exercising if the activity was not fun or enjoyable half of participants were not at all confident (NC: 2(14%)) or moderately confident

(5(36%), indicating that fun is an important factor in exercise activity. While 6(43%) participants were highly confident that they could continue exercising if their work schedule conflicted with their exercise session the majority of participants were moderately to less confident (NC: 3(21%), MC: 5(36%)) that they could continue exercising, also indicating that scheduling around their work time is important. These results suggest that vacation, a difficult exercise location, liking the activity program, participating in a fun program and a schedule that would not conflict with work is important to a number of participants.

When it came to personal stress, participants were split between moderately and highly confident that they could continue exercising if they were under personal stress of some kind (NC: 2(14%), MC: 6(43%), HC: 6(43%)). Pain or discomfort while exercising also received mixed ratings with 4(29%) subjects responding that they would not be confident that they would continue exercising, 5(36%) that they would be moderately confident, and 5(36%) that they would be highly confident. These results suggest that stress, pain, and discomfort while exercising could cause the majority of participants to discontinue exercising.

2.4.2.2 Exercise Self-Efficacy

Most of the participants (92%) were highly confident that they could continue exercising for 40+ minutes, 3 times a week, for the next 8 weeks. One subject answered moderately confident to all 8 weeks. Another subject changed from highly confident to moderately confident for the 7th and 8th week.

2.4.3 Subject Training

The time to complete each portion of the training sequence for all participants is given in Table 4. Study participants were able to able to complete the training script and game play portion of the study in an average of 23.9 (+/- 9.1) minutes. One subject was able to complete phase 1 in six minutes, this subject owned the video game and reported that he had beaten it numerous times. Participants were able to complete the timed demonstration in an average of three (+/- 0.9) minutes. All subjects were able to complete the demonstration portion of training in less than five minutes, without needing to repeat a task. Initially, it was required that a subject complete the independent set up of the GameCycle™ in three minutes. However, this was increased to five minutes because there were subjects who were capable of the task, but limited because of upper extremity function. Average total training time was 30 minutes, and ranged from 9 to 39 minutes. Participants had 12 to17 years of formal education, completing their GED or receiving a high school diploma to receiving a Masters degree. Out of the fourteen subjects eight of them identified as having some gaming experience and five reported having no experience.

Table 4. Training Results and Education

ID	Phase 1: Script and Play	Phase 2: Demonstration	Total Training Time	Years of Formal Education	Highest Degree
1	0:23	0:03	0:26	17	Masters Degree
2	0:06	0:03	0:09	13	Associate Degree
3	0:36	0:03	0:39	12	HS Diploma or GED
4	0:30	0:03	0:33	17	Masters Degree
5	0:27	0:05	0:32	12	HS Diploma or GED
6	0:12	0:03	0:15	13	HS Diploma or GED
7	0:22	0:03	0:25	17	Bachelors Degree
8	0:24	0:03	0:27	12	HS Diploma or GED
9	0:31	0:04	0:35	17	Bachelors Degree
10	0:30	0:03	0:33	12	Associate Degree
11	0:35	0:03	0:38	12	HS Diploma or GED
12	0:15	0:01	0:16	14	Associate Degree

Table 4 (continued)

13	0:14	0:02	0:16	17	Masters Degree
14	0:30	0:03	0:33	16	Bachelors Degree

2.4.4 Exercise Testing

Figure 4 is a plot of the raw VO2 data obtained from participant 52, indicating where steady state was calculated to begin and the end of the exercise session.

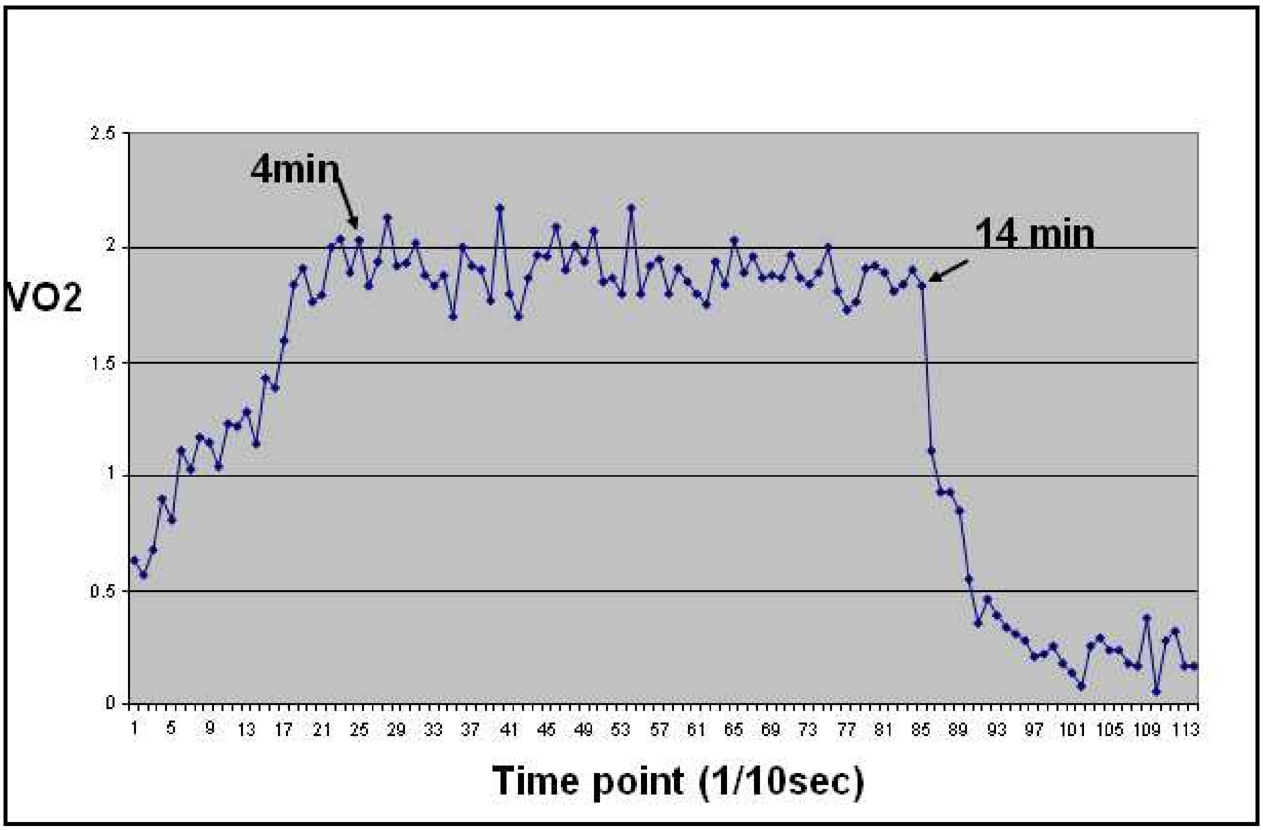

Figure 5. Plot of Raw VO2 Data (Subject6)

Table 5. Exercise Session Results

ID	SCI Level	Age	60% MHR	Target Zone Reached	Mean HR* BPM	Mean VO2* l/min	RMax	RMode	BORGMax	BORGMode
1	T5	36	97	Y	148	0.69	4	4	9	7
2	T12	33	99	Y	107	0.90	8	4	9	7
3	C6	40	95	Y	102	1.21	5	4	14	12
4	C7	31	100	Y	142	1.38	4	4	13	12
5	T11	46	91	Y	108	0.23	4	4	9	9
6	T11	37	97	Y	125	1.16	4	4	9	9
7	C4	37	97	Y	114	0.36	1	1	18	17
8	C5	32	98	N	84	0.74	5	4	17	15
9	C5	24	105	Y	119	0.71	4	3	13	10
10	T4	44	93	Y	98	0.35	7	7	6	6
11	T7	43	93	Y	114	0.34	5	5	12	12
12	T12	39	96	Y	118	1.38	5	5	11	11
13	C7	35	98	Y	125	0.97	5	5	12	9
14	T7	48	90	N	89	0.74	6	6	14	14

(*values calculated during steady state)

Table 5 shows results for all of the variables measured during the exercise bout. Twelve of the fourteen subjects (86%) were able to elicit and maintain an exercise effect, defined as meeting or exceeding 60% of their predicted maximum heart rate for arm work. Figure 5 is a graphical representation of the average oxygen consumption (left) and average heart rates (right) exhibited by the subjects during the 14 minute exercise session. For the group average oxygen consumption ranged from .23 to 1.38 L/min with an average of 0.80 L/min (+/- 0.39) and average heart rate ranged from 84 to 148 bpm with an average of 114 bpm (+/- 18).

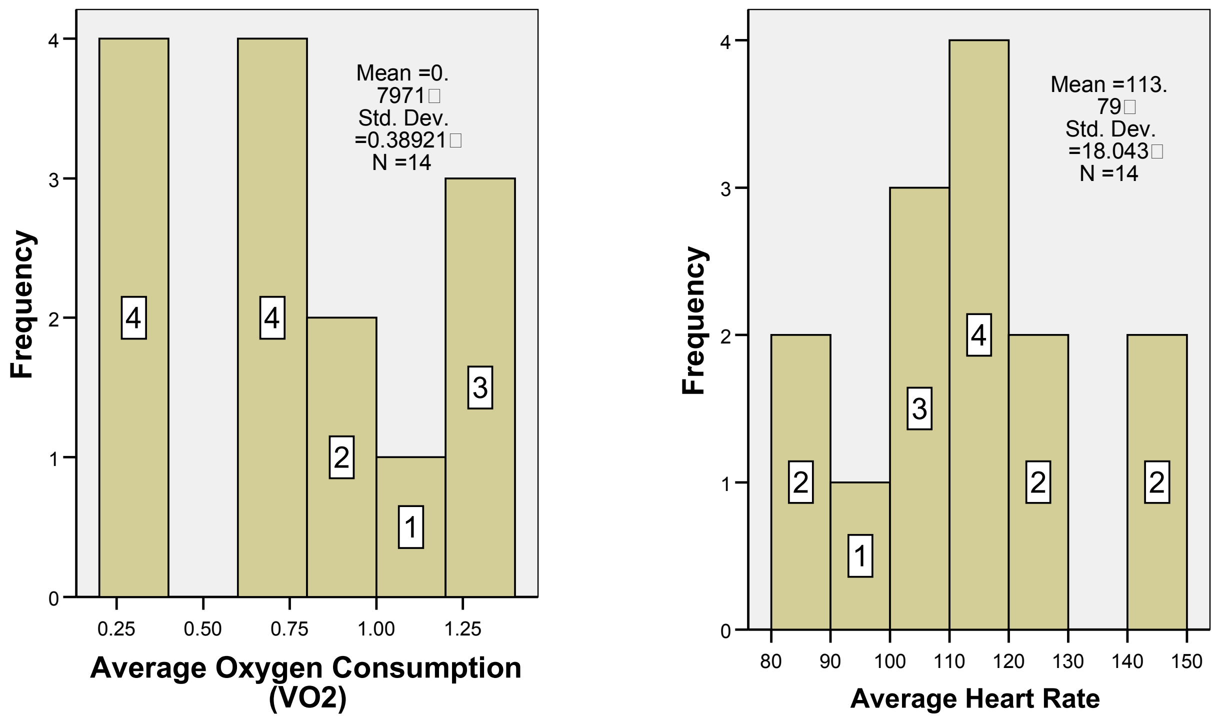

Figure 6. Left: Average Heart Rate (bpm) After Steady State, Right: Average VO2 (l/min) After Steady State

The GameCycle^{TM}'s resistance settings ranges from 0 to 70 lb.-in. (0 to 7.91 N-m) and steps up 7.78 lb.-in. (0.88 n-m) for every resistance level increased. The maximum resistance used by participants was a resistance of eight (corresponding to 7.03 N.m or 62.22 lb.in) while the minimum was a resistance of one (corresponding to 0.88 N.m or 7.78 lb.in). The most common resistance setting was a resistance of four (corresponding to 3.52 N.m or 31.11 lb.in). The high frequency of a resistance setting of four may have been due to subjects not being comfortable using the GameCycle^{TM}. Subjects were often more concerned with learning to maneuver the car than performing vigorous exercise.

