UNIVERSITY OF CALIFORNIA,
IRVINE

iXercise:
An Immersive Exergaming Platform to Promote Physical Activity in the Pediatric Population

DISSERTATION

submitted in partial satisfaction of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

in Networked Systems

by

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DEDICATION

To god, my wife, my daughter, my parents and my dear friends for endless love and support.

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The text of this thesis/dissertation is a reprint of the material as it appears in "iXercise: An immersive platform for exercise intervention for special needs populations" and "MineBike: Exergaming with Minecraft". The co-authors listed in these publications are "Yunho Huh, Justan Klaus, Magda El Zarki" and "Yunho Huh, Gregory Thomas Duarte, Magda El Zarki" respectively. The co-authors directed and supervised research which forms the basis for the thesis/dissertation.

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ABSTRACT OF THE DISSERTATION

iXercise: An Immersive Exercise Cloud Platform

By

Yunho Huh

Doctor of Philosophy in Networked Systems

University of California, Irvine, 2019

Professor Magda El Zarki, Co-Chair

Professor Shlomit Radom-Aizik, Co-Chair

The benefits of regular physical activity are well known. In recent years, the health industry focused on developing motivational products to get people to exercise, with habit forming as a key concept. Studies that have shown that exergaming can result in immediate health benefits. However, benefits tend to be short term with a player's initial excitement declining over time. Current exergames are unable to meet long-term exercising challenges because the underlying game design criterion to sustain player engagement is absent.

To address this issue, I incorporated innovative game design principles to create the iXercise platform, a virtual environment exergame that provides an adjusted intervention fitness program targeted to special needs populations. Chapter 2is focused on a discussion of the iXercise platform. I describe the system design and how I implemented the various iXercise system components such as a web-based interface, a cloud gaming application, middleware, sensors, embedded systems firmware and communication channels. In chapter 3, I introduce how a novel exergame, named "MineBike", encourages and maintains

the participant's motivation. I describe game design elements for the immersive exergaming experience that encourages mid-to high-level exercise intensity. In chapter 4, I present the evaluation of the iXercise platform. To evaluate the platform, 1) exercise intensity (measured by workload) and duration was observed, 2) physiological responses (heart rate and oxygen uptake) was measured, 3) behavioral assessment (enjoyment, motivation and engagement) were assessed through a questionnaire, 4) correlation of physiological responses to game activities was observed, and 5) sex and age group differences were compared. Twenty-two 9-15 y/o healthy children were recruited for the study. Over three visits, the children exercised on an adjusted stationary bike and played the game for about 40 minutes while wearing multiple sensors. After each gameplay they answered behavioral assessment questionnaires.

From the collected results, I was able to observe that MineBike successfully increased participants' heart rate (> 120 bpm) for the target time (20 minutes). Also, MineBike was able to induce mid- to high- intensity exercise. Survey results were universally positive. Children enjoyed the game, wanted to continue playing, and thought that they would be more motivated to exercise with the Minebike exergame than without. They remarked that they especially liked the game content and the bike pedaling experiences.

In summary, I, 1) developed the cloud based iXercise exergaming platform, 2) built prototype devices to retrofit exercise equipment, specifically cycle ergometers, 3) developed an exergame "MineBike" based on a popular game Minecraft, 4) collaborated with medical experts at the Pediatrics Exercise Research Center (PERC) at UC Irvine School of Medicine, on the design concepts that will suit the fitness abilities of a young recuperating population.

Chapter 1

1. Introduction

1.1 Copyright Notice

There is some published material included within this dissertation. The materials are used with permission.

1.2 Exergaming

Exergaming, a relatively new type of fitness gaming, combines video games and exercise. The game tracks the physical activity of players using advanced technology. Exergaming breaks the shortcomings of traditional video games which often lack any physical activity and promote a sedentary lifestyle. Instead, it promotes a healthy lifestyle and exercise by weaving physical activity into the game.

Exergaming has grown as another game genre over time. Throughout its history, there have been several development milestones. In 1986, Nintendo Entertainment Systems (NES) released Power Pad [1] which was the first use of exergaming. In the following year 1987, Foot Craz [2] was released on the legendary game platform Atari 2600 with the game titles Video Jogger [3] and Video Reflex [4]. However, these early exergaming titles were not successful. A few years later in 1998, Konami initially released Dance Dance Revolution (DDR) [5], which was considered to be one of the first successful exergames, to be used on arcade game machines. The success of DDR led to Sony to port it to its PlayStation platform. More than 3 million copies of the game title were sold. Since the success of DDR, several exergames have been released and have achieved similar success. For example, Nintendo has sold approximately 23 million copies of Wii Fit [6] since its release in 2007, generating through 2011 over 2 billion dollars in profit worldwide [7]. Following Nintendo's success, the word exergaming was included in the Collins English Dictionary [8]. Several studies over the years have shown that exergaming can improve the health of its users. As a result of those early findings, exergaming was recognized as a viable method to improve the physical and mental health of individuals.

Whether for rehabilitation, preventive care, or for maintaining general health and wellness, motivating people to exercise and increasing their participation in some form of daily physical activity is the ultimate goal of most healthcare programs. With the obvious benefits of encouraging a more physically active lifestyle, exergames are actively being promoted by health organizations. In particular, a review of exergaming and its role in increasing physical activity, showed that it can have a positive impact on encouraging healthy behaviors such as chronic disease management, exercise, and diet [9]. Although they are not a replacement for actual physical exercise, the consensus is that exergames can promote increased physical activity among users who are normally not physically active. Lieberman [10]–[12] recommends that exergames that focus on physical health incorporate compelling health-related challenges and goals, support information seeking, use genres and technologies that appeal to the target user group, include learning-by-doing in the experiential environment of a videogame, and facilitate social interaction.

A game that increases awareness and motivation while promoting participation should prioritize providing players with an enjoyable gameplay experience. Players do not want to be lectured or feel that they are being preached to, instead, they want to feel that they are in a problem-solving environment that can be either collaborative or individualistic, depending on circumstance and/or player choice. For example, the game Re-Mission 2 [13] (upgraded version of the earlier Re-Mission game), a collection of online mini-games, is designed to make young adolescent cancer patients more aware about their condition, and better understand the sometimes unpleasant treatments that they have to undergo. The game has been shown to have a positive impact on promoting healthy behavior in that community. Some of the game themes , such as ones that involve plots to destroy "cancer", give the patients a sense of power and control over the disease. Some of the best game environments are ones in which a group of characters (i.e., players) have a shared challenge, or mission. The games with the most enjoyable experiences provide continuous feedback and rewards based on both individual and collaborative/team performance.

Popular gaming platforms, such as the Nintendo Wii, Microsoft Kinect/Xbox, and Sony PlayStation, have developed new environments that aim to improve health through structured physical activities. These platforms detect user movement, and through an avatar in the game, immerse players in game activities, such as boxing, playing tennis, dancing, avoiding obstacles, etc. Although the iFit [14] or LFConnect [15] solutions are a step in the right direction, they both stop short of creating a virtual presence for the participating users that provides feedback based on physical performance in terms of game rewards or an immersive storyline that keep users enthralled and engaged.

Figure 1. 1. Health Benefits with Popular Platforms

Pediatric Rehabilitation

There are many reasons that children with chronic diseases limit their participation in exercise [16], [17]. First, the physiological constraints of the child's particular disease, drug therapy, or comorbidities (in the case of acute lymphoblastic leukemia these include loss of muscle mass, anemia, fatigue, etc.) may prevent the child from being physically able to participate in exercise programs geared towards otherwise healthy children. Secondly, there may be psychosocial and behavior factors ranging from the stigma of chronic disease, parents' or caregivers' perception that the child is fragile and would be hurt by exercise [18], or the child's own perception that he or she does not match peer or popular images of a healthy child or adolescent capable of participating in all "normal" activities [19], [20]. In a study which examined reasons for limited participation rate in an intensive 12-week intervention program, which combined physical exercise and psychosocial training for children with cancer, parents reported several additional reasons for not participating in the study: “too time consuming,” “participation too demanding for the child,” and “travel distance from home to hospital” [21].

Integrating or embedding biofeedback systems that are connected to intrinsic reward structures can strongly motivate people to participate in physical activities, such as walking, running, biking, rowing, etc. That can be done on ergometric devices in safe spaces. Exergaming presents a very flexible and accessible exercise environment that in-person personal trainers or scheduled classes do not provide.

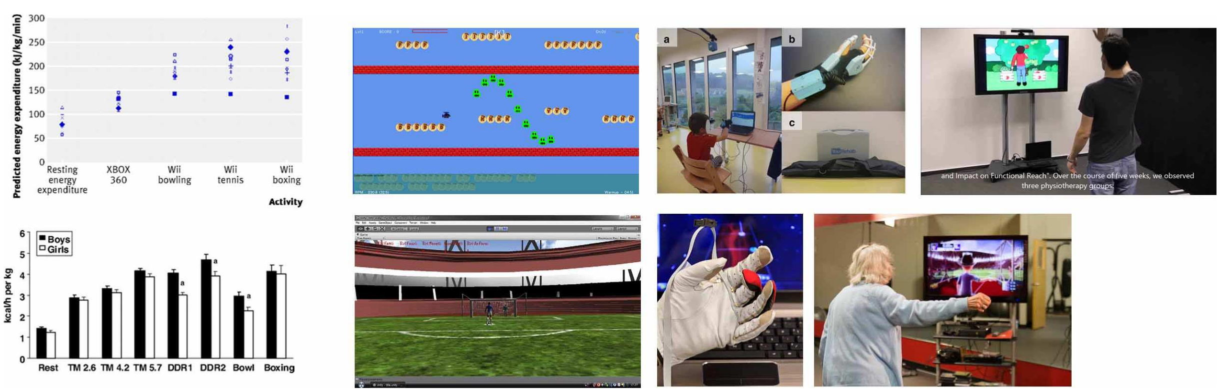

Figure 1. 2. Exergames for Rehabilitation

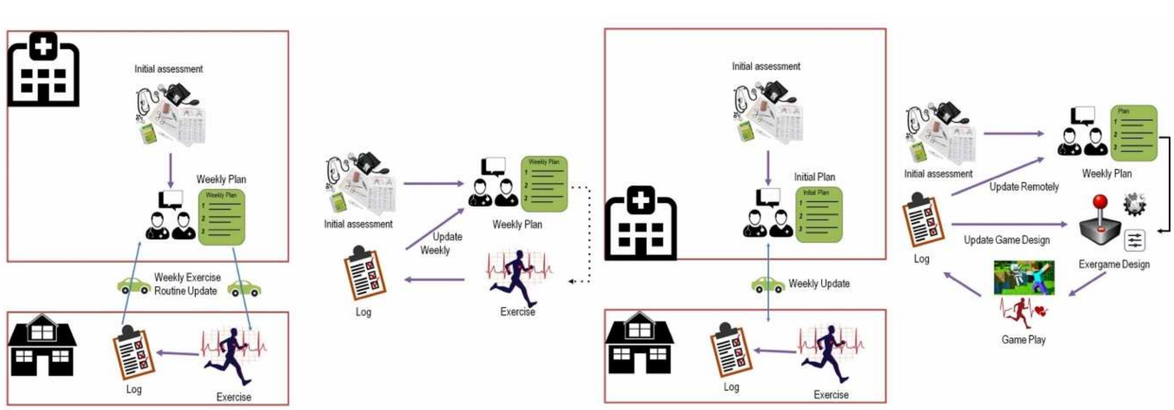

Figure 1. 3. Remotely administered re-hab program

1.3 Motivation and Potential of Exergaming

Many studies show that exergaming can yield immediate results over short periods of time. Although some studies show that they do actually yield increased physical activity, most show that they cannot replicate the levels of intensity of actually playing a physical sport [22]. Exergames attract demographics (e.g. obese children) who do not normally engage in physical activity. However, the level of user retainment of most current exergames is the subject of some controversy [23], [24]. Users, in particular adolescents, are generally initially attracted to games, but quickly lose interest once they have completed most of the challenges and have no new goals to achieve. That is because most current exergames are not designed with long term goals that are reflected in a gaming world with and missions that present new challenges that can only be attempted and solved if prior levels in the game have been achieved. This is the crux of successful game design: creating a user population that comes back for more. The design of the game has to be habit changing, and to do that it needs to have the right triggers, corresponding actions, resulting rewards, and increasingly challenging goals that continuously introduce new content and missions that keep users engaged and wanting more.

Figure 1. 4. Exergaming – Current exergames do not achieve the recommended physical activities intensity levels)

In this thesis, I propose an exergame platform, iXercise, to help patients, who have medical complications that make it difficult to participate in traditional physical activity, to exercise regularly. Through a collaboration with the pediatrics department, it became my goal to develop an engaging and motivating gaming environment, such as previously described, for special needs populations. The project involved researching and developing the underlying technologies that are necessary to build a platform for an exergaming application. The exergaming application, which we called MineBike, a modded version of Minecraft (see Section 1.3), focuses on motivating the targeted special needs population to follow a daily exercise regime by having them play the exergame, engaged in missions that require skill to achieve game specific goals based on performance metrics tailored to each individual participant. As part of its plot, the MineBike application uses several motivational techniques such as progress tracking, and competing, in order to foster long term interest in the game, resulting in habit forming.

iXercise has the potential of overcoming the barriers faced by children in rehabilitation programs by providing a safe and accessible means of reintroducing them to healthy physical activity by promoting levels of exercise that are specifically designed for the child's capabilities and that can be performed at home.

1.4 Minecraft– MineBike

Minecraft is a video game created by Markus Persson and developed by Mojang studio, a company which Persson founded in 2009. The game can be played either by a single player or by multiple players. In 2016, Minecraft became the second best-selling video game of all time [25], and is now available on multiple platforms (i.e. Microsoft

Windows, macOS, and Linux, Microsoft Xbox 360/One, Nintendo Wii/Switch, Sony PlayStation) (Minecraft).

In the Minecraft world, players can build 3-dimensional structures, explore the world, gather various resources, craft items, or fight against monsters. The basic unit of the Minecraft world is a block, which is a 3-D cube or fluid that can be collected by mining, and strategically placed to build complicated structures. There are different types of blocks which represent different substances, including lava and water. The virtual world is theoretically horizontally infinite and is procedurally generated; there is a limit on the vertical distance that a player can move their character. The Minecraft world also has virtual time with a day and night cycle, in which one full Minecraft day is equivalent to 20 minutes in the real world (Minecraft). Depending on the in-game time, Minecraft triggers different types of game events, for example Minecaft spawns zombies only during night times.

Over time, a variety of Minecraft versions and modified Minecraft (mods) have been developed with the different purpose. For example, Minecraft: Education Edition is used in classrooms to teach various subjects, including foreign languages and coding. It allows students to download the game at home and take pictures in-game that can be shared with other students (Transform Learning with Minecraft). According to a study called "Transforming Education with Minecraft" performed by Dr. Par Karsenti, 3rd to 6th graders in Canada using Minecraft as a learning supplement improved their problem-solving, teamwork, and motivation. Because their work is presented as a fun task, students are more excited about learning new material. In addition, the game can be used to monitor the students' progress in learning the material (Karsenti, 2017).

In a separate study by Benjamin Riordan, two groups of students in 7th grade class were taught class material. One group was taught using Minecraft while the other was taught using lectures; the students who had been taught using Minecraft performed better on tests (Riordan, 2017).

A Minecraft server, specifically for children and adults with autism, has been created and modified to serve the needs of people will autism. This server is known as Autcraft, and each user must be approved before they are able to play on the server. In contrast to many other Minecraft servers which exist, no monsters in the game will attack players, making it a safe place to explore (Porter, 2013). In addition, no bullying or swearing is allowed (Davidson, 2017). In the Autcraft server, members learn to regulate their emotions and their senses. They can create their own sensory spaces where they are able to take a break from the sensory input of the game while still remaining in the game's virtual world. Being able to have a break from the visual stimulation of the game allows the players to calm down and take a break from socializing with others (Ringland et al., 2017). They can share their thoughts and ideas in Autcraft without the fear that they will be harassed. The Minecraft server has a modification that allows players to teleport in the virtual world to support one another, which helps them build community and social skills. Those with autism are empowered by the ability to create their own worlds (Ringland, 2016).