The maximum BORG rating of perceived exertion given by participants ranged from six (very, very light) to eighteen (very hard). A BORG rating of 11 to 12 generally corresponds to 52-66% HRmax, 13 to 14 generally corresponds to 61% to 85% of HRmax, and 15 and above corresponds to over 86% HRmax. The majority of subjects (64%, n=9) rated a maximum of perceived effort greater than 10 while 57% (n=8) exercised at a perceived effort greater than 10 for most of their exercise session.

Figures 6 are plots of the maximum and mode BORG ratings, over time, for the two subjects that did not reach their target heart rate zones. These figures show that the subjects were rating their workout above an RPE of 13, which is equivalent to 61-85% of HRmax (not adjusted for arm work) in the able-bodied population.33 This data suggests that these subjects may have actually met their target zones.

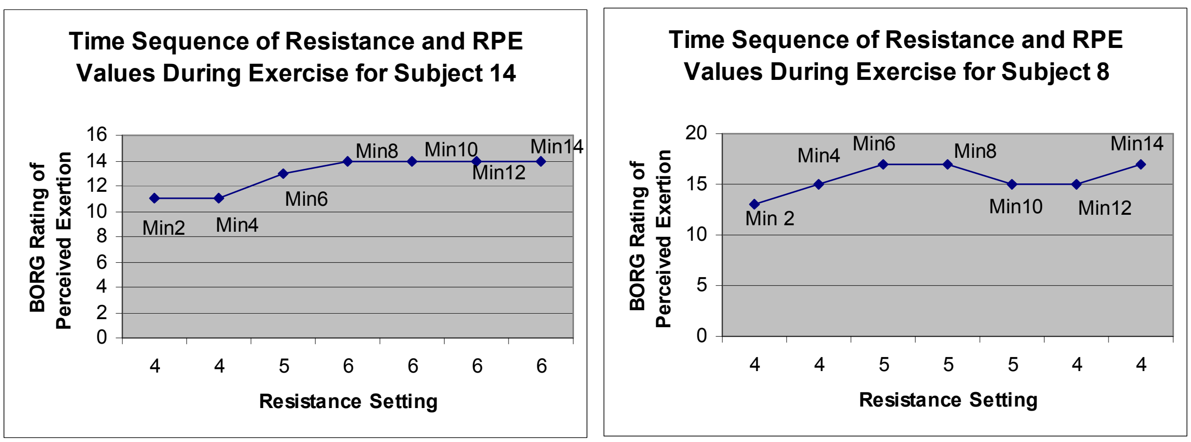

Figure 7. Resistance and RPE plots for Subject 14 and 8

2.4.5 GameCycle™ Evaluation

Results of the GameCycle™ questionnaire given during at the end of the Training Phase are summarized in Table 6. The results of this questionnaire were compared to those resulting from a focus group on a previous design, to assist the manufacturer in product development. Seven of the nine features reported by Guo et al were improved in the commercial product.

All of the participants found that the GameCycle™ was easy to learn, operate and had easily adjustable settings. The majority (93%) of participants felt that the GameCycle™

remained stable while exercising. Eighty six percent of participants found the system enjoyable to use and that it would motivate individuals who use manual wheelchairs to exercise on a regular basis.

When asked if they thought the GameCycle^{TM} to be easy to assemble and disassemble for easy storage, 36% of participants agreed, 50% were neutral and 14% disagreed and when asked if the GameCycle^{TM} was easy to mount and position oneself 79% agreed and 21% were neutral. Overall the GameCycle^{TM} received largely positive responses.

The results of questions Q1 through Q9 were compared to those reported by Guo et. al. in an article describing a prototype of the GameCycle^{TM} that was evaluated by a focus group of wheelchair users and clinicians.[8] The purpose of the focus group was to gather feedback from these end users regarding their perceptions of the GameCycle^{TM} in order to identify and improve any design flaws. The p-values are reported for Q1 through Q9 in table 6. Of the nine questions, seven of them reflected significant improvements from the original prototype to the commercially available GameCycle^{TM}. There was no significant difference between the prototypes for ease of learning and use, and the GameCycle^{TM} ability to motivate individuals to exercise.

For the remainder of the questions, the majority of participants were in agreement that the GameCycle^{TM} would help motivate them to workout longer and more frequently, that it was compact enough to fit in a room, that it used muscles similar to wheelchair propulsion, that playing videogames while exercising would create a challenging environment, that the handgrips were comfortable, that the on-screen instructions were clear, that the GameCycle^{TM} was physically challenging, and that they would be interested in purchasing a GameCycle^{TM}.

Participants were divided concerning whether the GameCycle™ used upper body motions different from those used in wheelchair propulsion.

Table 6. GameCycle™ Feature Questionnaire Results

	p-value	Agree	Neutral	Disagree
Q1: The GameCycle™ was easy to learn how to use and operate.	0.114	100%	0%	0%
Q2: The GameCycle™ system remained stable while I exercised vigorously.	0.003*	92.9%	0%	7.1%
Q3: The GameCycle™ seems easy to assemble and disassemble for easy storage.	0.015*	35.7%	50%	14.3%
Q4: The GameCycle™ was easy to mount and position oneself to begin exercise.	0.007*	78.6%	21.4%	0%
Q5: The steering mechanism on the arm-ergometer was comfortable to use.	0.002*	64.2%	28.6%	7.1%
Q6: The GameCycle™ vibrated excessively during use.	0.033*	0%	7.1%	92.9%
Q7: The GameCycle™ has easily adjustable settings to allow for individual configuration.	0.005*	100%	0%	0%
Q8: The GameCycle™ was enjoyable to use.	0.009*	85.7%	7.1%	7.1%
Q9: The GameCycle™ will help motivate other individuals who use manual wheelchairs to exercise on a regular basis.	0.342	85.8%	14.3%	0%
Q10: While exercising on the GameCycle™, I felt like I was in a awkward position.	NA	14.3%	7.1%	78.6%
Q11: The GameCycle™ will help motivate me to exercise more frequently	NA	92.9%	0%	7.1%
Q12: The GameCycle™ will help motivate me to workout longer once I get started.	NA	92.9%	7.1%	0%
Q13: The GameCycle™ is compact so that it will not dominate a room when fully set-up.	NA	85.7%	14.3%	0%
Q14: The GameCycle™ uses upper body motions and muscles similar to those employed in wheelchair propulsion.	NA	92.9%	0%	7.1%
Q15: The GameCycle™ uses upper body motions and muscles different from those employed in wheelchair propulsion.	NA	42.9%	14.3%	42.9%
Q16: Playing videogames while exercising created a challenging environment.	NA	92.9%	7.1%	0%
Q17: The hand grips were comfortable.	NA	85.7%	14.3%	0%
Q18: On-screen instructions were clear and easy to follow.	NA	100%	0%	0%
Q19: The GameCycle™ was physically challenging so that it let me quickly reach my target training zone.	NA	78.6%	21.4%	0%
Q20: If the GameCycle™ was available for purchase, I would be interested in buying one.	NA	71.4%	21.4%	7.1%

*significant at $p<0.05$

2.4.5.1 Open-ended Questions

When asked what it was about the GameCycle™ that they liked the best (Table 7), the most common response from participants were that they liked that the GameCycle™ took their mind off of exercising, suggesting that people do become immersed in the game. Other responses included that combining gaming and exercise was fun and that the game pushed them to exercise more. Participants responded that they liked the game including its graphics and that it focused on the road while they were racing. They also felt that the GameCycle™ would be a good alternative to a regular arm cycle as well as a good form of indoor exercise.

Table 7. Responses to the question "What is it about the GameCycle™ that you liked the best?"

It's cool and would be a lot of fun to play, especially for kids. It also takes your mind off the physical pain of exercise.
The screen focusing in on the road
The game screen, watching the video game takes your mind off of the exercise
I enjoyed using the game in combination w/ exercise.
It allows you to forget that you are exercising because you are busy concentrating on the game.
To do exercise; to lose weight to sweat.
Everything, I like the graphics as far as the game goes. For the physical part the stretching on the shoulders and the arm.
Interactive exercise is particularly good for cold weather climates or if outdoor equipment or environment is not available.
It didn't seem very difficult even when it wasn't working out.
Video game distracts you from the routine of exercise
It distracted me from the time - I've used a regular arm cycle before & I've become very bored while exercising.
Playing the game takes your mind off of the fact exercising. Also by playing the game it gives more reason to push yourself farther.

When asked what it was about the GameCycle™ that they disliked the most (Table 8) four participants responded having no dislikes and one did not respond. Three people responded that they didn't like the steering, that it was sensitive, hard to get used to, or difficult to back up. On participant said that it was difficult to use with his limited trunk stability. One subject stated that he found the game frustrating, but that he would hopefully advance. Other responses were that the GameCycle™ was instable when the subject tried to exercise vigorously, the game box was mounted too high, the location of the TV button was too high, could not turn on the

GameCycle™ independently, the buttons were small and that it was difficult to use in the wheelchair.

Table 8. Responses to the question "What is it about the GameCycle™ that you most dislike?"

The GameCycle™ was hard to get used to steering.
I dislike the small buttons on the GameCycle™ I thought they were difficult for a quad to manipulate independently.
Could not turn machine on by self. Can't see button on TV to high
Steering is very sensitive.
It was difficult for me with limited trunk stability. It was difficult for me to back up.
The chair interaction was awkward, unstable, was hitting my elbows on wheels
The game is a challenge for me - frustrating, hopefully I'll advance
Game box should be lowered so that someone that is in a wheelchair can look at what they need to do - instead of feeling your way.
The back of the machine bounced some when I really wanted to push it

When asked what they would do differently if they were in charge of redesigning the GameCycle™ three participants responded that they would design the GameCycle™ to be more compact for storage and portability while two responded that they would add weight or a platform to make the GameCycle™ more stable. Participants also would add bigger buttons, resistance buttons to the handles, and a forehead rest. Some also wanted to move the TV, game console, and handlebar closer to the user. Two participants wanted asynchronous cranks. Three participants responded that they would do nothing to redesign the GameCycle™.