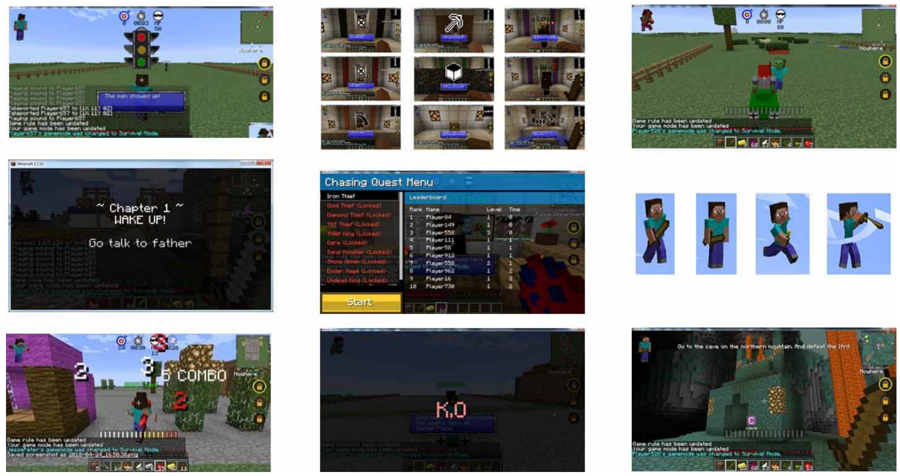

Figure 1. 5. MineBike – A Minecraft Mod (Modification)

MineBike is a modified version of Minecraft. MineBike is designed to deliver a customized exercise program as a game experience to serve a special needs population. MineBike provides a mini game in the form of a chasing sequence. The game players confront a variety of monsters and different types of obstacles in a procedurally generated map. The MineBike experience is built using a modded Minecraft world that includes hidden treasure, a village, a dungeon that ca be explore, a mountain, secret places, Easter eggs, etc. The players hunt down treasure, defeat bad guys/ monsters while controlling in-game characters through the exercise equipment.

This project incorporates cloud computing, cloud networking, and physical computing solutions in conjunction with innovative game design principles to create the iXercise platform, a virtual environment-based exergame that provides an adjusted intervention fitness program targeted towards special needs populations. Although existing virtual environments are known to support large player communities, they generally use costly dedicated hardware to do so. I investigated a novel cloud centric architecture leveraging cloud technology, with its ability to scale and cost effectively accommodate fluctuating and dispersed user populations. The aim was to deploy the iXercise platform on a cloud environment. Task partitioning and scheduling among edge and cloud resources and mechanisms to address the tradeoffs between sensing accuracy and user experience were studied as well as the overall synchronization problem. As proof of concept, I, 1) developed the cloud based iXercise exergaming platform, 2) built prototype devices to retrofit exercise equipment, specifically cycle ergometers, 3) developed the exercise program "MineBike", 4) collaborated with experts at the Pediatric Exercise and Genomics Research Center (PERC) at the UC Irvine School of Medicine, on the design concepts and implementation of the exergaming application that would suit the fitness abilities and activity levels of a young recuperating population, and 5) performed clinical trials with them. I tracked the physical fitness health outcomes of several recruited participants from UCI community. The keys to the success of the program were 1) the ability to turn physical activity targets into in-game rewards that are linked to individual performance (i.e., tailored to their physical abilities), and 2) via creative and engaging problem-solving challenges in the game, motivated a young pool of study participants to become engaged in the game and achieve the desired activity intensity levels set by the staff.

Chapter 2

2. iXercise Platform

In the iXercise project, I incorporated cloud computing, cloud networking, and physical computing solutions, in conjunction with innovative game design principles, to create the iXercise platform. iXercise (immersive exercise) is based on a virtual environment exergame platform that provides an adjusted intervention fitness program targeted to special needs populations. Chapter 2 describes our prototype of the platform and how I logged, stored, and analyzed user's exercise output and in-game progress data.

2.1 Introduction

The design of the game has to be habit changing, and to do that it needs to have the right triggers, corresponding actions, resulting rewards, and evermore challenging goals that repeat the cycle in order to keep users engaged and wanting more.

Creating such games is an expensive and time-consuming endeavor. I sought to speed exergame development by focusing on converting existing computer video games into exergames; by adapting a game which has already proven itself to be popular and capable of maintaining user attention for many hours, so a major part of exergame development can be bypassed.

Along with a video game, exergames require a human interface to translate real-world physical activities into in-game actions. I focused on adapting existing exercise equipment to exergaming instead of designing such machines de novo, as this meant much less engineering and manufacturing, considerably reducing expenses and liabilities.

To bring together existing video games and market-available exercise machines, thereby creating a quality exergame experience for the user, I created a platform consisting of an embedded system, associated middleware, and a cloud service. We call this exergame technology backbone the iXercise platform.

At the core of iXercise is the cloud technology platform that provides all the necessary systems support for the distributed, real-time interactive exergaming platform. It takes care of all the requirements for data collection, synchronization, connectivity, and scalability. Sensors, mobile tracking devices, and network interfaces are used to retrofit the equipment with the necessary software and hardware to enable the interactive game play and to extract key parameters for wellness and fitness. Logging into the iXercise platform will take place over the Internet. The intervention and fitness component of the project is managed by medical professionals and trainers. They oversee and manage the patient training program via a tailored user interface that is embedded in the exergaming application. Access by the medical professionals to the iXercise platform can be done remotely over the Internet with any mobile device.

2.2 Methodology

2.2.1 Analysis of a state-of-the-art Intervention Exercise Program

In cooperation with the UCI Pediatrics Exercise Research Center (PERC), I analyzed the current process and flow of their exercise programs for special needs children (specifically Acute Lymphoblastic Leukemia (ALL) patients that are often kept indoors for several weeks after their treatments to avoid exposure to germs). The medical personnel performed an assessment of the patients to create the patient profile that includes weight, gender, etc. Based on that profile, the medical personnel in conjunction with fitness trainers, created a weekly exercise program consisting of targeted heart rate, workload, and workout session duration. The participants are required to visit the PERC center for their exercise session, and perform the tailored exercise routine wearing sensors. Some sessions were conducted remotely via video.

At the end of each week, the patients and medical personnel discussed the patient logs and data. Using that information, a new diagnosis was created and the exercise program for the patient was updated. Depending on the update, the intensity of the exercise routine was adjusted.

2.2.2 The iXercise Platform – a solution for a remote intervention program

Any successful solution for a remotely controlled intervention program needs to provide the medical personnel with an ability to continuously track the patient's performance, diagnose the patient's state, update their health status, and adjust the exercise intensity to reflect the patient's progress. The collected exercise progress log should be secured and easily accessible, readable, and exportable to various file formats to facilitate the work-flow of the medical team.

For the iXercise platform, an exercise program update needs to affect the exergame difficulty/intensity level via a variety of game element parameters and properties (strength of monsters, difficulty of course, harder puzzles, etc.) to reflect the changes and ensure that the exergame and the exercise program are in sync, meaning they are not too easy or too hard, and achieve the target heart rate goals.

Our system design was guided by the following key requirements:

- Remote exercise program updates by the medical personnel via a tailored user interface
- Patient tracking and data visualization via the web
- Maintaining exercise motivation via exergaming
- Game and exercise statistics tracking via sensors and live data collection

The exergame should successfully achieve the workout effectiveness recommended by the medical team. Furthermore, the game should be attractive enough to develop and maintain long-term motivation to promote continuous usage. To find the optimal workout effectiveness, the difficulty of the exergame should be adaptable to the patient's medical condition and their cardio capacity that will depend on their gender, maximum heart rate, fitness level, etc. To balance out the game's attractiveness and workout effectiveness, the system should record the gameplay metrics that track various aspects of gaming sessions, (average session duration, in-game quest success rate, time spent in the quest, win/lose rate, combo counts, how many times player failed or died, etc.) and adjust the game accordingly.

2.3 System Description

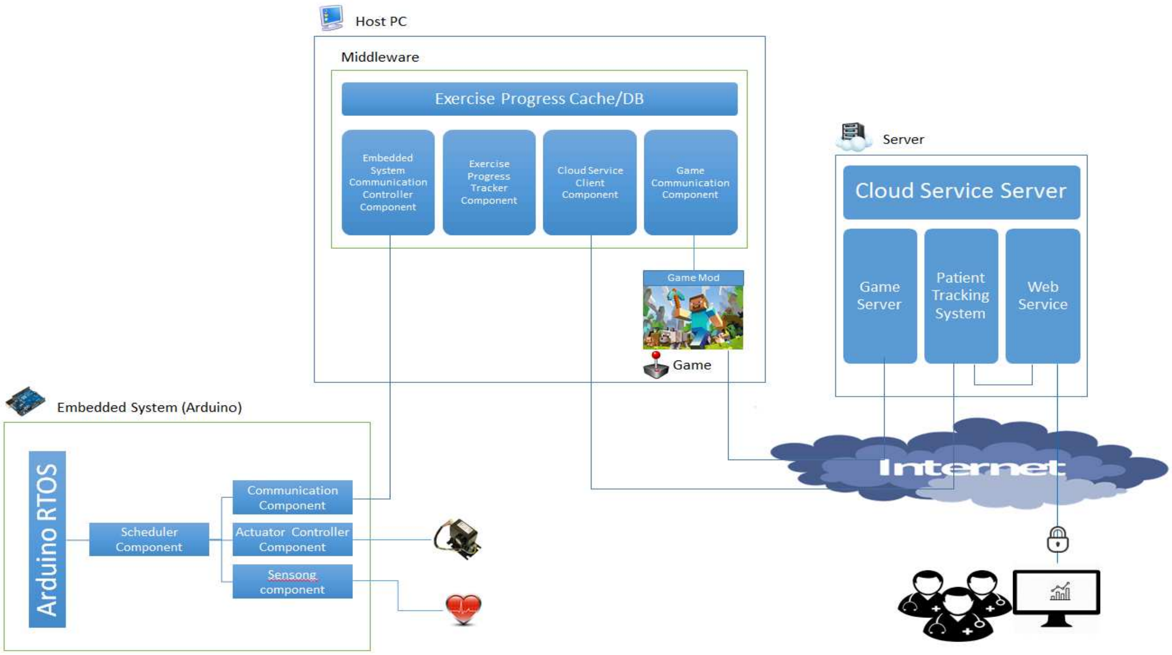

Figure 2. 1. System Overview

To aid the development of successful exergames, I have developed an integrated platform consisting of:

- **Electronics hardware** to interface readily available fitness equipment with a computer. The hardware allows sensors placed on the fitness equipment to send information to a gaming computer and a logging system.
- **Middleware Client Software**, installed on the small computer attached on the exercise equipment, to coordinate the interaction between the interfaced fitness equipment and a game program running on the computer. The middleware pipes coordinate data from the fitness equipment to the game so that real-world activities result in action(s) of the game world. The middleware can also translate game variables into resistance settings on the fitness equipment, enhancing the

immersive feeling of the exergame. The flexibility of the middleware allows the hardware to be quickly adapted to new games. Also, the middleware functions as an end node for collecting data and sending this information via secure connection to our cloud service.

- **Exergame and on Online Game Server** to enable multi-player gaming whilst exercising.
- **Logging System** to store game state and exercise statistics, as well as collected sensor data such as heart rate. The logging system saves game events and states, as well as biometric sensor data to a remote, secure cloud server that can be accessed remotely for updates and reports.
- **Web Interface** for easy accessibility for medical staff to view all logged data. The customized web interface allows for user-friendly and secure remote viewing via mobile devices by authorized personnel: doctors, therapists, and trainers.

These five platform features work together to allow for the rapid development of exergames specifically targeted for intervention purposes. Our proposed system is shown in Figure 2.1 above.

A user/usage analysis component that consists mostly of data collection on user participation was used to study the efficacy of the iXercise platform, i.e. adherence to the exercise program. Participants were interviewed by a psychologist at different stages of their intervention programs and were asked to submit a questionnaire on their motivation [26]. I evaluated the system through the collaboration with the UCI Pediatrics Exercise Research Center (PERC) after thorough testing of the platform's software and hardware.

The development of exergames requires, at minimum, integration of an exercise interface and a computer game; ideally, it also includes the functionality to measure, log, and share information regarding exercise progress. I have created hardware and software tools to simplify this work. These tools, which work together as a complete platform, greatly reduce the time and expense required to develop exergames. To showcase the platform, I constructed an exergame using an inexpensive exercise bike, Pro-Form models 120R, 460R and 135 CSX, and an open-source distribution of the popular computer game Minecraft.

2.3.1 Data Collection

I developed middleware that runs on the small computer attached to the exercise equipment. The major task of the software is to (1) communicate with the embedded system (sensors and microprocessor) to collect data, (2) cache player's progress in-game, (3) upload the cached player's progress to the cloud server, and (4) communicate with the game accordingly.

A cornerstone of our system is that it adapts the patient's fitness profile to the quality of gameplay. What that means is that a player that is physically weaker will be able to achieve the same gameplays as a player that is stronger; the resistance levels are automatically adjusted to reflect the physical abilities of the patient. A weak patient should not be penalized for their physical conditions in the gameplay. As the patient's health improves, the system automatically adjusts the resistance to reflect the gain in strength/fitness and stays in sync with the exercise program goals.

The system tags collected sensor data with patient information and transfers the tagged data to the cloud server. To protect the data collection from cyber attacks and malicious insiders, the system is equipped with a proper authentication method and a secure communication channel. For secure data communication, I set up an SSH server that consists of a login authentication process and a secure transfer channel.

In our demo, I collected the patient heart rate using an off-the-shelf heart rate monitor, the Polar T34 and H7. The cycling speed is recorded using a customized rotary encoder sensor.

2.3.1.1 Electronics hardware

A fun and frustration-free exergame experience requires sensors on the fitness equipment to detect even small changes in motion and to influence gameplay without perceptible time delays. To achieve these goals of real-time responsiveness and precise motion sensing, I constructed an optical quadrature encoder and added it to the exercise bike. The quadrature encoder includes two disks that attach to the bike's pedal crank spindle. The disks have teeth along their perimeter that can disrupt the beams in optical interrupter switches. Movement of the bike's crank arm rotates these disks, which causes the optical interrupter switches to flip states with a rate directly proportional to the speed of the crank motion. The use of two disks, 90-degrees out of phase with each other, and two optical interrupter switches results in four possible signal states, and examining the transition between states allows the determination of direction in rotation along with sense of speed. This system is accurate, precise, resistant to failure, and can be adapted to a variety of exercise equipment.

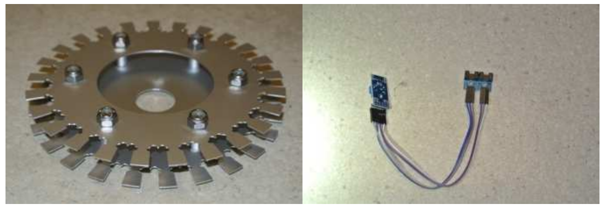

Figure 2. 2. Quadrature Encoders and Sensors

The stock Pro-Form 120R, 460R and 135 CSX included a motor with potentiometer-based position sensor to adjust pedaling resistance. I was able to adapt this feature into our exergame by determining the electrical pinout of the stock motor/sensor combination.

Figure 2. 3. Resistance Motor

To collect heart-rate data from the exergame player, I utilized a Polar brand T-34 and H7 chest strap heart rate chest transmitter. The player wears the chest strap, which transmits a signal to the proprietary or Bluetooth radio.

Figure 2. 4. Polar T34 and H7 Heart Rate Monitor and Radio Receiver

To read data from our quadrature sensor, resistance motor, and heart-rate sensor, and to move the resistance motor when changes in resistance are requested, these hardware items are connected to an embedded microcontroller. In our prototype I used "Arduino UNO" for the microcontroller. Arduino's primary functions were to read data from the sensors (heart-rate monitor sensor, resistance settings sensor, and quadrature encoder sensor), move the resistance motor, and enable the bike-to-host-PC communication to deliver the sensor data. I used functions adapted from the Arduino Firmata library to make the system capable of this communication.

Figure 2. 5. Hardware Deployment on the Bike

The firmware of Arduino has four major components on top of the default Arduino RTOS: a scheduler component, a sensing component, an actuator controller component, and a communication component. The scheduler component coordinates (1) when to read the sensor's data, (2) when to move the motor, and (3) when to flush sensor data out to the host PC's middleware.

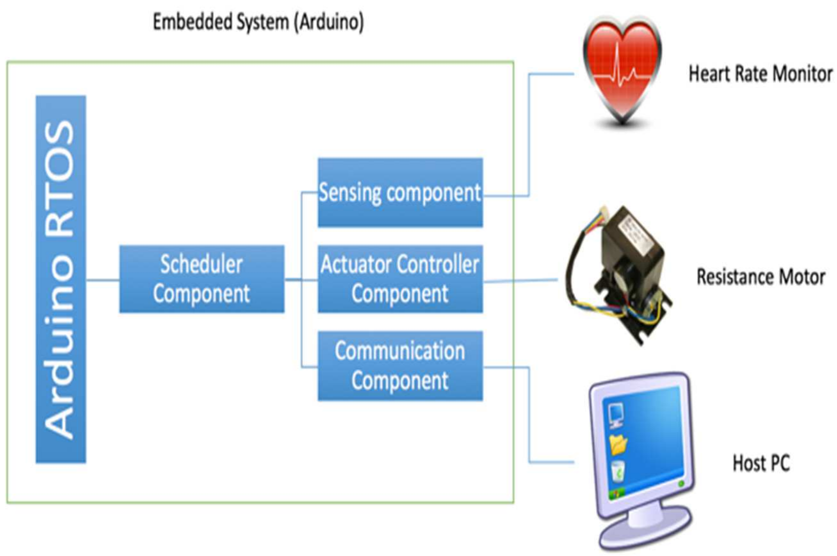

Figure 2. 6. Embedded System/Hardware Structure

2.3.1.2 Middleware client software

Middleware is a piece of software that runs on the small computer attached on the exercise equipment. As a major task, the middleware collects data through communication with the embedded system Arduino UNO, temporarily stores the users' progress, transfers the cached progress to the iXercise cloud service, and communicates with the game MineBike. The figure below shows the software components of this middleware.

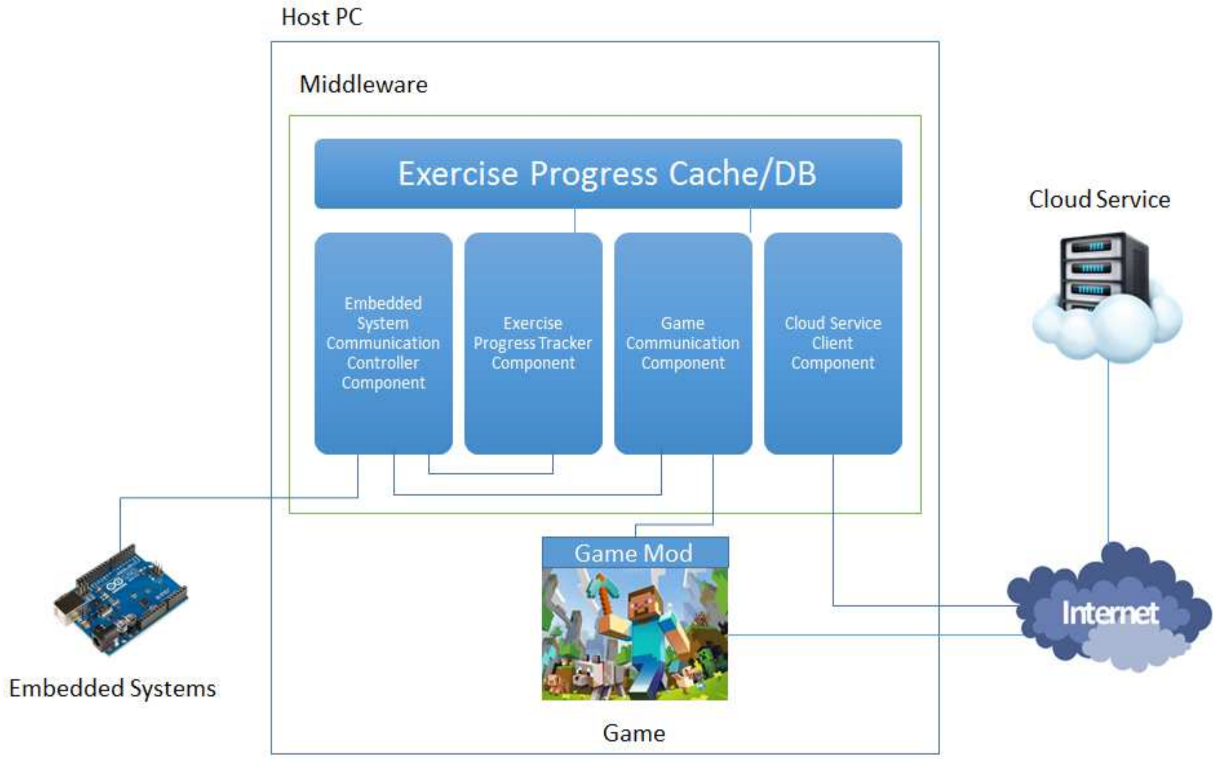

Figure 2. 7. Middleware System Overview

The Embedded System Communication Controller component provides the middleware with the capability to listen to sensors and to move the resistance motor. The Exercise Progress Tracker component collects the raw sensor data, caches the data to the local storage, and computes the exercise progress. The middleware has another communication channel that tunnels to the game mod for delivering sensor data and transmitting the resistance motor's state change. Through the communication channels, the middleware coordinates the interaction between the interfaced fitness equipment and the game program running on the computer. Also, the Cloud Service Client component functions as an end node for collecting data and sending this information via secure connection to our cloud service.

For the prototype, I implemented an embedded system-to-Middleware communication system using functions adapted from the Firmata4j library, which was developed to communicate with any standard Firmata-capable devices. For the communication between the middleware and the game, we developed a simple serial protocol that performs a connection handshake and transfers data on top of the IEFT Transport protocol, UDP. The simple serial protocol library is also packaged with the game mod so that it can interface with the middleware. Furthermore, the middleware's Cloud Service Client component transmits the cached exercise progress data to the cloud securely. The entire component of the middleware was written in Java and developed with Eclipse IDE.

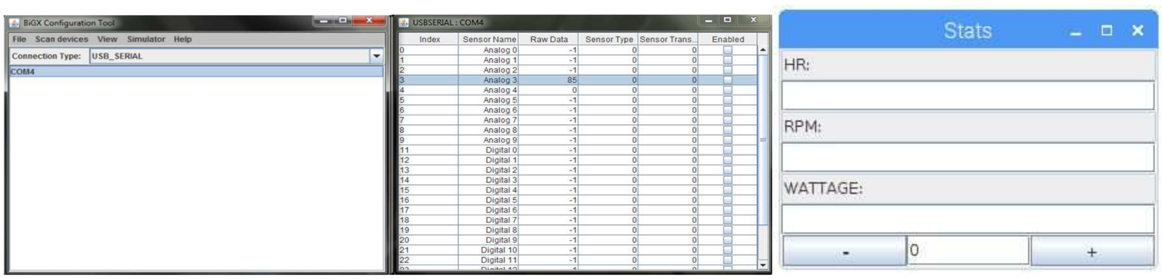

Figure 2. 8. Screenshot of middleware

2.3.1.3 Cloud service

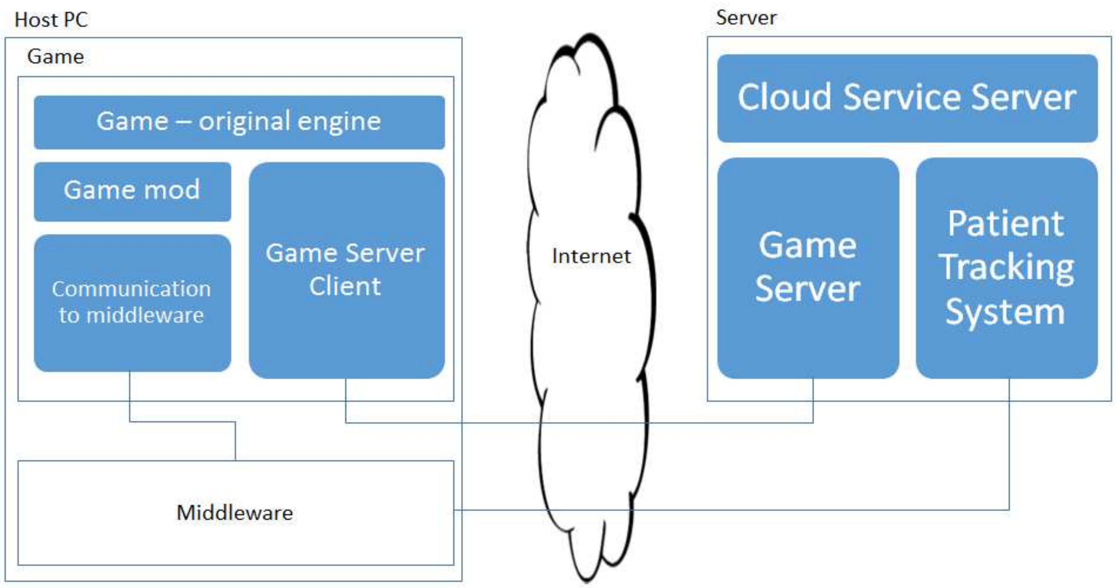

Figure 2. 9. Cloud Service Overview

The proposed system includes an online cloud service to store the collected data. The cloud server allows remote viewing and updating by authorized personnel such as doctors, therapists, and trainers. The system meets many different requirements: 1) maintain a daily record of the patient's exercise progress, 2) create progress reports that facilitate the work-flow of the medical team, and 3) provide a user-friendly web user interface (UI) to update the exercise program.

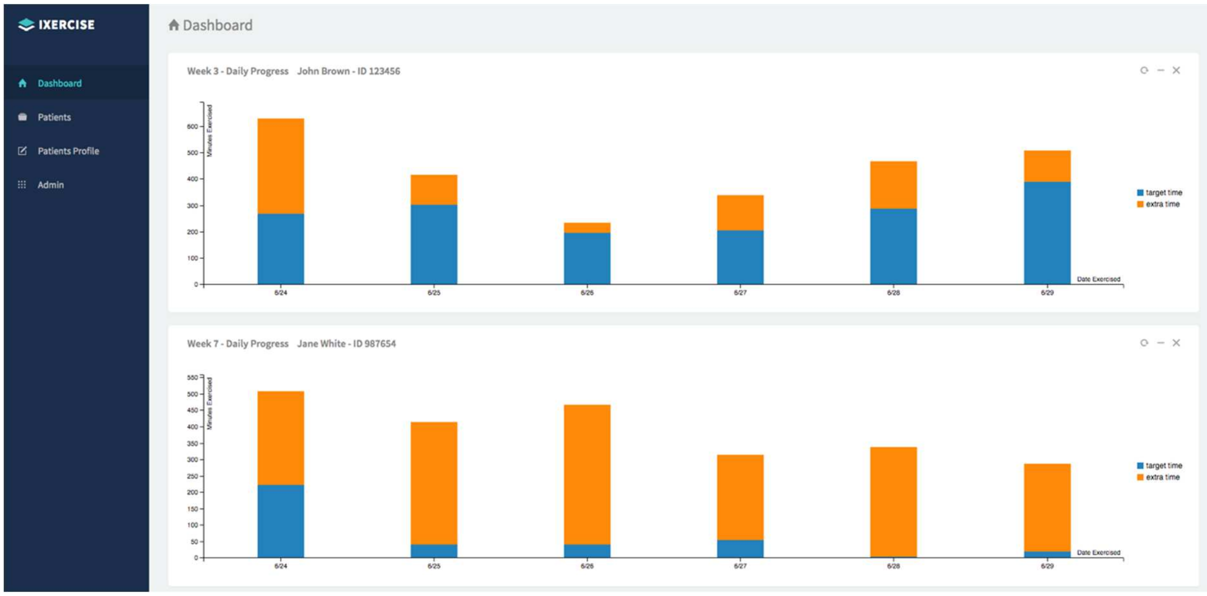

Figure 2. 10. Screenshot of Web UI for Authenticated User

For effective workflow, the data should be 1) easy to monitor, and 2) readily understood, directly from the dashboard page. Also, for useful data analysis, the web UI of the dashboard should be interactive and allow easy access to the actual data [27]. In our prototype, the dashboard is the home page for the health team (i.e., authenticated users) as shown in Figure 2.10. The dashboard gives a view of the high level statistics of the exercise progress and game states of a patient, and allows users to interact with the reports and graphs.

Access management of the health information follows the required and accepted privacy standards of the health industry [28] [29] [30] [31]. The system defines a clear access control policy [32]. In our prototype, the system provides a dynamic web UI depending on the role of the user. We defined the following roles: 1) doctors who have full access to patients, 2) fitness trainers who have full read and partial write access, and 3) system administrators with access to user profiles only. A user can be assigned multiple roles.

To create challenges within the exergame that correspond to the medical staff's prescribed exercise routines for a particular patient, the iXercise platform reads the patient's profile, and the prescribed exercise routine, and generates a corresponding set of in-game goals to be met to achieve the target heart rate. The core of the goal setting game design is an intelligent routine that adjusts the game mechanics, consisting of space [33], object/attributes/states, actions, rules, skill, and chance to the patient's condition and exercise routines set by the health providers.

For the prototype, I implemented the two cloud service components: Data Management System (DMS) and an iXercise web service. Data Management System is a piece of software that 1) listens to the middleware for collecting progress data, and 2) registers the data to the database. To protect the system from any of cyber-attacks, the DMS opens a secure data channel over SSH. Also, the DMS authenticates each connection for data transfers. For our prototype, I used an SSH protocol Java library from the Apache MINA framework. For each progress report upload, DMS signals the API server to create statistics of the reports. The prototype of the DMS transmits the signal over a message queue RabbitMQ. The second cloud system component, Web service, is responsible for delivering stored progress raw data and statistics to the doctors. The prototyped web service consists of two small components: 1) an API server and 1) an interactive frontend web page. The iXercise API application serves web clients to handle the Http requests of iXercise user profile, progress raw data, progress statistics, patient lists, patient profile, etc. The prototype was implemented on top of Apache Tomcat web service in the conjunction with Spring framework. For user profile data storage, I used a NoSQL database MongoDB that is well known for its ease of usage and scalability. Figure 2.11 illustrates the current web API that iXercise API application services. We also integrated web User Interface (UI) framework Bootstrap to support multiple web browsers from different types of platforms such as iPhone iOS, Android, Mac OSX, and PCs. For better user experience for dynamic web page interactions, I implemented iXercise web pages as the single page application (SPA).

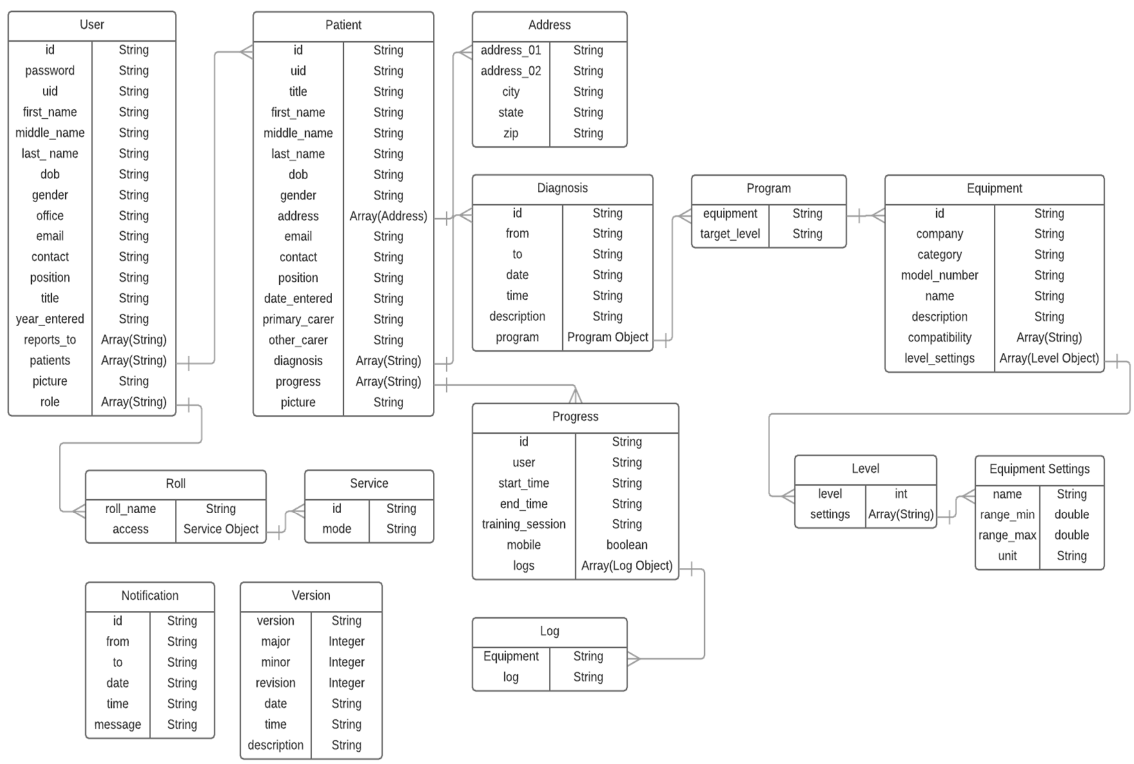

Figure 2. 11. Database Scheme

2.3.2 Mobile Application – iXercise App

Our proposed platform includes middleware software that runs on a small terminal attached to the bike. The small computer primarily functions as a gateway to the iXercise platform, coordinating user login, caching and forwarding data to iXercise storage. As a gateway, the small computer 1) interacts with the exercise equipment, ‘exercise bicycle’, to collect pedaling speed in RPM and workload in wattage, 2) communicates with heartrate monitors, and 3) interacts with iXercise cloud to pull up user profiles and push exercise progress. In order to control the gateway, users are required to select a bike and log in to iXercise system. Mobile devices such as iPhones and Android phones are now easily accessible to most people. With ease of access, people have become comfortable and familiar with using mobile applications to control information. Mobile applications need to 1) connect to the exercise bike in the network and 2) communicate with gateways. For device discovery, I deployed multicast DNS (mDNS) technology on the gateway device using Avahi [34] and Android Network Service Discovery (NSD) [35] on the mobile app.

mDNS is a network protocol described in RFC 6762. In recent years, many consumer electronics such as Apple TVs, Apple Macbooks, and network enabled printers or software applications such as Rhythmbox [36], Banshee [37], iTunes [38] and gShare [39], to adapt and use mDNS for different types of services. The network protocol was designed to aid small networks that usually do not have a local name server, so the small networks can resolve host names to IP addresses. It is a zero-configuration service that is commonly used for network enabled printers. The protocol is supported on different platforms through different implementations, for example, bonjour in Apple, NSD in Android, Avahi in Linux, and a mDNS service in Windows. mDNS basically follows the same format of packets, semantics, and programming interfaces as the standard domain naming systems (DNS). Therefore, mDNS can operate harmoniously with unicast DNS. For resolving a hostname from an mDNS client, for example, the client issues an IP multicast mDNS request; and then the target mDNS hosts multicast their IP information to the network. Usually the mDNS hosts include their service names and protocol names in their hostnames along with ".local" at the end. Then, the mDNS hosts multicast mDNS response packets back with IP information such as IPv4 and IPv6 addresses, Next SECure (NSEC) records, and additional descriptions of services. For example, when an mDNS client queries an Apple Airport mDNS hostname with a query "_airport._tcp.local", the Airport hosts in a local network multicast mDNS response packets with the IPv4 and IPv6 addresses and port numbers.