Table 9. Responses to the question "If you were in charge of redesigning the GameCycle™, what would you do differently?"

Build an attached platform to sit a wheelchair on to keep the GameCycle™ from bouncing.
Make the buttons a little bigger & a little farther apart or provide matchstick(?) and holder
If It were at all possible to make it work w/ a home system making it more compact & portable.
T.V. and handbar a little closer
Only thing I would do differently is weight, something you can slide in the closet. Less bulk.
Put resistance control on handles for easy access during play.
I would put a forehead rest on it. I would make the steering so it could be done asynchronously.
Asynchronous crank
Perhaps have a smaller footprint, I have a small apartment
For now moving the game box down so that you can see.
A weight for the back bar to maybe anchor it a little better

2.4.6 Secondary Analysis: Differences Between Participants with Paraplegia and Quadriplegia

The Man-Whitney shows that there is a significant difference between the groups concerning age (p=0.039) with the average age of the participants with paraplegia being 41 and the average age of the participants with quadriplegia being.[40] There is no significant difference between participants with paraplegia and quadriplegia in terms of years with a disability (p=0.156) or years of education (p=0.169). Results of the Fisher's Exact showed no significant difference between participants with paraplegia and quadriplegia in terms of gaming experience (p=0.592) or their ability to reach their target training zone (p=1.000). There is also not a significant difference between the time it took participants from each group to complete phase 1 (p=0.437), the timed demonstration (p=1.000), or their total training time (p=0.399)

There was not a significant difference between groups concerning degree level (p=0.505) and there was no significant relation between total training time and degree (p=0.516). There was not a significant correlation between age and total training time (p=0.192) as well as no significant correlation between years of education and total training time (p=0.284).

There was a significant difference between the groups when comparing CESD scores (Exact Sig (2sided) p=0.023, asymp sig p=0.082). The mean CESD score for persons with quadriplegia was 3 (SD=2) and the mean score for persons with paraplegia was 5 (SD=4). The results of the Pearson Chi-Squared exact test (2 sided) were that there were on SF-36 scores that were statistically significant for the groups: Totph p=.567, role physical p=.758, general health p=.329, vitality p=.544, social functioning p=.254, mental health p=.347, role emotional p=1.000, bodily pain p=.590, Pcs p=1.000, MCS p=1.000.

Concerning the results of the exercise test there are no differences between the maximum and mode resistances reached by the participants with quadriplegia and paraplegia (p=1.000, p=1.000) nor maximum and mode Borg ratings (p=0.171, p=.664 respectively). There was no difference between average heart rate (p=0.926) and average oxygen consumption (p=0.437).

2.5 DISCUSSION

2.5.1 Psychosocial Measures

The purpose of collecting the psychosocial measures of the study participants was to better understand the group of participants sampled for the study. Overall participants were healthy and did not exhibit markers of depression. Participants from this training study will be eligible to participate in an extended in-home phase using the GameCycle™ in which these psychosocial measures will be looked at over time.

A limitation to the Exercise Barriers and Self-Efficacy Survey used is that there are barriers often encountered by people with disabilities that are not measured with the tool used in this study. These include transportation and accessibility issues. All the barriers surveyed, except for exercising alone, were rated as a barrier that could possibly keep a person from exercising, by at least one participant. Overall the majority of participants in the study were highly confident that they could continue exercising regardless of the barriers presented, which suggests that the recruited subjects either do not encounter these barriers or are able to overcome them, possibly through motivation.

2.5.2 Subject Training

All subjects successfully completed training as well as the timed demonstration, suggesting that users can be quickly trained to use the GameCycle^{TM}. There were a number of subjects who were new to videogames and who found the game difficult to play due to lack of experience; however any lack of experience did not seem to impact the training time. One subject that did lack experience was also unable to attain the target training zone as he seemed to be focused more on driving the car properly than exercising. What we are unable to measure is how much training is required to allow people to comfortable enough to exercise vigorously while racing.

While most of the subjects did not have difficulty using the GameCycle^{TM}, researchers did note a few problems encountered during training for a few subjects. These included difficulty accessing the GameCube^{TM} and LCD monitor buttons because of their height or location to the back of the device, difficulty pressing the GameCycle^{TM} buttons, and difficulty scrolling through menus while cranking and steering. A few subjects who chose to use the gloves found that the straps were too short to use independently, the gloves were not large enough or had difficulty disengaging the gloves from the GameCycle^{TM}.

The problems that subjects did encounter with the GameCycle^{TM} can be corrected through simple design changes such as mounting the GameCube^{TM} lower and closer to the user and replacing the present buttons on the face of the GameCycle^{TM} with larger, more sensitive buttons. Currently, the GameCycle^{TM} is turned on and off through a power strip, which could be made more accessible by integrating and on/off switch into the electronics housing. The gloves that were provided for participants with limited hand function were gloves typically used for hand cycling. Simple modifications could be made to address the issues with the gloves, such as adding longer straps or trimming the webbing away making the gloves much easier and comfortable.

2.5.3 Exercise Testing

Exercise testing results showed that persons with spinal cord injury who use the GameCycle™ are able to elicit a training effect even though it was their first time using the system. This validates findings by Fitzgerald et. al. when studying a previous version of the GameCycle™ [7] and findings by Widman et. al when studying the in home use of GameCycle™ by adolescents with spinal cord dysfunction[9]. Future work will look at the impact of persons with spinal cord injuries using the GameCycle™ in their homes.

2.5.4 Study Limitations

The clearest limitation of the study was the small sample size due to funding limitations. Because of this small sample and the fact that people who are motivated to exercise are more likely to participate in an exercise related study our sample population most likely represents a more physically active portion of the spinal cord injured population. Variables that were not measured, that would have added to the study in clued participants physical activity levels and fitness levels.

It would also be interesting to see if there is a difference in people's perceptions of new equipment due to their level of physical fitness. Is it possible people who do not already have equipment available to them would rate a new system differently than those who already have alternatives available to them? Looking at differences between athlete's perceptions and the average person's perceptions would have been interesting.

While there was no formal warm up, participants were required to complete two trial laps, which were considered a warm up to the exercise testing performed immediately after training was complete. This may or may not have been a sufficient warm up for some participants. It is highly likely that the protocol used in this study did not push some of the participants to perform their most vigorous workout, while being quite challenging to others. However, the goal of the study was not to evaluate the fitness of the participants, but to simply show that the GameCycle™ could be used to initiate a training effect.

Another limitation of the study is that the researcher that provided the participants with training was the same researcher who evaluate whether or not they were able to independently use and setup the GameCycle™, which could have introduced bias into the study. The same researcher was also responsible for recording difficulties that participants had with the system as well as participant comments. A final limitation is that learning cannot statistically be established because there was no pre and post-test measure. However, the goal was not to measure learning per se, but simply show that the system was easy to use.

Future work should look at the ability of the GameCycle™ to provide people with vigorous workouts, allowing them to reach their maximum aerobic capacity for exercise. It is unknown whether or not the resistance levels that the GameCycle™ is designed with will meet the needs of all users, including those with high levels of aerobic fitness.

2.6 CONCLUSIONS

This study was able to show that individuals who use wheelchairs were able to be quickly taught how to safely and effectively use the GameCycle^{TM} Exercise System and that the majority subjects were able to reach and maintain their target aerobic training zones. Results suggest that the Training Script was clear and that the GameCycle^{TM} as sold in 2005/2006 is easy to understand and use. It is important for clinicians who are teaching the GameCycle^{TM} to their clients to recognize that individuals learn at different rates and that user function and experience playing video games may play a role in the amount of time it takes to train individuals. Also, GameCycle^{TM} users may require extra assistance after training, if they are new to video gaming technology

This study showed that the commercially available GameCycle^{TM} can provide wheelchair users with a workout to meet exercise training needs. However, it is important to realize that learning rate and comfort with using the game directly affects the user's workout. New users agreed that the GameCycle^{TM} was comfortable, adjustable, enjoyable to use and that it would motivate individuals who use manual wheelchairs to exercise on a regular basis. Future studies should aim to examine the effects that the GameCycle^{TM} has on exercise participation compared to that of standard arm-ergometry.

3.0 COMPARISON OF ARM ERGOMETRY WITH AND WITHOUT VIDEO GAMING DURING EXTENDED IN-HOME USE

3.1 ABSTRACT

The number of exercise programs and methods are limited for people with disabilities. The GameCycle™ combines arm-ergometry with video gaming with the goal that it will provide a fun and motivational exercise platform. Nine persons with spinal cord injuries (1 women, 8 men, 36.2 +/- 5.5 years) completed a four-month in-home trial in which they were asked to exercise with the GameCycle™ for two months and a standard arm-ergometer for two months, the order of which was randomized. Results suggest that there is not a significant difference between the number of sessions completed with each method (p=0.172), but that subjects exercised for significantly longer durations (p=0.035) with the GameCycle™. Subjects had significantly higher average RPMs (p=0.021) with the standard arm-ergometer since video games require variable RPMs to complete game objectives. This suggests that the GameCycle™ is more enjoyable and will increase exercise dosage for long-term exercise compared to standard arm-ergometry.