In order to prototype mobile application's major functions, I implemented iXercise Android app. I added an mDNS service on the small terminal, raspberry pi by using Avahi on Raspbian, and implemented an mDNS client with Android Network Service Discovery (NSD). Through the mDNS service, the prototype of iXercise mobile app could discover raspberry pi on a local network. Also, I included few other information such as the Bluetooth status information for heart rate monitors on mDNS message so the mobile application can easily read heart rate monitors status. I implemented login functionality on the mobile app so that users can signal an exercise bike to retrieve personal profile from iXercise cloud service, as shown in Figure 2.12.

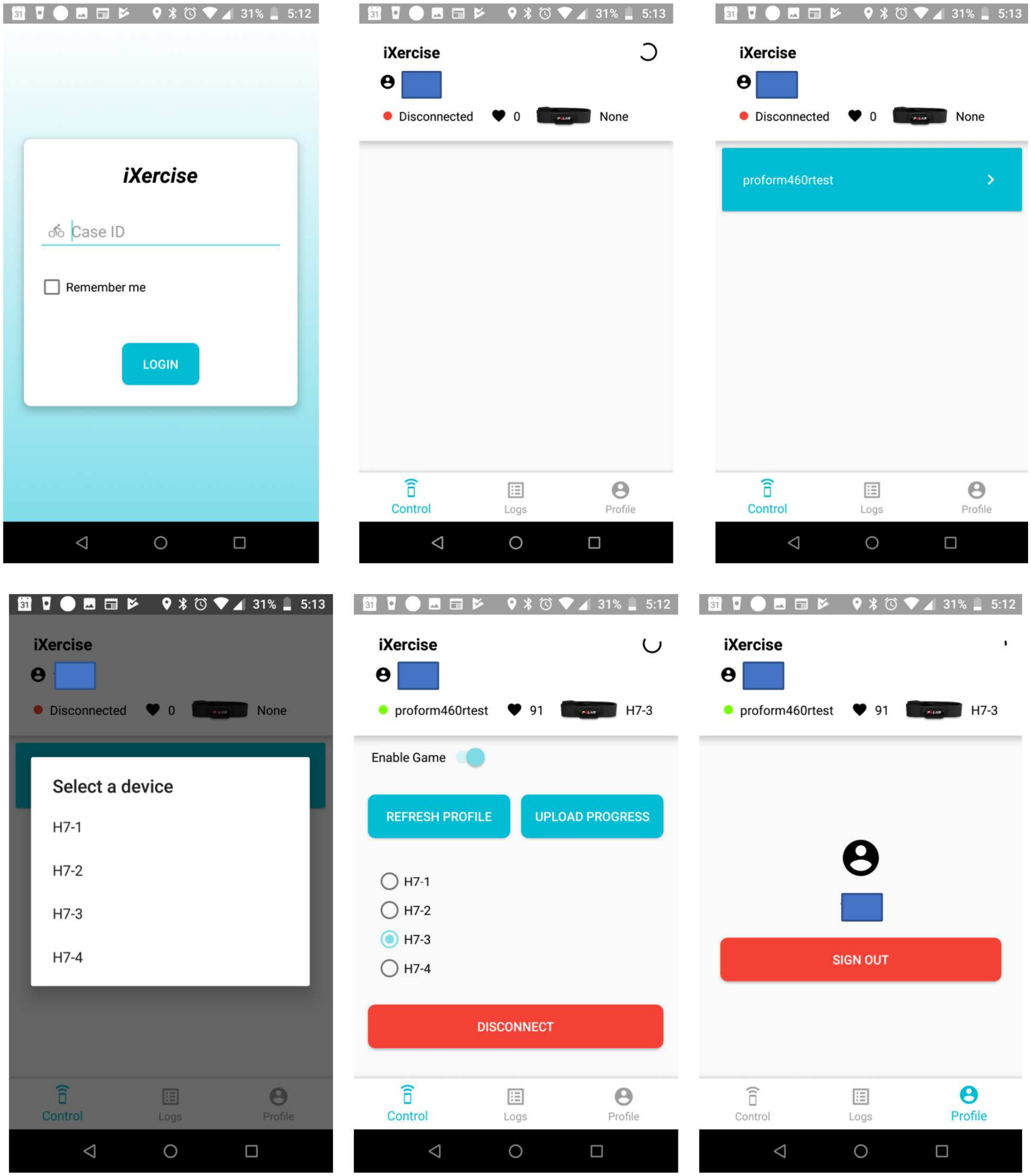

Figure 2. 12. iXercise Mobile Application

2.4 Preliminary Trials – Demo at UCI 50th Anniversary

Figure 2. 13. Children Playing iXercise Prototype

An earlier prototype was recently demonstrated at the University of California, Irvine, 50th annual Discovery Fair as shown in Figure 2.13. Male and female children, from the ages of 5 to 15, played the game for up to 15 minutes. We surveyed each participant after their turn on the bike to get feedback about their experience.

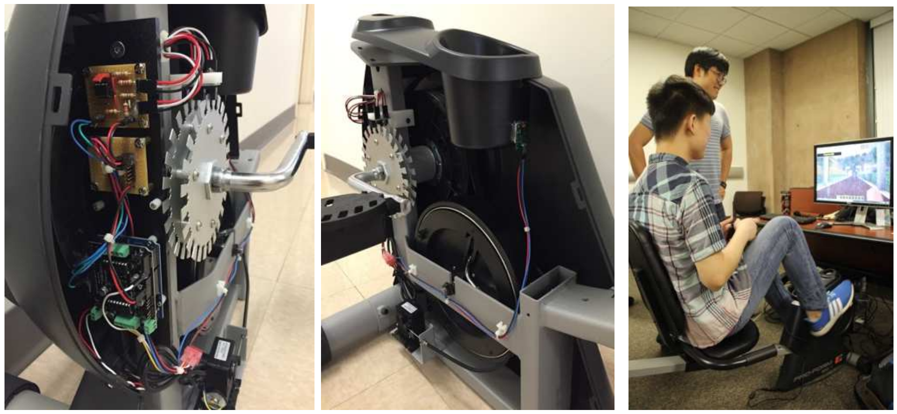

Figure 2. 14. Photos of the Prototype

Survey results were universally positive. The children enjoyed the game, wanted to continue playing, and thought that they would be more motivated to exercise with our exergame than without it. They remarked that they especially liked the game's content and the bike pedaling experiences. Parents were also pleased with the exergame paradigm, especially being able to see heart rate changes visibly displayed on the screen.

I used an in-person, subjective survey of the iXercise Exergame so that we could gauge the players' satisfaction, with the game experience. The one-on-one Q&A study also allowed us to get information on when, where, and for how long the participants normally played games.

From the collected results, we were able to observe that most of the game players kept their heart rates in the exercise heart rate zone (50% ~ 85% of the maximum heart rate of average10-15 years old children: 105 bpm ~ 178.5 bpm) as shown in Figure 2.15. MineBike successfully placed the participants in the desired exercise heart range (above 50% of the maximum heart rate, i.e., average close to target heart rate).

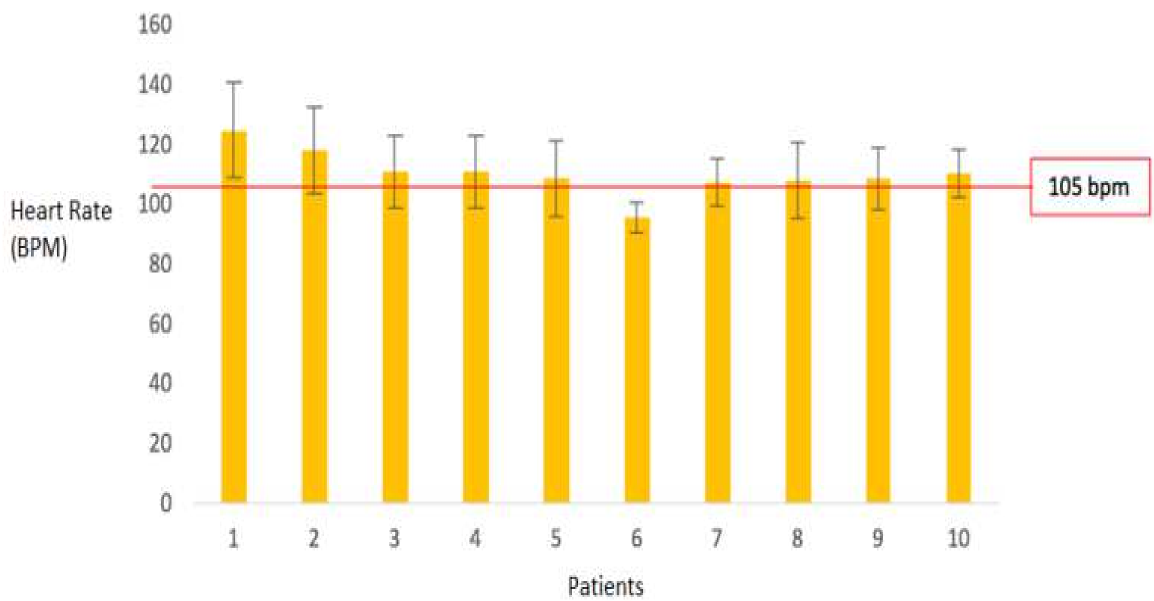

Figure 2.15. Average heart rate for each participant

Chapter 3

3. MineBike: Exercise Program on Minecraft

3.1 Introduction

The goal of the iXercise platform is to encourage patients in intervention programs to exercise to achieve target goals set for them by their health providers and trainers. To achieve that, an exergame's goal is to not only distract the patient from the often boring routine of exercising and engage them in an immersive game in which they not only challenge themselves but other players too, but most importantly, to have them fully engaged over long periods of time, for long term benefits. To make the exergame enjoyable, the system should: 1) set a clear in-game goal that corresponds to the exercise goal, 2) give proper rewards that can trigger intrinsic motivation, 3) introduce in-game incentives from the usage of workout equipment, 4) grab and maintain gamers focus on gameplay, but not on the exercise burden, and 5) give appropriate in-game feedback.

Online games enable multiple patients to play the exergame together by cooperation and competition. That sense of community has been shown to develop intrinsic motivation and long-lasting interest [40], [41]. To create a successful online game experience, the game should include the following motivational components: achievement component (advancement, mechanics, and competition), social component (socializing, relationship, and teamwork), and immersion component (discovery, role-playing, and customization) [42].

In addition, for an exergame, it should also introduce the concept of physical exercise targets, and in the intervention case, those set by medical staff and trainers. For exercise effectiveness, the exergame should be able to adjust the exercise intensity levels corresponding to changes in the game difficulty, all within the minimum and the maximum exercise intensity settings that are dependent and set based on the gamer's physical capacity. Moreover, the exergame goal should be aligned with the exercise goal recommended by the medical team.

As technology has evolved, so have the user interfaces of game platforms (for example, Microsoft Xbox, Nintendo Wii, Sony PlayStation). I have seen a significant advance in the user interface aiming at making the game experience more enjoyable. The games on those platforms that target physical health have input methods that detect the users' motion to control the characters in the game. For example, Microsoft Kinect reads whole body motion by extracting users from a captured image. Another example is the Nintendo Wii Remote, which detects behavior with motion sensors such as gyroscopes and accelerometers. Through the in-game characters, the users participate in game activities such as running, dancing, tennis, soccer, etc. Studies have tracked the level of physical activity throughout the exergaming sessions and the effects on children's health. The change in user interfaces have resulted in a new trend that aims to enhance health, specifically children's health, through framed gameplay sessions [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53], [54].

Although exergames can produce immediate results for a short time [51], [53], [55], [56]; studies have shown that they do not provide the same level of intensity of physical activity as do outdoor sports such as baseball, football, and soccer [46], [47], [22], [50],

[57]. Some other studies have shown that exergaming can play a role in fitness improvement for particular populations, e.g., obese children, that tend to have a sedentary lifestyle with infrequent participation in physical activities. There has been a marked rise in skepticism surrounding the health benefits of exergaming, mostly due to the long-term sustainability of the technology - maintaining motivation over long durations [55], [58]. I have seen the ability of exergames to attract young audiences; however, I also see a rapid loss of enthusiasm. That loss is mostly, if not entirely, attributable to the lack of new and persistent challenges that is the essence of any "good" game design. Commercial video games have gamers come back to complete sequences of quests that continuously provide new challenges. The ability to bring back a player over and over is what is at the heart of a successful video game design. To have a lasting effect on users' habits, exergames too have to run motivational cycles that consist of triggers, actions, challenges and rewards, to build a strong bond between the user and the game that will have them not only come back for more, but motivate certain physical behaviors that are directly mapped to the in-game actions.

Game content creation is a resource-intensive production that requires a significant budget for development, distribution and marketing. For example, Call of Duty Modern Warfare spent 250 million U.S. dollars for game development and marketing [59]. To minimize game-development cost, I chose to modify a popular game to function on existing exercise equipment. The iXercise platform is based on an exercise bike that incorporates a game modification (aka modding) of a popular game, Minecraft [60].

Minecraft is a sandbox-genre game. In the game, users (minecrafters) can create their own worlds using in-game resources such as blocks, items and tools. The game is well known for its popularity, not only with children, but also adults. The game had 74 million monthly active users in December 2017 [61]. The company, Mojang, has sold over 144 million copies [61] on multiple systems that include game consoles, PCs, and mobile devices. The audience that plays Minecraft is broad: ranging from teenagers through adults ages 30-50. One major reason for Minecraft's popularity is that the game actively engages a player's imagination as shown in Figure 3.1. Minecrafters use their creativity to survive monsters' attacks, craft stronger tools, and build more splendid structures. Some players use their creativity in additional ways, they participate in game modding to enhance the minecrafters' experiences. The mods include customized world generation algorithms, new game rules, item extensions, capability extensions for non-player-characters (NPC), graphic user interface extensions, and many more. The ongoing efforts with Minecraft modding have shown endless possibilities. One big advantage is that the modders tend to open source their work to share their ideas and cooperate with others within the Minecraft developer community. Due to its vast popularity, Minecraft has been used by other interest groups to promote learning and other activities for targeted populations. For example, educators, they use Minecraft as an educational tool to teach math, the arts, geography, or as a tool for 3D-printing [62].