3.2 INTRODUCTION

Disability affects nearly 49 million Americans and has tremendous impact on the United States healthcare system.[10] Disability within this statement is defined as an impairment that limits one or more activities of daily living. Much is known about the benefits of regular physical activity in the general population; including improvement in levels of physical functioning (e.g., aerobic capacity) and numerous health benefits. There is evidence, though, that a significant proportion of the population of people with disabilities possesses a greater than average risk of acquiring cardiovascular disease. Finding ways to promote physical activity within this group has become a key challenge.[11]

The activity level of people tends to decrease after the occurrence of a spinal cord injury (SCI).[10, 12-14] Sedentary individuals with SCI are not as fit as their physically active counterparts or the sedentary unimpaired population.[14] Sawka et al. studied the wheelchair exercise performance of young, middle-aged, and elderly subjects and reported that many middle-aged and elderly subjects demonstrated abnormal signs or symptoms that were suggestive of cardiovascular disease.[15] Janssen et al.[10] and Sedlock et al.[14] reported that daily wheelchair propulsion of an individual with a spinal cord injury (SCI) is not sufficient to maintain or improve his/her cardiovascular fitness level. As a result, cardiovascular diseases are an increasing health concern for wheelchair users and the SCI population.[15] Cardio Vascular Disease is the leading cause of death in populations with disabilities[17-20], with death occurring at a younger age than the general population. For individuals surviving more than 30 years after a spinal cord injury, cardiovascular disease is reported as the number one reason for death.[17]

With limited exercise programs and methods available to persons with disabilities[11], the GameCycle™ has been developed as an alternative to standard arm-ergometry with the goal of providing an entertaining, interactive, and challenging environment to motivate wheelchair users to exercise. The GameCycle™ is an arm-ergometer that has been modified to act as a game controller compatible with the Nintendo GameCube™. In this modified arm-ergometer, video games are controlled by cranking and steering, similar to hand-cycling. The GameCycle™ was developed through university (Human Engineering Research Laboratories (HERL), Pittsburgh, PA) and industry (Three Rivers Holdings, Arizona) collaboration, and is currently available to consumers.[7, 8, 46, 47] Previous research has shown consumer interest in the GameCycle™ and its effectiveness as an exercise platform[7, 46], and has focused on refining the design of the prototype for consumer use based upon feedback from both wheelchair users and clinicians. [8, 47]

Research on the commercially sold GameCycle™ includes a training phase which found that adult subjects with spinal cord injuries were able to be trained to use the GameCycle™ as well as reach their target heart rate zones.[48] Widman, et. al. studied the use of the GameCycle™ with eight adolescent subjects who have spina bifida. Subjects reported that the video game was motivational and enjoyable. Authors suggested that the GameCycle™ is an adequate exercise device for this population.[9]

This paper focuses on in-home use of the GameCycle™ by adults with spinal cord injuries. The objective of this research was to provide GameCycles™ to subjects for use in their homes to evaluate the effectiveness of the System (as compared with a standard arm-ergometer) in the context of extended, in-home use. The following hypotheses were investigated:

- participants will have significantly ($p < 0.05$) greater physiologic and metabolic activity (VO2, HR) when using the GameCycle™ System than when using an arm-ergometer alone,

- despite expected greater physiologic and metabolic activity when using the GameCycle™, participants will report significantly ($p < 0.05$) higher ratings of perceived exertion (RPE) when using the arm-ergometer along, than then using the GameCycle™ System,
- participants will adhere to a significantly ($p < 0.05$) more demanding exercise regimen (exercising longer and more frequently) when using the GameCycle™ System than when using an arm-ergometer alone.

3.3 METHODS

3.3.1 Subject Recruitment

Subjects who completed the Training Phase[16] were invited to participate in a 4-month In-Home trial. Participants were persons with spinal cord injuries that used a wheelchair as their primary means of mobility, had no history of cardiovascular or cardiopulmonary disease, could safely use an arm-ergometer, were between the ages of 18 and 50, and had received their physician's consent to participate. The study was approved by the University of Pittsburgh and Pittsburgh VA Medical Center Institutional Review Boards; all subjects provided informed consent prior to participation.

3.3.2 Experimental Protocol

In this two-month cross-over study, subjects were randomly assigned to one of two groups. The first group (n1=5) used the GameCycle™ for two consecutive months of exercise followed by two months of standard arm-ergometry (the GameCycle™ with the video game disabled). The second group (n2=6) used standard arm-ergometry for two months before finishing with two months of the GameCycle™. A restricted randomization process was used to ensure near to equal group sizes.[50] The subject recruiter was blinded to the group assignment.

A GameCycle™ was delivered and installed in working order to the home of each research participant by a trained member of the research team. Deliveries were made from 2.5 to 10 months following the Training Phase, therefore subjects were retrained to use the GameCycle™ including how to position themselves as well as how to turn on and set up the video game. Participants were provided with their preferred choice of handles (a horizontal grip or gloves (Bike-On.com, Coventry, RI) that snap into the handles for participants with limited gripping ability) as well as two video games, Need for Speed Underground© and Monster Trucks Masters of Metal©. Subjects were also free to use any game they found to be compatible with the GameCycle™.

At the time of delivery subjects were given an information packet that contained a number of references for the subject, including a quick start guide, a GameCycle™ user's guide, and exercise logs. Additionally they were provided with copies of the Upper Extremity and Neck Flexibility Program published online by The Nicholas Institute of Sports Medicine and Athletic Trauma[51] and Exercise Guidelines for People with Disabilities published online by The National Center on Physical Activity and Disability[52], and exercise logs. The quick start guide provided an overview of the four month trial including the dates during which participants would be using the GameCycle^{TM} with or without the video game, how to log on and off of the GameCycle^{TM}, and other relevant information. The GameCycle^{TM} users guide accompanied the GameCycle^{TM} and gave more in depth detail regarding the use of the system. Participants were encouraged to contact us if they experienced any difficulty using the equipment and visits were made to the participant's home if the problem could not be resolved over the telephone.

Subjects were required to login to the GameCycle^{TM} prior to every exercise session, whether they were exercising alone or playing a game against an opponent, so that the system could collect the following data: user ID, date and time, revolutions per minute (RPM), and resistance level (R). Potential players other than the subject were instructed to login under a different user ID (guest). The procedure to log into the system was demonstrated to subjects and written instructions were provided for reference. All participants were also asked to keep an exercise log, recording the date and time they started and stopped exercising with the GameCycle^{TM}.

During the 4-month trial period subjects were contacted once every two weeks by telephone to determine if the subject was following the exercise regimen, and answer any questions or concerns. In addition, subjects were visited in their home, once a month during which data was collected from the GameCycle^{TM}, exercise logs were collected, and an exercise test was performed. Participants were required to exercise with the GameCycle^{TM} an average of twice per week over a one-month period

3.3.3 Data collected

Demographics including age, gender, ethnicity, injury level, and years living with a disability were collected using a short questionnaire. Along with being required to login to the

GameCycle™ to collect the resistance, RPMs, time, and date of GameCycle™ exercise sessions, participants were asked to keep written exercise logs in which they noted the time and date of their exercise sessions. Participants were also asked what other activities they were participating in during the course of the study; the frequency and duration of these activities were noted.

At the end of the study participants completed the 10 item Center for Epidemiologic Studies Depression Scale (CES-D 10)[40,41] and the Medical Outcomes Study Short Form (SF-36) (Medical Outcomes Trust, Boston, MA)[42,43] to screen for depressive symptology and to measure health status. A third questionnaire was the Exercise Barriers and Self-Efficacy questionnaire (Appendix A). The questionnaire rated participants' responses to questions on an 11 point ordinal scale, incrementing from 0% to 100% by 10%. Participants were asked how confident they were (0% not at all confident, 50% moderately confident, 100% highly confident) that they could continue to exercise if they encountered the following barriers: bad weather, boredom, vacation, lack of interest, pain or discomfort, exercising alone, exercise was not fun or enjoyable, exercise location was difficult to get to, etc.

3.3.4 Exercise Testing

The exercise test entailed completion of a 14 minute exercise test, following the same procedure as the Training Phase.[49] Maximum heart rate (MHR) was calculated (MHR=220-age) and the target zone was determined to be 60% to 80% of the subjects MHR. All subjects were encouraged to exercise at their target zone. Resistance was set at four at the start of the exercise test. During the exercise testing, resistance settings were incremented every two minutes according to the subject's ability to continue exercising for the entire 14 minutes, and recorded. Ratings of perceived exertion (RPE) using the Borg scale were recorded every two minutes as well. Data was collected during exercise with or without game play, depending on the condition of that session. Metabolic data was collected using an Aerograph VO2000 portable gas analyzer (Medical Graphics Corporation, St. Paul, MN) interfaced with a laptop. Heart rate was collected with a Polar Heart Rate Monitor. A minimum of five minutes were provided for cool down.

3.3.5 Statistical Analysis

3.3.5.1 Demographics

All data was analyzed using SPSS 14.0 statistical software. Significance for all tests was set at $p < 0.05$. Descriptive statistics were calculated for subject age, gender, ethnicity, SCI level, and years of disability. Descriptive statistics were also calculated for type, frequency and duration of physical activity outside of the study requirements. The CES-D and SF36 were scored according to their standardized scoring procedure. Responses to the Exercise Barriers and Self-Efficacy questionnaire were tallied and frequency percents are reported. Because of the small cell sizes, ratings of strongly agree and agree were combined as well as strongly disagree and agree. Descriptive statistics were calculated and reported for these surveys.

To investigate whether there were differences between the participants who remained in the study and those that dropped out of the study a Fishers Exact test was used to look at differences in gender (male, female), ethnicity (Caucasian, African American), type of spinal cord injury (paraplegia and quadriplegia), and randomization group (GameCycle™ with the video game first and no video game first) and a Mann-Whitney test was used to look at differences in age and years living with a disability.

3.3.5.2 Hypothesis 1

A repeated measures analysis indicated that metabolic steady state began at 4 min. For each monthly exercise test, HR and VO2 data was averaged starting at steady state for the remainder of the 14 minute exercise trial. A repeated measures analysis was conducted on average VO2 and HR (over time and between groups) ($p < 0.05$). The results of these tests were not significant therefore overall metabolic variable averages were calculated for both exercise with the GameCycle™ and standard ergometer. Finally, a repeated measures analysis was conducted to examine hypothesis of whether there were differences between metabolic variables collected while playing the GameCycle™ and the standard ergometer.

Secondary Analysis: Minute values were calculated for HR and VO2 by averaging the last time values of each minute over the 14 minute trials. A t-test was used to look for significant differences between the GameCycle™ and standard ergometry conditions.

3.3.5.3 Hypothesis 2

Maximum BORG ratings were calculated for the exercise testing sessions. A Wilcoxon Signed Ranks Test was used to compare max Borg with GameCycle™ to max Borg without game ($p < 0.05$) at the end of month two and month four.

Secondary Analysis:

Mode and maximum values were also calculated for the resistance values that were collected every two minutes during the exercise testing sessions. A paired samples t-test was conducted to compare maximum resistance values between exercise testing sessions with the GameCycle™ and standard arm-ergometry.

3.3.5.4 Hypothesis 3

The number of exercise sessions and the average duration of the sessions were calculated from both self-report exercise logs and GameCycle^{TM} data. Hypothesis testing was conducted using data recorded by the GameCycle^{TM}. With the GameCycle^{TM} data, a repeated measure analysis showed consistency within groups and over time. A Wilcoxon test ($p < 0.05$) was conducted to compare session duration with and without the video game and to test the hypothesis that there was a significant difference between the number of exercise sessions performed with and without a video game.

Secondary Analysis:

Secondary analysis was conducted calculating the intraclass correlation coefficient between the exercise session and duration data collected with the GameCycle^{TM} and self-report scales. Also the mode and maximum resistance (R) settings participants used for each exercise session was calculated as well as average RPM. A Wilcoxon was used to compare the RPM values between the GameCycle^{TM} and standard ergometry to see if any differences existed.