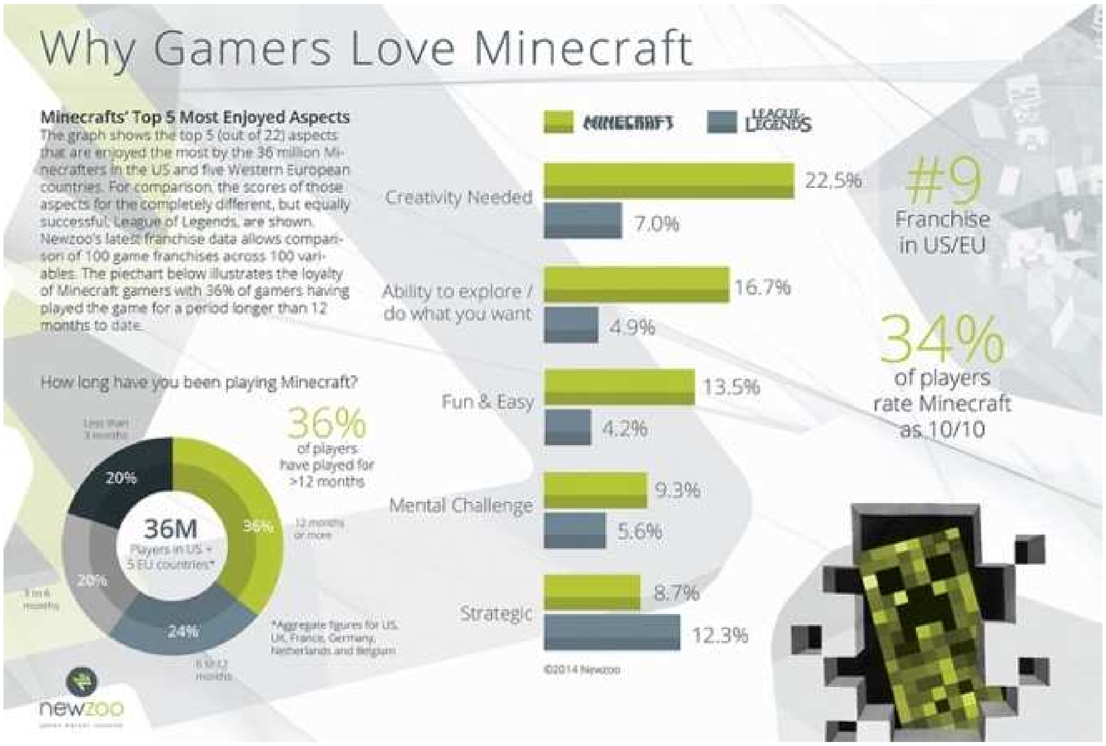

Figure 3. 1. Minecraft Popularity https://newzoo.com/insights-/articles/analyzing-game-franchises-gamers-love-minecraft/

The initial prototype of the iXercise platform [60] incorporated an exercise bike with a modded Minecraft, henceforth referred to as MineBike, that translated peddling into forward and backward movement in the world. A game controller was used to move left and right and enable game actions. The outcome of the initial tryout showed that the users were able to induce a moderate level of physical activity during the game play sessions. However, I did not observe any consistent moderate to vigorous physical activities over longer durations and multiple sessions. The level of physical activity I observed changed, based on 1) the game tasks the users were working on or 2) the environment the users were in. I therefore concluded that it would take more than just to transpose a popular game onto an exercise platform to achieve our goals. I had to engage the user with exploits that not only forced them to exert energy but also sustained that a level of activity for a while.

In the rest of this paper, I address this very issue and outline the approach I took to make iXercise a viable exercise platform, in particular for children in rehabilitation that are often times limited to staying indoors and are required to do repetitive exercises to recover their physical strength.

3.2 Methodology

3.2.1 Heart Rate and Fitness Benefits

Previous studies noted that there is a correlation between heart rate and expenditure, depending on a person's age, height, weight, and other physical factors [63].

The American Heart Association (AHA) suggests that the target heart rate for exercising should be 50% to 85% of the maximum heart rate. Keeping the heart rate within this range prevents participants from under exercising and over exercising [64].

The maximum heart rate can be calculated by the formula:

Max Heart Rate = 220 – Age

Depending on the percentage of the maximum heart rate, the benefits of fitness are different. The 55% ~ 69% of the maximum heart rate targets weight management and 65% ~ 90% of the maximum heart rate provides cardiorespiratory fitness benefit.

3.2.2 Dual Flow Model

To design and develop a successful exergame experience, the game should 1) attract users and retain their attention and 2) provide a targeted level of exercise intensity via a physical activity. The dual flow model suggests that an exergame necessitates a good balance between game play skills and level of the game challenge so that users become fully engaged in the game content. Also, the fitness of the user, and the physical workload demanded by the game should be balanced to provide an effective exercise session. Maintaining the balance in these two dimensions brings users into what is referred to as the “flow” state - the users are fully engaged in an activity and exerting energy. In the sporting world, “being in the zone” refers to this state [65].

To hold a user's attention, to put them in the flow state, a game needs to follow these game design principals: 1) clear goals, 2) no distractions to maintain focus, 3) direct feedback for each action, and 4) continuous challenge [33]. Continuous challenge in particular, is the crux of every successful game [33]. The level of the challenge’s difficulty affects the user's interest in a game. For example, users easily get bored, when challenges are too easy. On the contrary, if the challenge is too difficult and not achievable, then users feel frustrated and abandon the game. The challenge therefore should be adjustable to suit a player’s skill level [33].

3.2.3 High Intensity Interval Training (HIIT)

High Intensity Interval Training (HIIT) is a popular type of exercise program. According to ACSM (The American College of Sports and Medicine), HIIT was the most conducted fitness program in 2017.

HIIT is an exercise technique that pushes participants to their limit through quick bursts of exercise, periodically followed by short recovery sessions. The advantage of the HIIT exercise technique is 1) it causes the heart rate to rapidly escalate and 2) it causes rapid fat burn as a result of increased heart rate. Exercise programs based on HIIT techniques do not always require exercise equipment, but rather utilize the participant's body weight. Thanks to its simplicity and quickness, HIIT has gained popularity among the young population in recent years.

A typical HIIT training program usually consists of multiple short intensive workout sessions followed by a period of quick recovery resting of about 30 seconds. A variety of the exercises can fit into the workout sessions, such as 40 sit-ups, 30 seconds of continuous jumping jacks, 20 squats in a row, etc. Depending on the training program, the number of workout and resting sets varies. Also, exercise routines repeat different numbers of times based on the program.

With the integration of technology in people's everyday lives, there are several options to access exercise programs including: TV broadcasting, digital media, mobile application, or fitness training programs. First and foremost, people participate in the HIIT exercise routine through fitness center programs. The program consists of trainers and trainees of the exercise routines. Usually the role of the trainers is to lead the group of participants, correct their posture, control time, and handle unexpected events. By doing exercise routines at the gym, participants' motivation grows as they work out in a group setting. HIIT can also be accessed through digital media platforms such as YouTube or Microsoft Xbox Health. These digital media programs provide fixed content that is recorded with a series of workout routines. Similarly, there are mobile applications that contain HIIT exercise routines. Compared to the digital media option or in-person programs, mobile application users can work out anytime and anywhere as long as they have access to their mobile device. Furthermore, using mobile applications can be a more cost-effective option.

Usually, mobile applications provide multiple routines so users can pick a customized program. However, mobile applications lack the same level of motivation that can be gained from group activities.

HIIT is regarded as a better choice to train children than exercise routines that continue for longer amounts of time, such as the physical education offered in school. Also, Thum et al. reported that the enjoyment level from shorter length HIIT routines could be higher than the enjoyment level of longer sessions. [66] Through multiple testing sessions, we found that the nature of HIIT is aligned with the mechanics of mini games that usually hold game players' attention for around 5-10 minutes. To prototype the exercise program inside of Minecraft, we deigned a mini game that includes a chasing sequence as an intensive gameplay session to push the gamers to their physiological limit for 5-10 minutes. After each active mini game session, there is a cool down period where gamers perform low-intensity exercise to collect in-game rewards and then start another round.

3.2.4 Accessibility

To keep users in the flow state, an exergame needs to adjust the exercise intensity to maintain the right level of cognitive function [67]. Cognitive function peaks when people perform moderate intensity exercise, it drops when the exercise intensity increases [67]. In exergaming, a cognitive performance drop would not only result in a decrease in game skill level, but also in an exercise induced injury. To minimize the possibility of injuries in the exergaming community, game controllers were redesigned to better suit the type of physical exercise that the player was engaged in whilst playing. For example, both the VirZoom bike [68] and Cyberbike [69] integrated joypads onto the bike handle; and the

RealRyder Go Kart [70] system installed a big red button at the center of the bike handle. Game controller redesign requires familiarizing the gamer on how to use the new interface. Generally, a tutorial session is recommended at the beginning of gameplay. To make a tutorial session effective, Erik et al. suggests that 1) the information that needs to be imparted should be contextually aligned with the users in-game context and 2) an on-demand source of help can be beneficial [71].

3.3 Prototype - MineBike with a static game contents in a Los Angelcraft

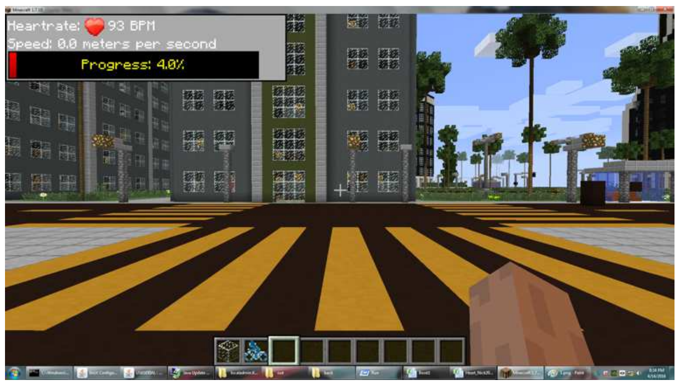

Figure 3. 2. Screenshot of the first version of MineBike

For the initial prototype, I developed a Minecraft exergame mod, “MineBike,” for use with our customized stationary bike as the exercise device. Figure 3.2 shows a screenshot of the game. For the initial demonstration, I used the Minecraft world “Los Angelcraft” (a large city created in minecraft and inspired by Los Angeles) [72]. It is a city themed adventure map filled with sky scrapers, town houses, streets, lights, trees, etc. In the Los Angelcraft world, the gameplayers explore the world by pedaling the bike along streets and paths.

The exercise goal of the prototype MineBike is to pedal at a certain speed (varies by player) to maintain a specific heart rate for a predefined amount of time, determined by the physicians for the patients' intervention program. For example, achieve a heart rate of 140 BPM for 15minutes. The minutes do not have to be consecutive, they can be accumulated over a 24hr period. However, during the session, I observed that the activity level was very inconsistent during the game play sessions. It was very dependent on the game events and in-game activities. The following sections address how we tackeled this problem and designed a game that encouraged more consistent exercise activity.

3.4 Game Design Choices

3.4.1 Original Minecraft tasks

Minecraft provides a variety of resources for the gamer to use, including building blocks, currency, tools, etc. Depending on how the gamers utilize these game resources, they will be categorized as miners, builders, warriors, explorers, etc. Just as people have multiple jobs in the real world, so do minecrafters in Minecraft. In Figure 3.3 show an example of: building, mining, fighting, and exploring [73]. As a builder, for example, you are required 1) to explore a Minecraft world to search for resources, 2) to mine the resources, and 3) to use the collected resources to build something. According to [73], the mostly played task is "build", the second most played task is "fight", followed by "explore" and lastly "mine." Data illustrating this behavior is displayed in Figure 3.4.

Figure 3. 3. Minecraft Tasks

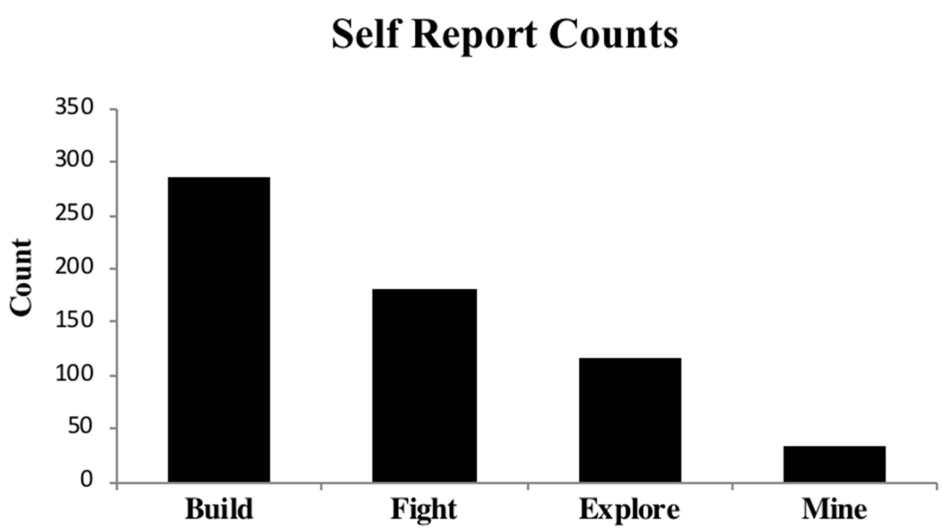

Figure 3. 4. In-game Tasks Statistics

3.4.2 Minecraft Tasks and Physical Activity

In our initial investigations [60] I observed that each task provided for a different level of physical activity on the part of the gamer. For example, in case of mining, users stayed put until they finished mining a desired number of blocks. Mining is not a task that encourages the user to exercise. However, players were actively pedaling when they were exploring a new virtual world [60].

The intensity of the exercise was very dependent on the particular environment they were in. For example, when they explored a world with indoor hallways, players tended to slow down in order to control their in-game characters more accurately. When the users were in a wide open area, they moved around at a faster pace. The conclusions I drew from our initial tests were that the basic Minecraft (MC) tasks were not pushing/motivating the players to exercise at the required intensity level as shown in Figure 3.5 below.

Since MineBike's intention is to encourage more physical activity, I needed to craft worlds that included more open spaces and activities that would tempt the player to peddle faster for longer durations of time. In the rest of the paper I introduce the theme - "chasing" - into the game to prod the payer to achieve the desired level of exercise intensity.

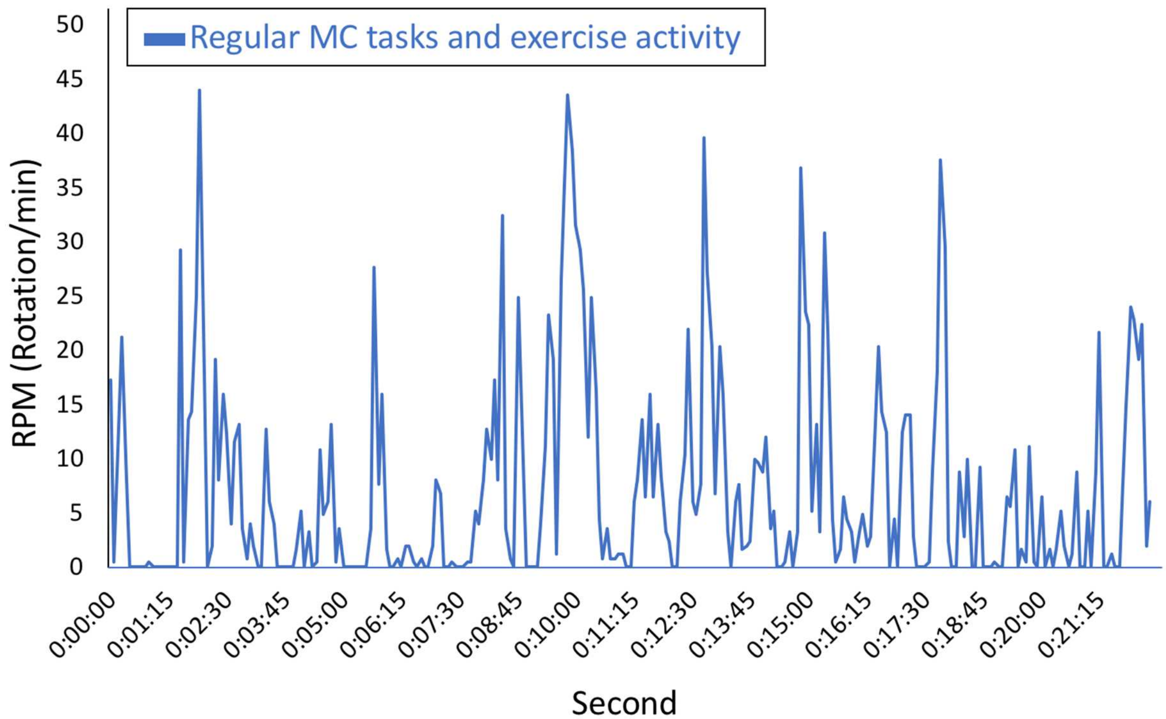

Figure 3. 5. Regular Minecraft (MC) tasks and exercise intensity

3.4.3 Chasing Task

I prototyped a mini-game that included a chasing sequence. To hold the users in a flow state, I designed the chasing task keeping in mind the four game design principals: 1) clear goal, 2) minimum distraction, 3) clear feedback and 4) continuous challenge with minimal frustration. The goal of our mini-game is to chase a Non-Player-Character (NPC) (either a thief or a monster), and defeat the character once caught. In order to complete the quest, the player should 1) get close to the NPC who does its best to evade the player's character and 2) to administer damages to the NPC till the NPC's health reaches 0. The NPC is constantly on the run with a fixed speed. The speed is set so that a user has to pedal the bike with a rotation per minute (RPM) in the range of 60 – 80 to stay close in distance to the NPC. This RPM range is known to be the ideal rotation speed for long cycling sessions on stationary bikes. The resistance of the wheel is adjusted to the physical strength of the user, so that this RMP can be achieved without harming the player, yet encouraging the player to achieve the targeted heart rate.