3.4 RESULTS

3.4.1 Subject Demographics

There were fourteen subjects who completed the training phase and were asked if they would be interested in participating in the study. Of those subjects, eleven s volunteered to participate in this cross-over study. Those who did not participated cited the following reasons: no room for a GameCycle^{TM} in their home, adopting a child, lack of time because of work.

Two subjects dropped out during the study due to personal issues which included being too busy with home repairs and having a "lack of motivation," resulting in nine subjects completing the study. Subjects that completed the study included one woman and eight men, with a mean age of 36.2 (+/- 5.5) years, of which eight subjects were Caucasian and one was African American. Subjects had lived with an injury for an average of 11.7 (+/- 5.8) years. Of the nine subjects injury levels ranged from C4 to T12, with five subjects having an injury C7 and above. Of the participants that completed the study, eight of them opted to keep the GameCycle™ and one opted for cash compensation for their time and effort.

Table 10. In-Home Participant Demographics

ID	Age	Gender	Ethnic Origin	Disability	Years of Disability	Starting Exercise Group
01	37	F	Caucasian	SCI T5	20.7	Game
02	32	M	Caucasian	SCI C7	12.8	Game
03	38	M	Caucasian	SCI T11	12.5	Game
04	39	M	Caucasian	SCI C4	7.4	No game
05	33	M	Caucasian	SCI C5	2.8	No game
06	25	M	Caucasian	SCI C5	7.2	No game
07	45	M	African-American	SCI T4	10.6	No game
08	40	M	Caucasian	SCI T12	19.9	No game
09	36	M	Caucasian	SCI C7	12.2	Game
10*	41	M	African-American	SCI C6	3.6	Game
11*	48	M	Caucasian	SCI T7	29.6	No game

*participants who dropped out of study

The results from the Fishers Exact tests showed that there was no significant difference between those who participated in the study and those who dropped out of the study concerning gender (p=1.000), ethnicity (p=0.345), type of spinal cord injury (quadriplegia vs. paraplegia) (p=1.000), and the group that they were randomized to (GameCycle™ with the video game first and no video game first) (p=1.000). Mann-Whitney results also showed no difference between age (p=0.059) and years living with a disability (p=0.814). The close to significant difference in age can be explained by the 10 year difference in average age between participants (Mean=35, SD=5) and drop outs (Mean=45, SD=5).

Over the course of the four month trial, nine participants participated in physical activity other than the GameCycle™ (Table 11). Rugby, swimming, calisthenics, fishing, and cycling were reported as having one subject participating in the activity. Two participants reported that they participated in weight lifting, basketball, or racing and three people practiced wheeling. Activities reported but not included in the calculations included baby sitting, working on a vehicle, basketball camp and coaching, and shopping.

Table 11. Physical Activity Outside of Protocol Requirements (n=9)

Type of Activity	#	%
Weight Lifting	2	22%
Basketball	2	22%
Wheeling	3	33%
Racing	2	22%
Rugby	1	11%
Swimming	1	11%
Calisthenics	1	11%
Fishing	1	11%
Cycling	1	11%
None	1	11%

Table 12. Physical Activity Participation Outside of Study Requirements

ID	Frequency	Duration (Hours)
01	12	1 to 2
02	2	1 to 3
03	7	1.5 to 2.5
04	0	0
05	2	0.5
06	1	0.5
07	7	3.5
08	1	1.5
09	4	0.75 to 2

Six participants exercised or participated in some type of physical activity 1 to 12 times a week for 0.75 to 3.5 hours (Table 12). Overall activity levels of the study participants was near to recommended guidelines.[53]

Table 13 summarizes the SF-36 and CESD-10 scores for all study participants. The results of the SF-36 suggest that the majority of study participants have problems with work or other daily activities as a result of their physical health (Role Physical Median = 0) and emotional problems (Role Emotional Median = 0). However results also suggest that the majority of participants have no limitations performing physical activities (Physical Functioning Median = 100), see their personal health as excellent (General Health Median = 77), are not limited due to pain (Bodily Pain Median = 84), and that physical and emotional problems do not interfere with normal social activities (Social Functioning Median = 88). Vitality results (Median = 60) suggest that participants can feel tired or worn out and Mental Health results (Median = 44) suggest that participants do have feelings of nervousness or depression. The Physical Component Summary (Median = 54) suggests that there is some limitation in self-care and the Mental Component Summary (Median = 32) suggests that emotional problems cause psychological distress.

Table 13. SF-36 Norm-based scale and component scores and CESD-10 Scores

Scale	Median, Range, Skewness	Subject #								
		1	2	3	4	5	6	7	8	9
Physical Functioning	100, 0–100, -1.17	100	100	100	0	60	100	40	60	100
Role Physical	0,1 – 100, 1.93	0	0	0	100	0	0	50	25	0
General Health	77, 32–100, -1.06	72	80	100	42	87	87	77	32	77
Vitality	60, 50 – 80, 0.34	55	55	70	70	80	50	60	60	70
Social Functioning	88, 75–100, 0.00	75	88	88	75	100	88	88	88	100
Mental Health	44, 28 – 56, -0.05	48	40	32	56	44	48	28	44	32
Role Emotional	0, 0 – 100, 3.00	0	0	0	100	0	0	0	0	0
Bodily Pain	84, 41– 100, -0.63	84	80	100	52	100	100	41	41	100
Physical Component Summary	54, 31 – 61, -0.98	54	55	61	31	51	57	45	38	58
Mental Component Summary	32, 29 – 56, 2.21	31	31	29	56	39	32	34	38	31
CESD-10	Mean: 3.67 SD: 1.66	2	4	4	2	3	2	7	4	5

CESD-10 scored resulted in a range of responses from 2 to 7 with a mean of 3.67 (SD: 1.66, skewness: 0.893). A parametric independent samples t-test compared results between persons with paraplegia and quadriplegia and results were not significant (p=0.417).

Table 14. Exercise Barriers and Self-efficacy Results

Exercise Barriers and Self-efficacy	*Not Confident (0%-30%)*	*Moderately Confident (40%-70%)*	*Highly Confident (80%-100%)*	*N*
I believe that I could continue to exercise 3 times per week for the next 3 months if:				
The weather was very bad (hot, humid, rainy, cold)	0 (0%)	0 (0%)	9 (100%)	9
I was bored by the program or activity	1 (11%)	2 (22%)	6 (67%)	9
I was on vacation	3 (33%)	4 (44%)	2 (22%)	9
I was not interested in the activity	2 (22%)	4 (44%)	3 (33%)	9
I felt pain or discomfort when exercising	2 (22%)	4 (44%)	3 (33%)	9
I had to exercise alone	1 (11%)	2 (22%)	6 (67%)	9
It was not fun or enjoyable	2 (22%)	3 (33%)	4 (44%)	9
It became difficult to get to the exercise location	4 (44%)	3 (33%)	2 (22%)	9
I didn't like the particular activity program that I was involved in	1 (11%)	4 (44%)	4 (44%)	9
My work schedule conflicted with my exercise session	3 (33%)	5 (56%)	1 (11%)	9
I felt self-conscious about my appearance when I exercised	1 (11%)	2 (22%)	6 (67%)	9
The instructor did not offer any encouragement	2 (22%)	1 (11%)	6 (67%)	9
I was under personal stress of some kind	3 (33%)	3 (33%)	3 (33%)	9
I am able to continue to exercise three times per week at moderate intensity, for 40+ minutes without quitting for the NEXT				
Week	2 (22%)	2 (22%)	5 (56%)	9
2 Weeks	2 (22%)	1 (11%)	6 (67%)	9
3 Weeks	2 (22%)	2 (22%)	5 (56%)	9
4 Weeks	2 (22%)	2 (22%)	5 (56%)	9
5 Weeks	2 (22%)	2 (22%)	5 (56%)	9
6 Weeks	2 (22%)	3 (33%)	4 (44%)	9
7 Weeks	2 (22%)	3 (33%)	4 (44%)	9
8 Weeks	2 (22%)	3 (33%)	4 (44%)	9

The responses to the Exercise Barriers and Self-Efficacy questionnaire are presented in Table 14. 100% of participants felt highly confident that that they could continue to exercise 3 times per week for the next 3 months if the weather was bad. 67% felt highly confident that they could continue exercising a. if they were bored by the program or activity, b. had to exercise along, c. if they were self-conscious about their appearance, and d. the instructor didn't offer any encouragement. This suggests that bad weather, exercising alone, boredom with the activity, self-consciousness about appearance, and the lack of instructor encouragement are not barriers to exercise for the majority of the study's participant population.

Participants were split regarding whether or not they could continue exercising if they didn't like the particular activity program they were involved in with 44% responding that they were moderately confident and 44% responding that they were highly confident they could continue to keep exercising.

44% of participants only felt moderately confident that they could continue exercising if they were on vacation (NC: 33%, MC: 44%, HC: 22%), they were not interested in the activity (NC: 22%, MC: 44%, HC: 33%), or if they felt pain or discomfort while exercising (NC: 22%, MC: 44%, HC: 33%). 44% of participants felt highly confident, 33% felt moderately confident, and 22% felt not at all confident that they could continue exercising if it was not fun or enjoyable. Responses were evenly distributed regarding whether participants felt they could continue exercising under personal stress (NC: 33%, MC: 33%, HC: 33%). These results suggest that vacation, interest in the activity, pain and discomfort, and personal stress were moderate barriers for this population. Work schedule also seems to be an important barrier as 33% were not at all confident, 56% were moderately confident, and 11% were highly confident that they could continue to exercise if there was a conflict with their work schedule.

3.4.1.1 Exercise Self-Efficacy

Most of the respondents (56%) were highly confident that they could continue exercising for 40+ minutes, 3 times a week, for the next week, while 22% were not at all confident and 22% were moderately confident. Two subjects answered not at all confident to all 8 weeks, which is possibly due to the duration of the exercise session (40 minutes) being used in the question. 44%

of respondents felt highly confident that they could keep exercising in 8 weeks, with 33% moderately confident and 22% not at all confident.

3.4.2 Metabolic Results

Figure 7 shows the plot of raw VO2 data over time for one subject. The highlighted data point at minute four shows the approximated point of steady state used for calculating average HR and VO2. This is an appropriate estimation for the beginning of steady state.[44] The sharp decrease in VO2 noted at minute fourteen represents the end of the exercise session.