Figure 3. 6. MineBike views

To minimize the distractions, I modified a terrain generation algorithm to create an environment on a super flat world. On the super flat world, users can proceed simply with straight forward pedaling and no other controller functions (i.e., no left or right, no jumping, activities that can cause a distraction). I also set a predetermined path for the NPC again to minimize the burden of character control so that the player can focus solely on chasing the NPC to get close enough to cause damage as shown in Figure 3.6. As in every game, there are perimeter boundaries (fences) on each side so that the player cannot wander off as shown in Figure 3.7. For example, I may want the player to run Southward after the NPC, but not Eastward nor Westward.

Figure 3. 7. Terrain/obstacle generation during the chasing quest

In order to provide clear feedback, our prototype displays game information on the screen and notifies a user of events by playing audio tracks.

An on-screen avatar reflects the player's character's actions such as standing still, walking, running, and attacking as shown in Figure 3.8. To display the avatar, I included Mo'Bends Minecraft mod [74]. Through the player avatar, users can check what state their character is in. Also, the users can check if their inputs trigger corresponding actions correctly.

Figure 3. 8. Character status indicator

MineBike also displays the distance to indicate how far the user is from the NPC, the elapsed time, and the health of the NPC to indicate how much damage remains to defeat the NPC as shown in Figure 3.9. MineBike displays a warning message on the screen to indicate that the user needs to pay more attention as shown in Figure 3.10.

Figure 3. 9. Chasing progress indicators

Figure 3. 10. Warning message

J Schell et al. [33] points out that audio feedback is more instinctual and effective when compared to visual feedback. In our prototype, to give better feedback on damage, the game displays damage counts on the screen, and the game plays audio tracks so players notice whether or not their attack was effective as shown in Figure 3.11.

Figure 3. 11. Visual and audio feedback on damage

The chasing sequence task balances the level of difficulty by having: 1) buildings generated by terrain generation algorithm, 2) obstacle structures spawned by NPCs. In addition, the NPCs' health changes as the chase progresses and interacts with the player. Depending on the terrain theme, the terrain generation algorithm shapes a track by placing natural guard rails on each side through the use of buildings, trees, etc. The buildings and the trees limit the space a player character can move around in. By confining/narrowing the space, the user is required to control the player character more accurately. During the chasing sequence, the NPC spawns random types of obstacle. The obstacles hinder the players' progress from being in the attackable range, i.e., close enough to cause damage and reduce the NPC's health. This is done by 1) blocking the player's path with obstacle structures, 2) forcing the player to wade through water, mud, etc., and 3) trapping the player by spawning a pond, a canyon, etc. The difficulty of the chase is adjusted by the health of an NPC. As the health increases, the expected damage also increases, therefore, the overall playtime gets extended. The extended play time naturally decreases the user's cognitive performance. As a result, the relative game difficulty of the challenge increases.

As shown in Figure 3.12, the NPC is successful at making the game player run (i.e., peddle fast) for sustained periods of time during the MineBike quest session, thereby increasing the heart rate.

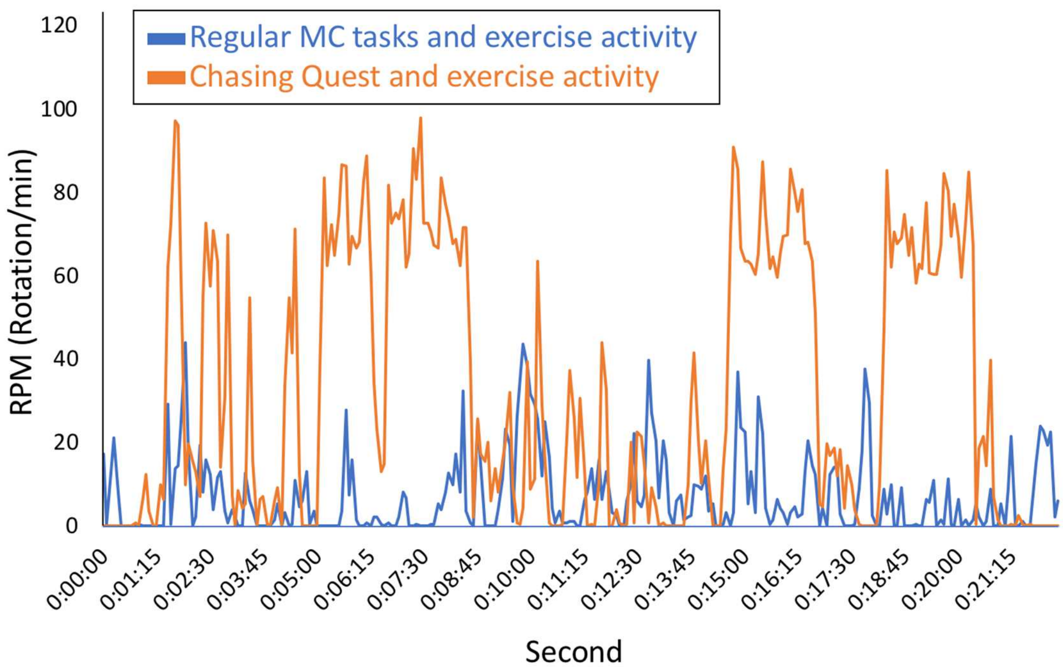

Figure 3. 12. MineBike with game quests

3.4.4 Additional skills for providing incentives for exercise

In order to play Minecraft, Minecraft players need to perform the following basic tasks/chores: mining, attacking, building, and exploring. The most intuitive way of introducing the pedaling experience into the gaming experience is to move the in-game characters accordingly. During the dry run test, most players were comfortable to control their characters with bike pedaling. In order to expand the bike pedaling to other tasks, we also explored the other possible options such as pedaling for mining, attacking or building. The purpose of introducing different pedaling modes was to reduce the repetitive in-game chores through exercise. For example, the pedaling for the mining mode increased the speed of the mining based on the pedaling speed, the pedaling for attacking mode strengthened the in-game character's power, and the pedaling for building automatically placed the blocks in the world to build a virtual structure. In order for these modes to be activated, the mode for moving had to be deactivated. As a result, we found that the players were not comfortable utilizing pedaling for these basic Minecraft tasks. They responded that it was not intuitive to remove character movement during the use of the aforementioned modes.

In order to smoothly trigger a Minecraft task through bike pedaling, the game is required to introduce indirect triggers that are completely decoupled from pedaling. As well, the trigger of the in-game task is required to be triggered by the intention of players, not randomly. Traditionally, video game characters possess some special moves or skills. The in-game special abilities are often used to increase damage, improve moving speeds, and are often time sensitive. The skills help game players to have easier in-game progress. In other words, in some games, the game provides special skills as an incentive. For example, Dungeons and Dragons 2 provides LB-Oil items to trigger an explosion that gives considerable damage to monsters as illustrated in Figure 3.13. During gameplay, players can collect these items as rewards from monster fights, treasure chests, or market place. In the upgraded MineBike, I introduced new skill sets: speed, damage and mining boosts instead of pedaling modes to not be effective immediately, but to be saved for later uses as shown in Figure 3.14. Those skills are designed to temporarily reduce the burden of basic Minecraft in-game chores: 1) move, 2) attack, and 3) mining. Speed boost increases the speed of the character movement, damage boost improves attack damage count, and the mining boost increases mining speed. These skills were designed to be triggered as the gameplayer presses a gamepad button. To prevent using skills too many times in a row, I introduced skill effective time and cool down for each skill usage. Then I introduced a new skill point system that tracks exercises so the players can redeem the effort. In the following section I address how these new statistics (stats) are designed.

Figure 3. 13. Special skills in Dungeons and Dragons 2 from

http://blog.naver.com/PostView.nhn?blogId=whitethewal&logNo=80069663463&redirect=Dlog&widgetTypeCall=true

Figure 3. 14. MineBike Skills

3.4.5 Stats

In video games, all in-game characters have stats that determine their capabilities. In role playing games, the players can increase or decrease the stats of their virtual characters through “level-ups” or “job-switches”. Usually, games define characters with the following stats: Health/Hit Points (HP), Magic/Mana Points (MP), Skill Points (SP), strength, speed, and intelligence. The strength, speed, and intelligence stats are a static type of stats used to define attack physical/magical damage and frequency of attacks, etc. This static type usually does not decrease with game events, but can increase with characters’ growth through, for example, level-ups. The HP, MP and SP are dynamic stats that can increase or decrease with in-game events such as damage from monsters and magic spells or skill usages. Usually, the dynamic stats are critical points in video games. For example, empty HP indicates the character’s death, and empty or low MP/SP indicate that a player cannot use any of the magic skills. Therefore, to be a good gameplayer, a player needs to find a way to keep balancing those dynamic stats properly at any moment. For the dynamic stats points, there are two point types; 1) those start with full levels and go down, and 2) those start with empty levels and go up. As introduced above, maintaining the levels of points above certain thresholds is critical for type-1 dynamic stats. In contrast, the type-2 ones are usually used for boosting up the gameplayers skill effectiveness or power. For example, Marvel Super Heroes vs. Street Fighters, released by Capcom, has a skill point stats that increases with effective attacks as shown in Figure 3.15. The points can be redeemed to trigger special or super moves.

Figure 3. 15. Skill Points in Marvel Super Heroes vs. Street Fighters from https://gamefabrique.com/games/marvel-vs-street-fighter/

Minecraft originally defines a main character with two major dynamic stats: 1) health points and 2) hunger points. The health points determine live/death of characters, and the hunger points determine the level of health decrease. Both health and hunger points are critical for in-game survival. In order to provide indirect incentives for the amount of exercises performed, I introduced a third dynamic character stats "skill points" that increases through physical activity, bike pedaling. The level of skill points can be redeemed by using the newly introduced skills: speed, damage and mining boosts. Through the skill uses, the exercise burden is compensated for a lack of game competency. In order to balance the skill points to motivate continuous exercise, the skill points decay over time. During the pilot studies, I found that some participants consecutively used speed boost to catch up with the monster when they are falling behind too much, and cannot keep up the pedaling speed.

Figure 3. 16. Skill Points GUI

3.4.6 Warming up and cooling down – hidden chests, npcs, reward sessions

The American Heart Association (AHA) recommends warm up and cool down activities before and after exercise. Those warm up and cool down sessions can play a big role in 1) improving exercise performance, and 2) decreasing potential exercise risks such as muscle pains and stiffness. Throughout warm up sessions, participants' blood vessels expand to deliver oxygen according to the demand of the muscles. Also, their bodies increase the temperature in muscles to improve flexibility and efficiency. Warm ups allow a wider range of motion, and decrease burden on joints and tendons [75]. The recommended warm up length in general is 5 to 10 minutes, and for a more intensive exercise goal, the participant needs to have a longer warm up session with a full body low intensity exercise routine. For example, walking a few minutes on a treadmill and doing some push-ups or bent-knees would be enough [75]. Similar to a warm up phase, AHA points out the importance of a cool down phase after a workout. After a workout, a participant generally has 1) a higher heart rate than in normal situations, 2) dilated blood vessels, and 3) a higher body temperature. In other words, sudden stopping can cause light-headedness or even fainting. The recommended program suggested by AHA could be either a few-minutes of walking until heartrate slows to below 120 BPM ,or sets of 10 to 30 seconds of stretching. To practice stretching properly, stretching should be intense but not painful without a bouncing motion [75]. In order to create warm up and cool down effects in MineBike, I introduced "treasure hunting".

Treasure hunting in games is very popular. The objective of treasure hunting tasks is to locate treasure boxes or objects. As a reward, participants can keep the collected items. Treasure hunting has been implemented in different forms such as geocaching, scavenger hunt, and money hunt. Even in video games, treasure hunting has been implemented as a type of challenge. In typical Japanese role-playing games (JRPGs), gamers need to explore dungeons to find treasure boxes that contain special in-game items such as legendary weapons or armor with different stats or powers. Therefore, hunting down hidden treasure boxes gives a direct motivation for an exploration. To harvest the power of motivation, we placed treasure boxes in several places. Some boxes contain basic resources to help players survive in game events/challenges, and other boxes have special items such as other treasure box keys as shown in Figure 3.17.

Figure 3. 17. Treasure boxes

3.4.7 Story

Story is one type of game experience that contains details about items such as space, characters, the relationships between characters, and sequences of events and time. Therefore, although story and gameplay are game experience elements that affect each other, their relationship has been controversial for a long time [33]. However, the quality of the game may be improved when story and gameplays complement each other [33]. A game designer once said “Story and gameplay are like oil and vinegar. Theoretically they don’t mix, but if you put them in a bottle and shake them up real good, they’re pretty good on a salad.” [33]

A variety of old game titles have a “string of pearls” storyline that lineally connects a series of game events, as shown in Figure 3.18 [33]. Even though many people enjoy games with stories that follow this method, a number of people criticized the string of pearl method due to its non-interactive, fixed story nature as the story does not change based on the gameplay. Jesses Schell suggests that a good game is a story generator, which creates stories dynamically as gameplayers proceed in the game [33]. For example, video game titles such as Sim City, The Sims, and Roller Coaster Tycoon don’t have a fixed story line in mind in the development phase, but rather each gameplay creates a distinct story depending on how gamers build their world [33].

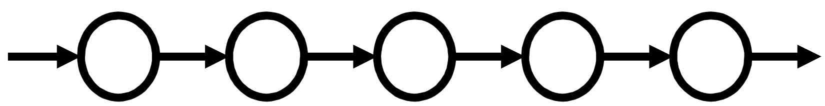

Figure 3. 18. String of pearl model

Jesse Schell claims that there is a major challenge in creating a good story generator, as gamers make each decision interactively and the size of the story tree exponentially grows. As a result, game players can experience all kinds of stories, which can potentially break the unity of the story [33]. In order to avoid negative artifacts, Jesse Schell introduces the following tips to create more engaging and amusing elements:

- Games need to introduce obstacles that keep gamers away from the ultimate goal. With the rise of conflicts between characters, story writers can introduce bigger obstacles.
- The game should maintain a simpler world than the real world and give extra power to make gamers stronger than they are in the real world.

- Game stories can be improved by using stories of a traditional hero's journey.
- The game development could be smoother when game stories are flexible, as long as the stories are consistent and accessible.
- Appropriately use clichés with slight tweaks to make stories more familiar to audiences and more interesting.
- Maps could be a useful tool to facilitate story building

In order to make MineBike more expandable from the chasing sequence, I implemented a story of a hero in a typical heroic journey. The journey includes a character with a normal life who receives a call from the characters' father. This call is regarding the character's recent efforts to aid police officers in enhancing security against an increase of thieves and monsters in town. Through several encounters with thieves and monsters, the in-game character grows into a warrior. With the help from neighbors, the character gets an upgrade, and is equipped with appropriate armor and weapons to be strong enough to fight against the monsters that pop up out of the village. When the main character is ready, the journey begins with the aim to remove the root of evil, which include both monsters and thieves. On this quest, gamers face multiple challenges, such as monster encounters, obstacle structures, searching for a special key to open a hidden chest, and puzzles to proceed.

3.4.8 Worlds – space, characters and aesthetics

Worlds are places and environments where game stories move on and gameplays occur. The worlds contain major game elements such as space and characters.

3.4.8.1 Spaces

All of the game events occur in certain spaces. Depending on how each event is related, the relationship between spaces should be defined and vice versa. Therefore, the architecture of spaces is regarded as one of the most important game development procedures that controls game experience [33]. That is why game designers and architects oftentimes cooperate to create a virtual structure to lead the gameplayers in order [33].

From a mathematical perspective, spaces are basically mathematical structures that have nodes linked to each other or regions divided by lines. According to Jesses Schell, spaces could 1) be discrete or continuous depending on the game rules, 2) have a number of dimensions, or 3) have boundaries that separate spaces [33]. For example, tic-tac-toe has a two-dimensional discrete space divided by 9 slots, on the other hand most sports games such as football, soccer and tennis have a two-dimensional continuous space called a field. Jesse Schell suggests the following types of space models: Linear, Grid, Web, Points in Space and Divided Space. Each model is named by the topology shape of the relationships between spaces [33]. Specifically, the Points in Spaces model is often used for some Japanese role-playing games (JRPG) such as Final Fantasy, Dragon Quest, and Pokémon RPG. In this model, there is a bounded continuous space with special points where certain events are triggered as shown in Figure 3.19 [33].

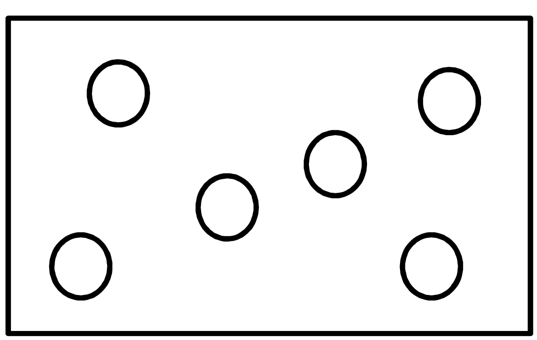

Figure 3. 19. Points in Spaces model

To prototype the story line on top of a sandbox genre game “Minecraft”, I adapt the Points in Spaces model to introduce multiple points within a regular Minecraft world that is a continuous third-dimension world. The design of spaces allows gameplayers to wander around to solve secret problems and puzzles freely. As major places in the game, I placed 1) village where main character grows up, 2) passage to the dungeon for heroic journey, 3) dungeon of final boss, and 4) a hidden cave for secret chest. The village is a place where the journey begins and the main character grows up as a warrior. Inside the village, there are multiple points that game players are interested in: home, market places, police offices, and villagers’ houses. In MineBike, home is the place where the game starts. At home a gamer will briefly learn the story through an NPC father and also learn how to play games through a tutorial. The marketplace is where a gameplayer can purchase armor and weapons to power up their in-game character. The other important place in the village is the police station. At the police station, the character receives the quick and immediate task of “chasing quest” from a police officer. Through the chasing sequence, the gamer can become more familiar with character maneuvers and the generic MineBike game mechanics about the chasing sequences. Throughout the chasing sequence, the gamer’s game skills usually get an upgrade (a “level up”). The passage to the dungeon includes a mountain climb along a trail that brings the character to the top of the mountain where the dungeon entrance is located. In the dungeon, there is a final boss that sits inside a secret room.

3.4.8.2 Characters

Characters are another key game element that defines the game world. In order to create great stories, those stories are supposed to include iconic characters. Jesse Schell introduces some tips of how to build memorable game characters such as building characters in-game jobs, choosing the personality by the interpersonal circumplex, demining status of characters and using the voice of characters.

In order to help the MineBike gameplayer proceed, the following two groups of characters were required: 1) static characters such as father, trainer, merchants and villagers, 2) dynamic characters such as police officer, thieves, monsters, and final boss, and 3) invisible third person voice.

The static characters are a group of NPCs who mostly stick to a certain location to serve in leading the character on the right path. The father serves as a mentor who provides the purpose of the journey to the gamer and guides them to a trainer who will teach them about basic skills. As other role-playing games, I placed multiple merchants who sell different types of items, such as armor and weapons, a skill seller, a trader and an enchanter. In order to better equip gamers, I placed several villagers within their houses. Every villager basically has a different job that matches with the items they are providing to the character. For example, a villager who is a soldier gives armor and a weapon, and another villager who is a farmer gives a hoe and a pickaxe.

Unlike the static characters, the police officer, thieves, monsters, and the final boss are characters who dynamically interact with the main character. The police office is a character who appears in the police office, and serves to give chasing quest tasks to the main character. Also, the officer exists in the chasing quest as a voice to give performance information of their progress. In order to create an iconic existence in the game, I gave the in-game police officer a typical police officer's image who is highly motivated to fight crime. To make it realistic, I gave the character's lines a stronger tone, and a deeper voice tone in the audio feedback. For creating the deeper voice effect, I added a "Batman" effect on the recorded voice tracks by using an Android app called "Voice changer with effects", developed by Baviux [76]. The monsters, the thieves, and the final boss are the characters who take on the role of villains in MineBike – their intentions are to break the peaceful atmosphere in the town. In order to reveal their evil personalities, I used dark voices for the audio effects such as the damage sound and the running away skill trigger sound. Since it requires actual voice acting, I utilized audio tracks from "freesound.org" [77] an open source database of audio tracks.

The last type of character is an invisible character who is hidden in the game. The character's task is to give game instructions and to explain the objectives of each chapter in the game's story.

3.4.8.3 Aesthetics

Aesthetics is a game element that determines the detailed artistic touch of games. Some game designer underestimates this aesthetics as "surface details" of games and they consider this game element to be a separate part from game design [33]. Jesses Schell states that "Aesthetic pleasure is no small thing. If your game is full of beautiful artwork, then every new thing that the player gets to see is a reward in itself." [33]

In order to make MineBike more appealing, I needed to upgrade the MineBike audible and visual details. The quickest way to upgrade visual effect was to update shaders and textures. In Minecraft communities, there are several shaders available online such as GLSL [78], Sildur's Sharders Mod [79], Sonic Ether's Shaders [80], and ShadersMod [81]. With the help of the Minecraft shaders mods, a variety of visual effects can be applied on various Minecraft elements such as sky, sun, moon, water, and texture of blocks. I used a combination of the Seus standard shader pack [80] and the ShadersModCore mod [81], because the mods are compatible with our graphics card. Originally Minecraft provides biomes for world generation. Depending on the biomes, the shape of terrain could vary and the type of blocks in the world could be different. For example, with the biomes for desert, the world generation algorithm places more sand blocks on the floor, and place cactus on the sand blocks to give a feeling of a desert. Since the biomes affect gameplay experiences, creating a world with a proper biome becomes very important. For our prototype village, Biomes O' Plenty mod [82] was used to generate a dynamic terrain, with a mountain next to the central village.

In order to improve the overall quality of the game content, the author in [33] suggests that improvement in audio effects is tremendously powerful. Original Minecraft provides default background music created any by a musician named C418 (Daniel Rosenfeld) [83, p. 418]. Basically, Minecraft plays different types of background music depending on 1) game character environments such as underwater, sunrise or sunset, 2) game mode such as creative mode and 3) jukebox existence [84]. In order to match the atmosphere of a heroic story, I replaced the default Minecraft music with a set of medieval times themed background music by using a set of fantasy music, named "Camelot". With the replaced background music, MineBike plays different tracks based on the virtual character's location such as home, wild, police station, and dungeon. In order to increase the level of tension in the chasing sequence, racing games and mini games with chasing-sequences often use fast paced music to create urgency. Similarly, I themed MineBike chasing sequence with several heavy metal songs that have fast and intense beats.

3.4.9 Types of progress messages

In fast-paced video games genres such as racing and first person shooting, game contents try to provide visual and audio feedback information about how well they are performing in the game. The types of feedbacks are the followings: 1) generic feedback such as damage sound effect, 2) cheering messages, and 3) warning messages. The generic feedback such as damage effect provides information about how effectively game players interact with the virtual world. For example, Overwatch displays extra aiming marks on top of a crosshair at the center of the screen, and plays various sound effects for different types of game events such as effective shots. Through these effects, gamers become aware that their action was effective even without checking the statistics. Also, when gamers are playing well, games often display cheering messages visually and audibly, such messages include “Great”, “Good job”, “Yeh!” and “Nice”. Warning messages are the other type of feedback to notify gamers that they are underperforming or not correctly following directions. For example, famous racing game titles such as Mario Kart and Kart Rider display warning messages with warning sounds when gamers start driving backwards.

In order to improve MineBike, I implemented, visually and audibly, multiple types of feedback messages. For example, when a gamer successfully lands an effective damage on a monster, MineBike displays the damage count, combo count, and cheering message as shown in Figure 3.20. Also, at the same time, MineBike plays several audio tracks such as a

"Yeh" sound as a cheering message along with an "Ah!" sound from monsters to indicate that the damage was effective.

Figure 3. 20. Visual Feedback example for damage and combos

3.4.10 Gating

For long-term gameplays, games need to continuously provide new challenges. As a way of providing new challenges, games often use a gating mechanism. Gating mechanism is one of the game design elements used for level design, which intentionally uses gates to prevent players from moving forward – i.e., slowing them down. Gates are game elements such as bottlenecks, dominant strength for monsters, fixed camera angles, and checkpoints [85]. When gamers are stuck, due to a gate, the gamers accept the gates as a challenge to overcome and make progress. For this reason, game designers use the gating mechanism to introduce challenges.

For the MineBike prototype, I implemented gating on different MineBike game elements such as chapter system and storyline. Since we introduced an exercise bike as the game controller, MineBike needs a way to educate users about how to use the bike as a controller. In order to guide the users such that they can successfully learn step by step the game mechanics and controls, I implemented a chapter system consisting of four chapters: chapter 1 to learn about the story objective, chapter 2 to learn about the controller, chapter 3 to learn about chasing challenge mechanics, and chapter 4 to guide them on the final boss. During chapter 1, players are locked in a home, where they are guided through a tutorial and talk to a father who gives the a brief overview of the game story. Once, the player finishes the tutorial, they are guided to the police office where they are sent off on a chasing challenge. In this chapter, the player is locked in the central village. When the player successfully defeats the monsters, the player is allowed to leave the village to challenge the final boss. An example of the chapter system is shown in Figure 3.21.

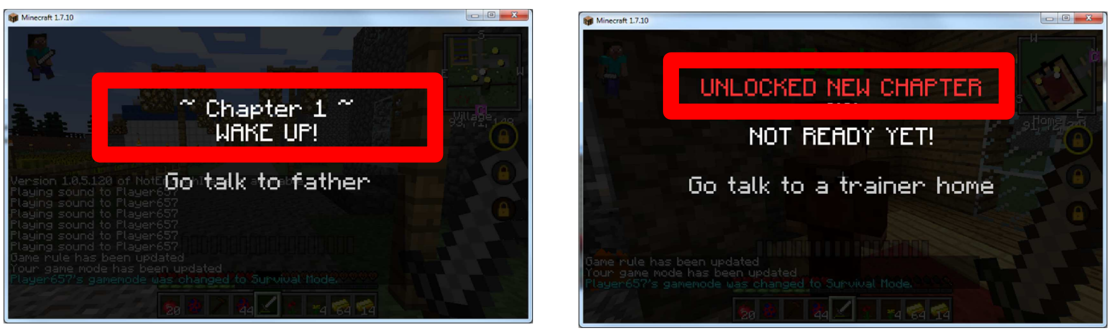

Figure 3. 21. Chapter System

In MineBike, the monsters' health increases as the monster level increases. This as done intentionally, I set up monster health as a gate to prevent players from navigating through MineBike too easily. Since the monsters' strength escalates quickly, players were required to find different ways to quickly level-up their characters too. To do this, i.e., get stronger, players can go off to explore the world hunting for hidden weapons, or visit the market place to purchase stronger weapons, etc.. Throughout the playtests that we conducted, I was able to observe that gamers tend to visit the market place more often when they were not able to defeat a monster.

3.4.11 Fight and chasing quest

Many traditional Japanese role-playing games (JRPG) such as Pokémon RPG, and Dragon Quest, adopted the random encounter feature. In those games, players encounter monsters at random intervals when the main character is out of village as shown in Figure 3.22. Lipkin et al. comment that good balance of random encounters can create positive game experience [86].

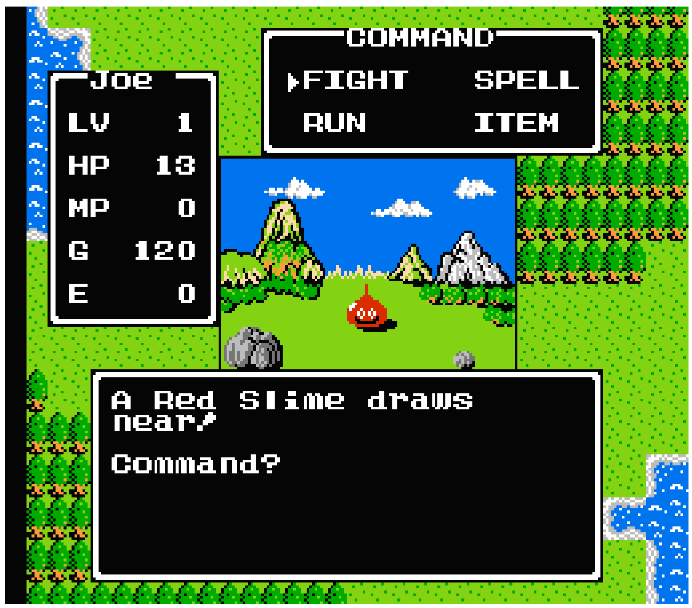

Figure 3. 22. Random Encounter in Dragon Quest from https://tvtropes.org/pmwiki/pmwiki.php/Main/RandomEncounters

In order to achieve recommended exercise time, multiple chasing quest sessions need to be triggered – this is because the expected length of each chasing challenge was about 3-7 minutes. The random encounter is a great method to trigger a chasing quest. To implement a random encounter in MineBike, I introduced a modified version of a chasing quest: the "Fight and chasing quest." It triggers few minute, whenever gamers are out of the village. During the playtests, I found that gamers would be physically over challenged and get frustrated by repetitive tasks when they had to spend a lot of time defeating a monster, Therefore, finding a good balance between a monster's strength and interval was critical to prevent frustration. In order to overcome physical frustration, I implemented a resting interval of at least 30 seconds, which is the recommended resting time suggested in HIIT. Also, to minimize the annoying repetitive tasks, I implemented a fight scene before chasing moments so that players can deduct health of monsters before entering the chasing scene as shown in Figure 3.23.

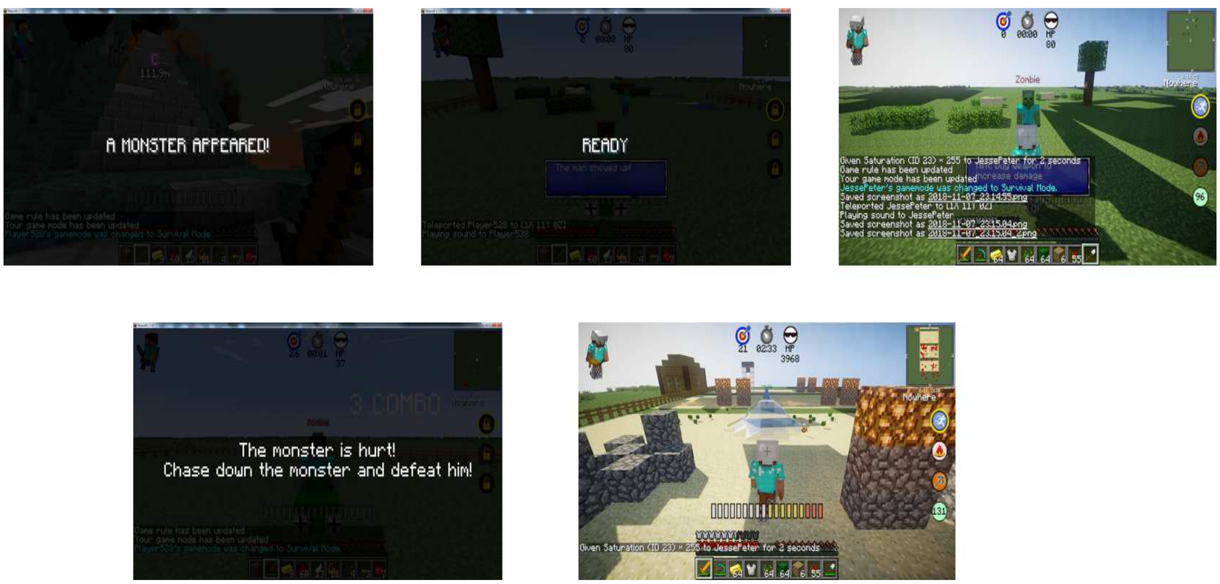

Figure 3. 23. Fight and Chasing Quest

3.4.12 Tutorial Session

To familiarize the user with the game interactions between the gamepad input events and in-game events, I developed a short tutorial. The tutorial consists of 9 individual sections that address each game event in MineBike: basic player character movements (e.g., moving forward/backward, jump, dash jump), mining, building, attacking, and character/block interaction as shown in Figure 3.24.