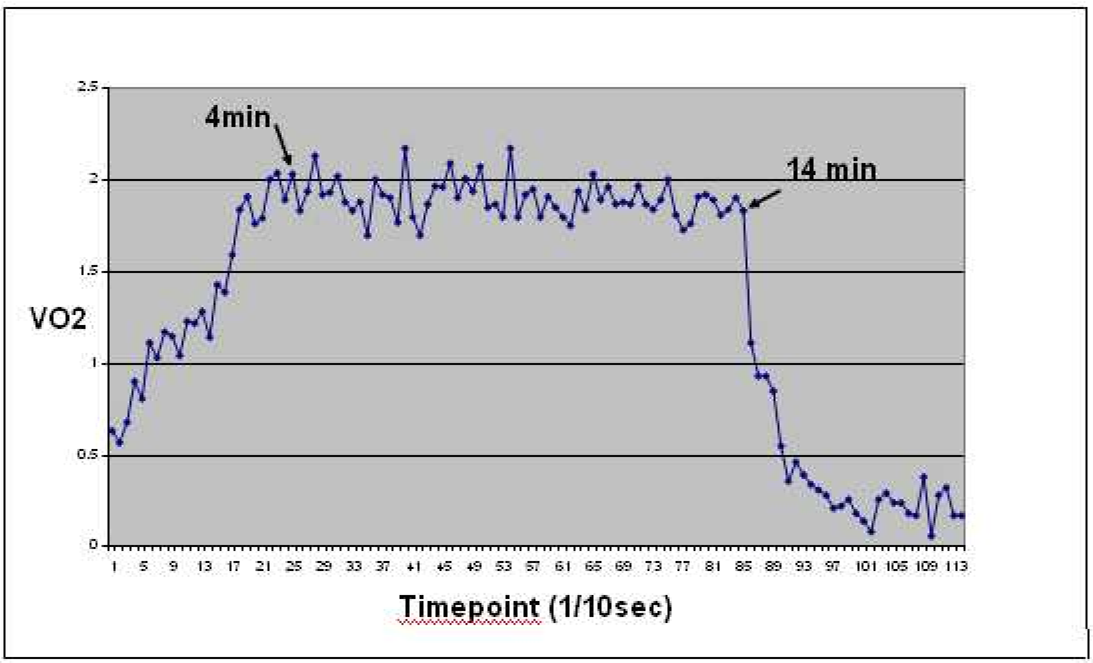

Figure 8. Plot of Raw VO2 Data (Subject 52)

Table fifteen shows the average HR and VO2 values calculated for each subject over the four month trial. A repeated measures analysis showed that randomization of the interventions was successful as VO2 was consistent over the entire trial. Table nine shows the average HR and VO2 values for each subject for each month of the study, by intervention. A repeated measures analysis conducted on each group showed that HR and VO2 variables were consistent within each group. Results of the repeated measures analysis comparing physiologic variables (HR, VO2) between the GameCycle™ and the arm-ergometer showed no significant difference, most likely due to the small population sample. Nine subjects completed testing while the study design required 25 subjects to reach a power of 80%.

Table 15. Average HR and VO2 Variables Over Time

	Baseline		Month 1		Month 2		Month 3		Month 4		
ID	HR	VO2	HR	VO2	HR	VO2	HR	VO2	HR	VO2	
01	139	0.83	145	1.35	146	1.54	136	0.80	128	1.50	*
02	112	0.79	120	0.90	154	1.35	118	0.84	108	0.72	*
03	127	1.33	152	2.06	137	1.64	137	1.89	134	1.90	*
04	113	0.44	135	0.34	122	0.68	146	0.46	107	0.45	
05	83	1.37	80	0.93	78	0.94	100	1.66	87	0.88	
06	96	0.57	121	0.90	109	1.13	114	1.19	101	0.79	
07	135	0.65	116	0.38	121	0.56	96	0.48	57	0.37	
08	133	1.20	114	0.36	128	1.14	125	1.42	110	1.22	
09	133	1.12	125	1.01	146	1.16	133	1.88	136	1.80	*

*Subjects randomized to the GameCycle™ first group

Table 16. Average HR and Average VO2 by Exercise Intervention

			GameCycle™						Standard Ergometer					
	Baseline		month 1		month 2		overall		month 1		month 2		Overall	
ID	HR	VO2	HR	VO2	HR	VO2	HR	VO2	HR	VO2	HR	VO2	HR	VO2
01	139	0.83	145	1.35	146	1.54	145	1.45	136	0.80	128	1.50	132	1.15
02	112	0.79	120	0.90	154	1.35	137	1.13	118	0.84	108	0.72	113	0.78
03	127	1.33	152	2.06	137	1.64	144	1.85	137	1.89	134	1.90	135	1.90
04	113	0.44	146	0.46	107	0.45	127	0.46	135	0.34	122	0.68	128	0.51
05	83	1.37	100	1.66	87	0.88	93	1.27	80	0.93	78	0.94	79	0.94
06	96	0.57	114	1.19	101	0.79	107	0.99	121	0.90	109	1.13	115	1.01
07	135	0.65	96	0.48	57	0.37	77	0.43	116	0.38	121	0.56	118	0.47
08	133	1.20	125	1.42	110	1.22	118	1.32	114	0.36	128	1.14	121	0.75
09	133	1.12	125	1.01	146	1.16	135	1.09	133	1.88	136	1.80	135	1.84

Subjects were divided into groups to see how average VO2 changed within the groups (figure 8). In this graph subjects who received the GameCycle™ first improved VO2 through out the whole trial. However, at month four the ergometer first group did show a decrease. The secondary analysis of VO2 and HR at minute fourteen of the exercise trials showed no significant difference between the GameCycle™ and standard-ergometry conditions. ($p=0.359$ and $p=0.514$ respectively).

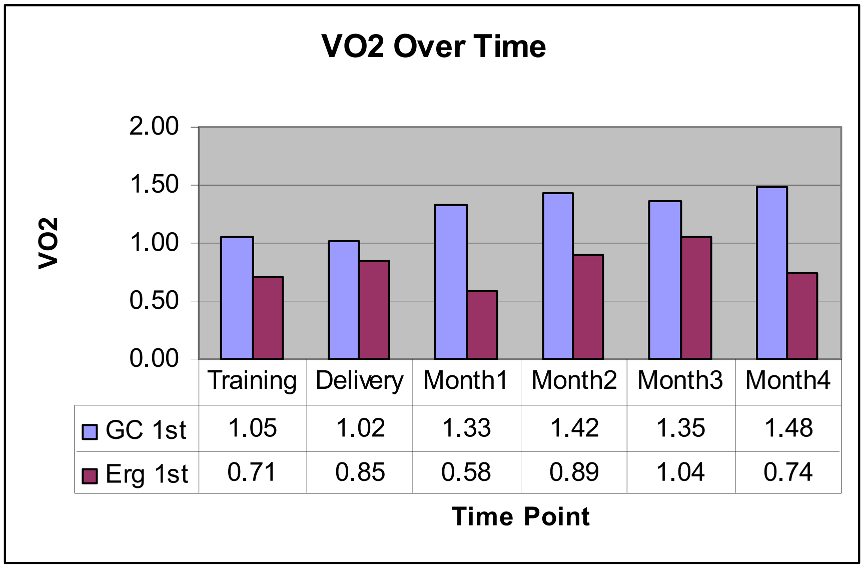

Figure 9: Average VO2 Over Time

3.4.3 Ratings Of Perceived Exertion

Table 17 shows the results of resistance settings and ratings of perceived exertion given during exercise testing. Results from the Wilcoxon Signed Ranks Test show that there is not a significant difference for the maximum RPE reported when using the GameCycle™ and performing standard arm-ergometry. The results of the paired samples t-test indicate that there is no significant difference between resistance values obtained between the GameCycle™ and standard ergometer ($p=0.482$).

Table 17: Results for Resistance Settings Used During Exercise Testing and Ratings of Perceived Exertions

	Baseline			month 1			month 2			month 3			month 4		
	Resistance		RPE	Resistance		RPE	Resistance		RPE	Resistance		RPE	Resistance		RPE
ID	Max	Mode	Max	Max	Mode	Max	Max	Mode	Max	Max	Mode	Max	Max	Mode	Max
01	5	5	9	4	4	7	6	6	8	7	7	12	7	6	10
02	5	4	13	7	7	13	8	8	16	7	6	13	7	5	15
03	6	4	8	9	9	6	9	9	6	9	9	6	9	9	6
04	4	2	17	4	2	15	4	1	13	2	2	17	0	0	13
05	3	3	15	3	3	12	3	3	13	4	4	12	4	4	12
06	4	3	11	4	4	11	4	4	12	4	4	10	4	4	11
07	4	4	11	5	1	8	5	4	10	5	5	8	7	7	9
07	5	5	13	8	6	15	8	4	15	6	6	12	7	4	12
09	5	5	14	5	5	15	5	5	13	6	5	15	7	4	13

3.4.4 Exercise Participation

3.4.4.1 Exercise Frequency and Duration

Table 18 summarizes the variables for each exercise method using the data collected by the GameCycle™ when the subject logged into the system. The number of sessions performed with the GameCycle™ as well as the average duration of the sessions was greater for six of the nine subjects. The results of the Wilcoxon test showed that subjects exercised significantly (p=0.035) longer with the GameCycle™ (41 + 39 minutes) than with the ergometer (29 + 29 minutes). The t-test showed that there was not a significant difference (p=0.172) between the frequency of exercise when using the GameCycle™ and when performing standard ergometry.

Table 18. Exercise Session Results for All Subjects by Exercise Method

*The exercise mode with greater sessions is highlighted

Subject Number	Exercise Type	Sessions	Average Duration (min/session)	Average RPM	Maximum RPM	Resistance Setting Mode	Maximum Resistance Setting
N=9	1=GameCycle^{TM} 0=Ergometer	Mean: 21.8 SD: 10.8	Mean: 35 SD: 34	Mean: 107.07 SD:14.37	Mean: 162.72 SD: 21.1	Min: 1 Max: 9	Min: 2 Max: 9
01	1	14	22	114.49	138	5	5
01	0	9	10	117.05	146	5	7
02	1	26	34	82.44	136	7	9
02	0	18	21	78.44	145	8	9
03	1	48	126	100.04	151	9	9
03	0	26	100	113.08	178	9	9
04	1	20	15	104.20	186	1	2
04	0	24	14	119.96	160	1	4
05	1	40	16	114.70	186	4	6
05	0	31	16	117.37	170	3	4
06	1	16	85	108.86	179	4	7
06	0	26	37	114.69	178	3	7
07	1	5	15	114.13	179	3	4
07	0	13	14	122.51	199	1	5
08	1	26	22	77.48	135	5	7
08	0	16	11	121.08	136	3	9
09	1	25	32	98.11	147	6	7
09	0	10	37	108.70	180	6	9

The intraclass correlation coefficient calculated for session duration recorded by the Gamecycle^{TM} and the self-report exercise logs was 0.987 (p=0.000), which shows that both the GameCycle^{TM} and self-report logs have reported exercise session durations that are nearly the same. The intraclass correlation coefficient calculated for the number of sessions recorded by the Gamecycle^{TM} and the self-report exercise logs was 0.883 (p=0.000), suggesting again that the number of sessions reported by the GameCycle^{TM} and self-report logs are consistent.

Table 19. Exercise Frequency and Duration with and without Video Gaming

		Exercise Logs		GameCycle™ Data	
ID	Game	Avg. Duration	# Sessions	Avg. Duration	# Sessions
01	0	10	12	10	9
01	1	23	16	22	14
02	0	24	18	21	18
02	1	38	10	34	26
03	0	103	28	100	26
03	1	133	53	126	48
04	0	15	23	14	24
04	1	17	23	16	20
05	0	15	31	15	31
05	1	NA	NA	16	40
06	0	48	25	37	26
06	1	89	15	85	16
07	0	26	13	14	13
07	1	22	15	15	5
08	0	12	18	11	16
08	1	23	29	22	26
09	0	42	10	37	10
09	1	42	25	32	25
*NA – Data Not Available					

3.4.4.2 Self-selected Exercise Intensity

Self-selected exercise intensity is defined as the RPMs and resistance settings used by participants while completing their exercise bouts. There was no difference between the maximum resistances used between the devices (p=0.133). Figures 9 and 10 are plots of a representative subject's raw RPM values over time while using standard arm-ergometry and the GameCycle™, respectively. Data collection is initiated as soon as the subject logged in to the system, regardless of whether the system was being used for exercise. Repeated measures analysis concluded that RPM values were consistent within the intervention (GameCycle™/Ergometer). Eight of the nine subjects exhibited using increased average RPMs when using standard ergometry.

One difference between standard arm-ergometry and ergometry with the GameCycle™ is that time is required to move through menus in order to set up a game. Data points at the beginning of the session that represented game setup were removed, as well as data points at the end of the session that represented ending the game and logging off of the system. The results of the Wilcoxon test showed that subjects had significantly ($p=0.021$) higher average RPMs with the ergometer (112 + 13) than with the GameCycle™ (102 + 14).

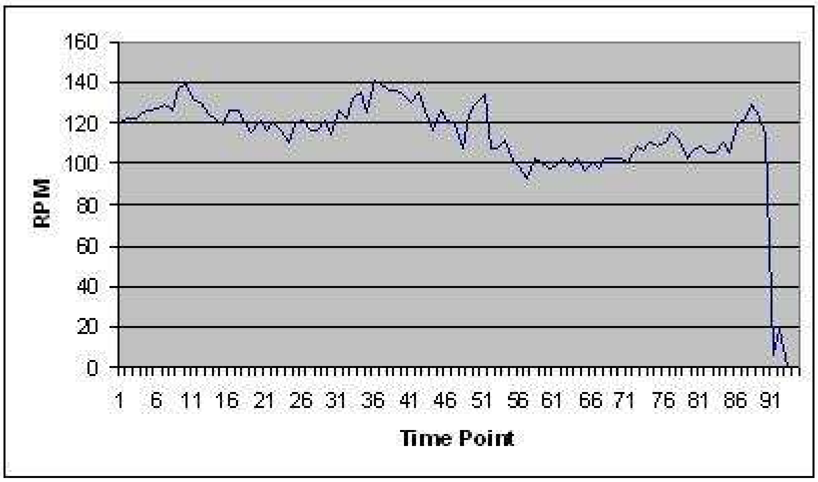

Figure 10. Plot of Raw RPM Data While Performing Standard Ergometry

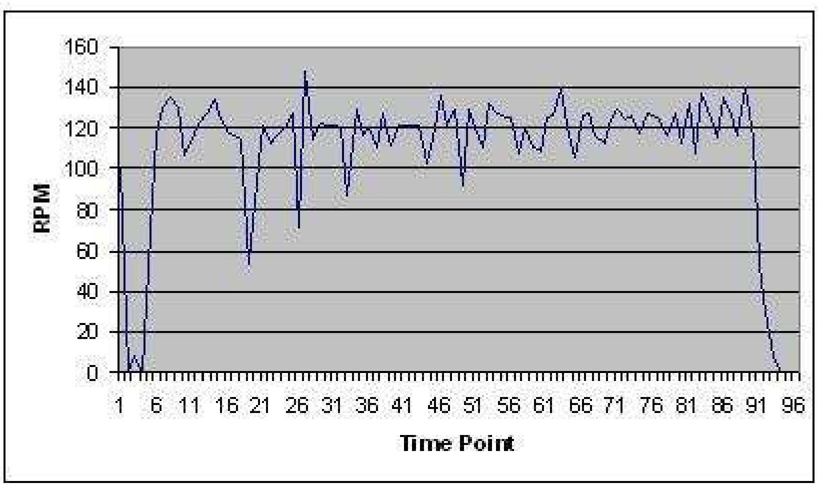

Figure 11. Plot of Raw RPM Data While Performing Ergometry with the GameCycle™

3.5 DISCUSSION

One of the challenges of this study was to create a testing protocol that was appropriate for the diverse sample. Physical activity levels ranged from sedentary to extremely active. The choice of requiring participants to exercise twice a week was appropriate for those subjects who were sedentary, but an increased frequency of use for more active participants may have given different results. The American College of Sports Medicine recommends that adults exercise for 20 to 60 minutes, three to five times a week. Some participants met this recommendation using the GameCycle^{TM} alone and some met the recommendation by continuing to participate in other fitness activities.

Future studies should develop a more controlled training protocol, controlling for participant fitness levels as they enter the study. One limitation to the presented study is that a maximum VO2 test was not performed at the time of delivery and therefore the submaximal tests performed were not target to track maximal VO2 over time, the most reliable measure of aerobic fitness. Another limitation was that participant physical activity levels were not measured at the onset of the study, so no conclusions can be drawn concerning how the GameCycle^{TM} impacted their physical activity routines.

For the purposes of this study, exercise session and duration data used for hypothesis testing was taken from the data collected by the GameCycle^{TM} when the user logged on to the system since it was assumed that this data would be more reliable than a self-report measure. Data analysis showed that both the self-report exercise logs and the GameCycle^{TM} data were consistent for the number of exercise sessions reported and the duration of the session.

The collection of both a self-report exercise log and objective exercise measures such as the system log to validate findings of exercise session frequency and duration cannot be underestimated as a number of situations can lead to incorrect results. Increased exercise sessions reported by the GameCycle™ could be caused by other users logging on to the system, the system resetting and requiring a second logon during the exercise session, or participants forgetting to log their exercise session. Decreased exercise sessions reported by the GameCycle™ could be caused by users not logging in to the system, corrupted data files, or a hardware malfunction that caused the data card to become disconnected. Future studies should keep these factors in mind.

Participants of the study were allowed to experiment with other video games during the course of the study and were free to use any video game that was compatible. There were a few subjects that took the initiative to do this over the course of the four months. No data were collected during the experiment regarding what games people used and how often. It would be interesting for future studies to look at this as it could be very important for businesses such as fitness facilities to provide a range of different games to their customers to keep them engaged.

The results of this study showed that there was no difference in metabolic variables (average VO2 and average HR over a 14 minute exercise session) or RPE ratings between the GameCycle™ and standard arm ergometry. This may be due to the exercise testing protocol that was utilized in previous GameCycle™ research which was meant to show that participants could meet target training zones and to compare equipment. Future studies should use a protocol to measure VO2 max and compare fitness levels between the GameCycle™ and a standard ergometer. Also the study is limited by the small sample size and could be the reason for not reaching statistical significance. Other limitations include not controlling for medications, time of day, food consumption, and activity prior to testing.

The most important results of this study are that subjects exercise for longer durations when using the GameCycle™ as compared to standard ergometry, which suggests that the GameCycle™ motivated people to exercise longer possible because it is more enjoyable or because people are focused on playing the video game. The fact that there was no significant difference in the number of exercise sessions subjects performed could be due to the requirement that subjects exercise an average of twice a week to remain in the study or could be due to the fact that the majority of participants were already very active. Future studies should focus on the sedentary part of the population, those in most need of improvements in technology and programming, and not those who are already very physically active.

Our findings also indicate that average RPMs were higher when using standard arm-ergometry. While playing racing games, users are often required to turn corners, coast, jump, negotiate obstacles and recover from wrecking. This is one cause for the difference in RPMs between the two methods of exercise. Also, while watching subjects play it was common for those who had carpal tunnel syndrome to stop cycling every few minutes to shake out their wrists. This would explain low values being found during standard arm-ergometry as well as GameCycling™.

3.6 CONCLUSION

The integration of video gaming and exercise activities shows promise as an alternative to standard exercise activities. However, stronger evidence is needed through larger studies and should focus on the more sedentary portion of the population of people with disabilities. Future work with the GameCycle™ will look at psychosocial outcomes of the study presented in this paper. The GameCycle™ has the potential to be used as a training device for arm-cycling, similar to the stationary bicycle that cyclists use to train. Also, it would be interesting to further develop the GameCycle™ so that it could be used online to exercise and develop an online exercise community.

4.0 SUMMARY

The previous chapters discussed a study focused on the usability of the GameCycle^{TM} and an in-home comparison of the GameCycle^{TM} and a standard ergometer. The GameCycle^{TM} is a great example of a technology developed at the university level, by a diverse team of engineers, technologists, clinicians and end users using an end-user centered design process. The discussed studies are focused on the commercial product, to evaluate the product and to provide valuable feedback to the manufacturer.

Lessons learned while observing participants use the device and set up the device in their homes will help develop future products designed specifically for in-home use. This includes lower and closer mounting of the GameCube^{TM} for easier access and buttons that require less force to push. The GameCycle^{TM} is 29" wide by 50" high by 50" long.[6] The weight of the GameCycle^{TM} makes it stable enough for vigorous exercise, yet it is designed with wheels to make it portable. For some participants, the integration of the GameCycle^{TM} into their homes was difficult because of the large size of the device, required to provide stability of a free standing exercise device. Suggested future development of the GameCycle^{TM} would be a smaller, table top unit that would be easier to store and transport, as well as more affordable.

The presented studies were greatly limited by the number of participants that researchers were able to recruit due to the cost of the GameCycles^{TM} and the in-home nature of the research. Future research should focus on changes in fitness over time while using the GameCycle^{TM} and would be strengthened by using a randomized clinical trial design and a controlled exercise regimen.

An article published by Rimmer et. al. showed that most facilities have been found to not to meet the needs of persons with disabilities.[54] Future research could be done focusing on how the integration of such accessible devices into facilities can impact the participation of persons with disabilities in exercise programs. The GameCycle™ also has the potential to increase the exercise participation of children as well as adults, with and without disabilities.

The GameCycle™ has the potential to have other benefits outside of being an alternative form of arm ergometry. Rimmer et. al. mention barriers such as emotional and psychological barriers and perceptions and attitudes of persons who are not disabled.[55] Incorporating exercise devices such the GameCycle™ in fitness facilities could be a great way to over come these barriers.

Finally, the possibility of providing people with virtual exercise environments that will allow them to compete with other people via the internet is also a future possibility. With the advancement of gaming technologies and the development of gaming consoles that can connect to gaming servers it is likely that this ability will be integrated into all gaming consoles, including the GameCube™. The type of community that forms when gamers connect on a server could provide people with an enjoyable alternative to exercising alone, giving them a community that would provide them with competition and camaraderie.

APPENDIX A

BARRIERS AND SELF-EFFICACY QUESTIONNAIRE

The following items reflect situations that are listed as common reasons for preventing individuals from participating in exercise sessions. Using the scales below, please indicate how confident you are that you could exercise in the event that any of the following circumstances were to occur.

For example, if you have complete confidence that you could exercise even if you were bored by the activity, you would circle 100%. However, if you had no confidence at all that you could exercise, if you failed to make progress, you would circle 0%.

Please answer honestly and accurately. There are no right or wrong answers. Mark your answer by circling a %:

I BELIEVE THAT I COULD CONTINUE TO EXERCISE 3 TIMES PER WEEK FOR THE NEXT 3 MONTHS IF:

The weather was very bad (hot, humid, rainy, cold)

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Not at all confident				Moderately Confident					Highly Confident	

I was bored by the program or activity

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Not at all confident				Moderately Confident					Highly Confident	

I was on vacation

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Not at all confident				Moderately Confident					Highly Confident	

I was not interested in the activity

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Not at all confident				Moderately Confident					Highly Confident	

I BELIEVE THAT I COULD CONTINUE TO EXERCISE 3 TIMES PER WEEK FOR THE NEXT 3 MONTHS IF:

I felt pain or discomfort when exercising

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Not at all confident				Moderately Confident					Highly Confident	

I had to exercise alone

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Not at all confident				Moderately Confident					Highly Confident	

It was not fun or enjoyable

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Not at all confident				Moderately Confident					Highly Confident	

It became difficult to get to the exercise location

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Not at all confident				Moderately Confident					Highly Confident	

I didn't like the particular activity program that I was involved in

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Not at all confident				Moderately Confident					Highly Confident	

My work schedule conflicted with my exercise session

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Not at all confident				Moderately Confident					Highly Confident	

I BELIEVE THAT I COULD CONTINUE TO EXERCISE 3 TIMES PER WEEK FOR THE NEXT 3 MONTHS IF:

I felt self-conscious about my appearance when I exercised

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Not at all confident				Moderately Confident					Highly Confident	

The instructor did not offer any encouragement

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Not at all confident				Moderately Confident					Highly Confident	

I was under personal stress of some kind

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Not at all confident				Moderately Confident					Highly Confident	

The next items listed below are designed to assess your beliefs in your ability to continue exercising on a three time per week basis at moderate intensities (upper end of your perceived exertion range), for 40+ minutes per session in the future. Using the scales listed below, please indicate how confident you are that you will be able to continue to exercise in the future.

For example, if you have complete confidence that you could exercise three times per week at moderate intensity for 40+ minutes for the next four weeks without quitting, you would circle 100%. However, if you had no confidence at all that you could exercise at your exercise prescription for the next four weeks without quitting, you would circle 0%.

Please answer honestly and accurately. There are no right or wrong answers. Mark your answer by circling a %:

I am able to continue to exercise three times per week at moderate intensity, for 40+ minutes without quitting for the NEXT WEEK.

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Not at all confident				Moderately Confident					Highly Confident	

I am able to continue to exercise three times per week at moderate intensity, for 40+ minutes without quitting for the NEXT TWO WEEKS.

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Not at all confident				Moderately Confident					Highly Confident	

I am able to continue to exercise three times per week at moderate intensity, for 40+ minutes without quitting for the NEXT THREE WEEKS.

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Not at all confident				Moderately Confident					Highly Confident	

I am able to continue to exercise three times per week at moderate intensity, for 40+ minutes without quitting for the NEXT FOUR WEEKS.

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Not at all confident				Moderately Confident					Highly Confident	

I am able to continue to exercise three times per week at moderate intensity, for 40+ minutes without quitting for the NEXT FIVE WEEKS.

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Not at all confident				Moderately Confident					Highly Confident	

I am able to continue to exercise three times per week at moderate intensity, for 40+ minutes without quitting for the NEXT SIX WEEKS.

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Not at all confident				Moderately Confident					Highly Confident	

I am able to continue to exercise three times per week at moderate intensity, for 40+ minutes without quitting for the NEXT SEVEN WEEKS.

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Not at all confident				Moderately Confident					Highly Confident	

I am able to continue to exercise three times per week at moderate intensity, for 40+ minutes without quitting for the NEXT EIGHT WEEKS.

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Not at all confident				Moderately Confident					Highly Confident	

APPENDIX B

GAMECYCLE^{TM} TRAINING SCRIPT

1. ***Note time.***

2. Training Script

Today we will teach you how to set up the GameCycle and configure it for your own personal use. Our goal is to train you so that you know how to use it independently and are able to show us how to set it up and use it yourself. Feel free to stop us and ask us questions at any time.

The GameCycle is an arm ergometer that has been interfaced with a Nintendo GameCube so that you are able to play video games while exercising with the ergometer. It has the capability to be used with almost any racing game. Currently, the prototype works with Need for Speed Underground, Racing Evolution, and Monster Trucks Masters of Metal.

a. GameCycle Setup

If you'll step to the side here, I will show you how to use the GameCube to load a game. The "Open" button is located on the top of the GameCube on the right back side. To load the game, press the "Open" button, place the disk inside, press down on the disk to click it in, and close the lid. Next, press the white "Power" button, located on the top front of the GameCube, on the left side, to turn the GameCube on. There is also a reset button located on the top right, front of the GameCube. A memory card, located on the right side of the Nintendo GameCube, saves information such as user profile and game statistics. Next, press the Power button on the LCD screen. It is the long slender button located at the top middle of the LCD. It is important to make sure that the TV is in AV2 mode so that the screen will work.

b. GameCycle Fitting

To properly use the GameCycle, roll onto the matt so that you are positioned with the GameCycle directly in front of you centered between your shoulders. Remember to put your breaks on. The height of the GameCycle can be adjusted with a pin located directly below the ergometer on the frame. The GameCycle currently requires a wrench for adjustment. (**Adjust the height of the GameCycle to fit the subject)** When adjusting the height keep in mind that the GameCycle should be comfortable to use and your arms should be close to a 120 degree angle when the cranks are furthest from your body. **Does the ergometer feel comfortable, or does it feel like it is too close to you or too far from you?**

The GameCycle also has a second handle option. Gloves are available for use and can be swapped in using a wrench. **(Would you prefer to use these handles?)** At any time during game play the resistance of the GameCycle can be changed using the up and down arrows. Up increases the resistance and down decreases the resistance.

c. Game Setup

The GameCycle controller is configured such as a GameCube controller would be. If you are familiar with the GameCube, pressing the A button, B button, or the arrows is the same as pressing the control pad or the "A" and "B" buttons on the GameCube controller.

You can scroll by using either rotating the arm cranks or using the up and down arrows. Rotating the GameCycle forward scrolls up and rotating the GameCycle backward scrolls down. Turning left and right moves left and right as well. The "A" button is typically used for selection and the "B" button is typically used to go back a menu. These vary from game to game.

Now we will use the buttons to set up the game.

- Press Start until you reach the "Driver Profile" screen
- Here you may select your profile. Select no by pressing the "A" button to go to the main menu for today.
- Select Quick Race using the cranks to scroll and pressing "A" to select.
- Select Circuit using the cranks to scroll and pressing "A" to select.
- Select your car by turning left or right and pressing "A" to select.

- Select Auto transmission by pressing the “A” button (you cannot select manual because shifting is not available).
- Choose the course “Olympic Square” for today.
- At this screen we will set mode options by cranking forward or backward to select the option from the list and turning left or right to change the setting.
- Set the number of laps to 2 for today’s session.
- Crank to select the traffic option and select “minimum traffic.”
- Set “catch up” to on.
- Set “opponent skill” to “easy.”
- When finished press the “A” button to “Accept.”

Allow the subject to play the game for two laps:

- If you have any numbness or tingling at any time we can stop
- We would like you to play for awhile to get used to the GameCycle. Then we will ask you to demonstrate how to set up the GameCycle for game play.

Pointers to give during game play

- The arrows on the screen show you which direction to go and you get a message when you are going the wrong direction.
- During racing you may press the “Start” button to pause, you will have the option to restart, quit, or choose other options.
- During game play it is recommended to shift your weight from side-to-side, as apposed to moving your shoulders
- Steering while turning will make your turn smoother and under control

- Break by cranking backwards when approaching a turn

<u>At the end of the two laps:</u>

- Do you have any questions?
- Are you comfortable with driving?
- Now we will turn the system off and remove the disk and have you set it up yourself.

3. ***<u>Note time and turn GameCycle monitor and GameCube off. Remove the game CD.</u>***

4. **Read Demonstration Script**

a. GameCycle Setup

<u>Subject</u> can you show or tell me how to load a game and turn the gaming system and monitor on?

b. GameCycle Fitting

<u>Subject</u> can you show me the appropriate position for using the GameCycle?

<u>Subject</u> can you show me how to adjust the resistance of the GameCycle?

c. Game Setup

<u>Subject</u> can you use the "quick start" option and play a game?

5. ***<u>Note time.</u>***

APPENDIX C

GAMECYCLE FEATURE QUESTIONNAIRE

Please tell it like it is – we want your honest opinion of the GameCycle. Only through your forthright responses can we make it better. For each statement below please check the response that best indicates your opinion.

1) The GameCycle was easy to learn how to use and operate.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

2) The GameCycle system remained stable while I exercised vigorously.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

3) While exercising on the GameCycle, I felt like I was in an awkward position.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

4) The GameCycle was enjoyable to use.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

5) The GameCycle will help motivate me to exercise more frequently.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

6) The GameCycle will help motivate me to workout longer once I get started.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

7) The GameCycle will help motivate other individuals who use manual wheelchairs to exercise on a regular basis.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

8) The GameCycle is compact so that it will not dominate a room when fully set-up.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

9) The GameCycle seems easy to assemble and disassemble for easy storage.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

10) The GameCycle uses upper body motions and muscles similar to those employed in wheelchair propulsion.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

11) The GameCycle uses upper body motions and muscles different from those employed in wheelchair propulsion.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

12) The GameCycle was easy to mount and position oneself to begin exercise.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

13) The steering mechanism on the arm-ergometer was comfortable to use.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

14) The GameCycle vibrated excessively during use.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

15) Playing the videogame while exercising created a challenging environment.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

16) The hand grips were comfortable.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

17) On-screen instructions were clear and easy to follow.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

18) The GameCycle was physically challenging so that it let me quickly reach my target training zone.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

19) The GameCycle has easily adjustable settings to allow for individual configuration.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

20) If the GameCycle was available for purchase, I would be interested in buying one.

Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree ☐

21) What is it about the GameCycle that you like best? Please explain your answer.

22) What is it about the GameCycle™ that you most dislike? Please explain your answer.

23) If you were in charge of redesigning the GameCycle™, what would you do differently? Please explain your answer.

Thank you very much for your time!!

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