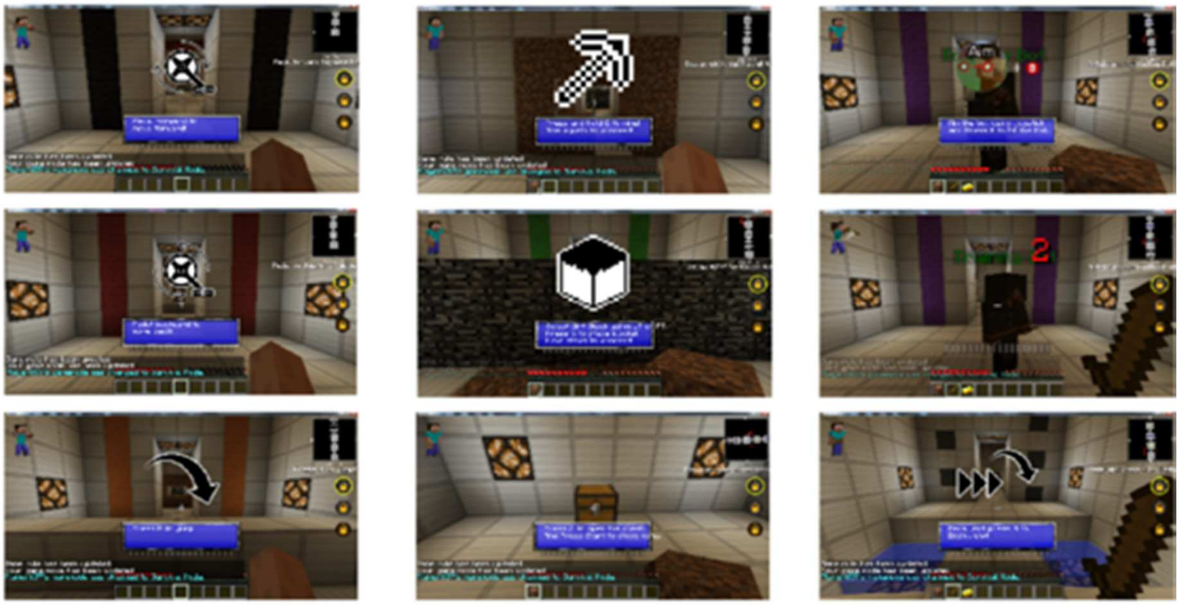

Figure 3. 24. Screenshot of tutorial in-game session

I also implemented a help screen that displays gamepad button arrangement while pausing the game session. For easy access to the help menu, I mapped a gamepad button to toggle the help menu as shown in Figure 3.25.

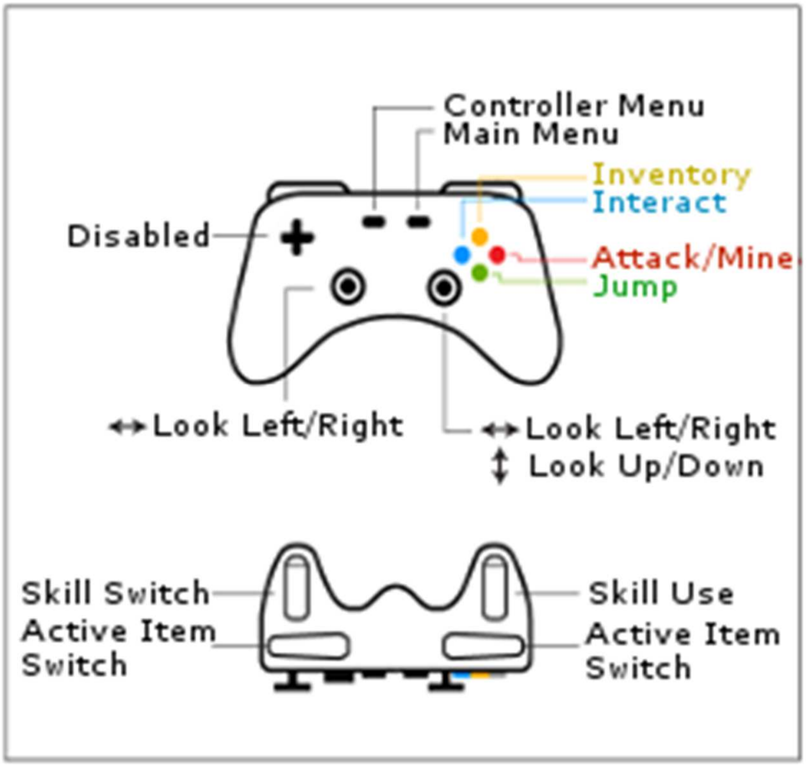

Figure 3. 25. Help screen

Chapter 4

4. Platform Evaluation

4.1 About the Platform

The iXercise platform (Minebike) is a modified version of the popular game Minecraft, designed for 8-15y/o children. Minebike was adjusted and modified to be played on stationary bikes and designed to promote physical activity in the pediatric population. Minebike incorporates HR measurements and can alter the resistance of the bike (activity level) in order to increase/decrease exercise intensity to be prescribed for each participant based on his/her level of fitness. Minebike added special features include a tutorial (instructions how to play the game), storyline (guide players into certain tracks that require more intense exercise), non-player-character interactions (give hints, to sell/buy items or to initiate events) and on-screen feedback messages. The game was modified to make the content and appearance richer by borrowing several Minecraft plugins and extensions. Since those features are available only in English we had no option to translate our Minebike version to additional languages.

4.2 Study Goal

The goal of this phase of the study was to evaluate the iXercise platform/ Minebike exergame.

Primary outcomes: Evaluate platform work load (Watts) and revolutions per minutes (RPM) in different game levels, and participant physiological responses: 1) HR (using HR monitors), with a goal to exercise > 20 minutes at target HR (60-85% predicted maximum HR) in each 40 min exergaming session and characterize HR responses in different game levels. 2) oxygen uptake (VO2, using a metabolic cart) to evaluate metabolic demands in different game levels.

Secondary outcomes: Evaluate platform usability, participants' performance and enjoyment and overall feedback.

4.3 Method

4.3.1 Study Participants

Twenty-two healthy children 9-15 y/o participated in the evaluation phase of the study. Only participants with some gaming experience were included in the study. The Institutional Review Board at the University of California Irvine approved the study and written informed consent and assent were obtained from all participants and their legal guardians upon enrollment.

4.3.2 Study Procedure

All study activities took place at the UC Irvine Health Pediatric Exercise and Genomics Research Center (PERC).

Each child participated in up to 3 exergaming sessions. Session 1 consisted of ~20 min of orientation and informed consent and assent, a questionnaire about gaming habits, approximately one-hour exergaming session (including a tutorial to introduce the MineBike game) and ~ 15 min of questionnaires administered by a study team member to evaluate platform usability, participants' enjoyment and overall feedback. The other two sessions required about 1 hour and included 40 min of Minebike exergaming and additional time for questionnaires. During the exergaming, participants' work rate (WR) and heart rate (HR) were continuously recorded and gas exchange to evaluate metabolic demands was measured using a metabolic cart in one out of the three sessions.

Detailed description of study activities for each session:

Session 1: Consent/assent, familiarization to exergaming, exergaming and questionnaires (about 90 min):

Subsequent to the consent/assent the following activities were performed:

- **Anthropometric measurements (height and weight)**
- **A questionnaire to gauge interest in computer games and gaming skills**
- **Introductory tutorial and practice on MineBike**
- **Game calibration procedure to set participant's physical activity level**
- **40 min of MineBike exergaming**
- **Post-game questionnaires - enjoyment, platform usability, overall feedback**

Sessions 2 & 3: exergaming and questionnaires (up to 60 min):

- **Game calibration procedure to set participant's physical activity level**
- **40 min of MineBike exergaming**
- **Post-game questionnaires - enjoyment, platform usability, overall feedback**
- **Gas exchange measurement to assess metabolic demands during the exergaming was performed in one out of the 2 sessions.**

4.3.3 Data collection instruments

Gaming habits questionnaire: The pre-screen survey (Appendix B) contains game habit questions to gauge the participants' understandings on gaming in general. The questionnaire asks for in-depth knowledge and gameplay experience about Minecraft.

Anthropometric Measurements: Standard calibrated scales and stadiometers were used to determine height and body mass. Body mass index [BMI = wt/ht2 (kg/m2)] percentile was calculated using the published standards from the Centers for Disease Control, National Center for Health Statistics [87].

Exercising ergometer: Participants played and pedaled on a modified stationary bike (Proform 120R or Proform 460R). Workload in Watts and revolutions per minute (RPM) were recorded. The resistance was set at the beginning of the game and the overall workload during the game was changed by changing the RPM. RPM controlled the in-game characters' movement.

Exercise intensity: Heart rate (HR) was continually recorded during the game indicating the different exercise intensity levels. Participants exercised while wearing Polar H7 HR monitor. The collected data was transmitted using wireless technology "Bluetooth" characterizing the HR responses at a specific gaming level and summarizing the total number of min participants exercised at the target HR zone (>120bpm). The iXercise platform tagged activity levels to each timestamp and summed up the timestamps.

Metabolic demands evaluations: Gas exchanges measurements were collected in one out of the three exergaming sessions. Participants exercised while breathing through a mouthpiece with a nose clip on, and breath-by-breath measurements were collected using a metabolic cart (SensorMedics Vmax 229, Yorba Linda, CA).

Platform usability questionnaire: platform usability was evaluated using participant satisfaction survey questionnaire (Appendix F).

Participant perception of the game exercise intensity: At the end of each exergaming session, participants indicated their Rating of Perceived Exertion (RPE) using an RPE Scale (Appendix E) Borg RPE scale gauge how the participants' perceived the exercise level. The scale range is from 6 to 20 where 6 means resting, such as reading books or watching TV, and 20 indicates the hardest effort where participants push their limit.

Enjoyment: The Feeling Scale (FS) (Hardy & Rejeski) (Appendix D) was administered on the bike immediately at the end of the game. The FS measures participants' mood with the scale ranging from -5 to +5 which correspond to "very bad" and "very good" respectively. Physical Activity Enjoyment Scale (PACES) (Appendix C) was used to assess how much the participants enjoyed playing MinBike. PACES contains 16 statements with a scale ranging from 1 to 5 which correspond to "Disagree a lot", "Disagree", "I am not sure", "Agree" and "Agree a lot". The questionnaire has two sets of questions, either with positive or negative tones. For gauging enjoyment level, the score of negative questions was reversed and summed up the scores to calculate overall enjoyment scores.

Engagement: The duration of the exercise sessions was recorded. The duration data was compared with the exercise duration answers given in the survey to evaluate whether the gamification of the exercise routine effectively hides the burden of the exercise routine.

Gaming performance evaluation: During the exergaming sessions, in-game activities (such as pedaling gauge changes, trajectory, quest activity, non-player-character interaction, skill usages, progress tags, location change tags, skill usage tags, skill gauge bar change tags, and quest activity tags and difficulty settings) were recorded. The collected tags allow us to evaluate the gaming performance in conjunction with the level of exercise.

4.3.4 Analysis

Statistical Application Software (SAS) version 9.4 was used for statistical analyses of the breath by breath dataset. Within subject averages of each Oxygen Uptake and Heart Rate were calculated for each intensity level. METS were calculated as Oxygen Uptake (ml/kg/min)/3.5 [88]. These within subject averages were the primary outcome variables.

Demographic variables (sex and age group), duration of sessions, and percentages at target heart rates were gathered in EXCEL merged with outcome data in SAS. Similarly, total and average scores for the Gaming Performance, PACES and satisfaction surveys were calculated in EXCEL and transferred to SAS for analysis.

SAS Procedures used: **SAS PROC MEANS** was used for summary and distribution statistics (e.g., means, standard deviation, percentages). Repeated measures analysis was performed using **SAS PROC MIXED** for all continuous variables to evaluate session mean differences, intensity level differences as well as the role of age and sex. For binary and categorical outcomes, session effects were evaluated with **SAS PROC FREQ Cochrane Maentle-Hantzel** adjusted chi-square tests due to the small sample size. A significance criterion of $p<=.05$ was implemented.

4.4 Results

4.4.1 Participants Demographic and Anthropometric

Thirteen boys and nine girls, 9 to 15 years old participated in this phase of the study. Participants demographic and anthropometric measures of the 22 participants are summarized in Tables 1 and 2.

Table 1. Participants demographic and anthropometric information

Sex	Age	Height (cm)	Weight (cm)	BMI %ile
Male	15 Years, 1 Months	177.2	55	14
Male	15 Years, 1 Months	174	54.7	21
Male	13 Years, 7 Months	174.7	75.1	93
Male	13 Years, 1 Months	157.6	45.9	50
Male	13 Years, 0 Months	158.4	45.55	45
Male	12 Years, 11 Months	159.6	44.4	33
Male	12 Years, 8 Months	160	40	8
Male	11 Years, 8 Months	144.1	31.5	7
Male	11 Years, 2 Months	153	34.45	6
Male	10 Years, 7 Months	146.5	37.15	56
Male	10 Years, 1 Months	142.8	34.85	58
Male	9 Years, 10 Months	129.9	25.75	22
Male	9 Years, 0 Months	149.9	44.1	90
Female	13 Years, 6 Months	154.1	48.35	66
Female	12 Years, 7 Months	146.3	53.5	94
Female	12 Years, 4 Months	171.1	68.6	90

Female	12 Years, 4 Months	155.7	46.85	63
Female	11 Years, 5 Months	138.4	29.25	12
Female	10 Years, 7 Months	148.5	48.35	91
Female	9 Years, 8 Months	135.2	24.2	1
Female	9 Years, 7 Months	134.7	46.55	98
Female	9 Years, 7 Months	128.8	28.35	58

Table 2. Boys and girls: demographic and anthropometric

Sex	Boys		Girls	
Age group	9 – 11 y/o	12 - 15 y/o	9 – 11 y/o	12 - 15 y/o
n (percent)	6 (27.27 %)	7 (31.82 %)	5 (22.73 %)	4 (18.18)
Height (cm)	144.37 ± 8.02	165.93 ± 8.85	137.12 ± 7.24	156.8 ± 10.38
Weight (kg)	34.63 ± 6.08	51.52 ± 11.75	35.34 ± 11.24	54.325 ± 9.93
BMI %ile	39.83 ± 33.61	37.71 ± 28.89	52 ± 44.37	78.25 ± 16.01

12 participants were normal weight defined by BMI%ile 10th >85th, 4 underweight (< 10th BMI%ile), 5 overweight (85th > 95th BMI%ile) and one obese (> 95th BMI%ile).

4.4.2 Activity Levels and Game Classifications

Game functions were categorized into four different activity levels (Table 3): Activity level 0 (RPM=0) reflects gaming with no exercise/pedaling. Activity level 1 (RPM <10) includes collecting items (chest interaction), marketplace events and player inventory interactions. During those types of in-game events, gamers usually stopped moving their virtual characters and interacted with Graphics User Interface (GUI) menus to purchase in-game items, equip armor or weapons, or exchange in-game items between a player inventory and a chest. Activity level 2 (RPM 10<40) includes game activities such as regular exploration, chasing quest reward collection time and other basic Minecraft tasks. Activity level 3 (RPM>40) reflects MineBike's chasing challenges. Figure 4.1 shows the RPM for a given game activity level.

Table 3. Activity Levels, Work Load, RPM and Game Classifications

Activity Level	Approximate Wattage	RPM *	MineBike activity sub-type
0	0	0	Gaming without exercising/pedaling
1	< 17	< 10	Collecting items (chest interaction), marketplace events and player inventory interactions
2	17 > 40	10 > 40	Exploration (a character explores virtual world)
3	> 40	> 40	Chasing sequence (a character chases thieves or monsters)

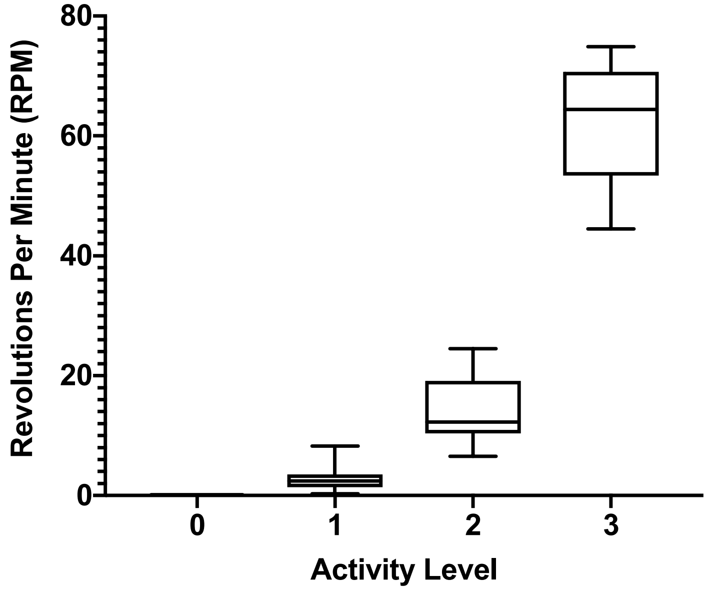

Figure 4. 1. RPM during the four different activity levels

As shown in Figure 4.2, participants spent the most amount of time playing activity level 3 (moderate- to high-intensity activity). On average participants spent about 3.65 ± 0.72 min at activity level 1, 16.73 ± 2.04 min at activity level 2, and 22.57 ± 0.55 min at activity leve3.

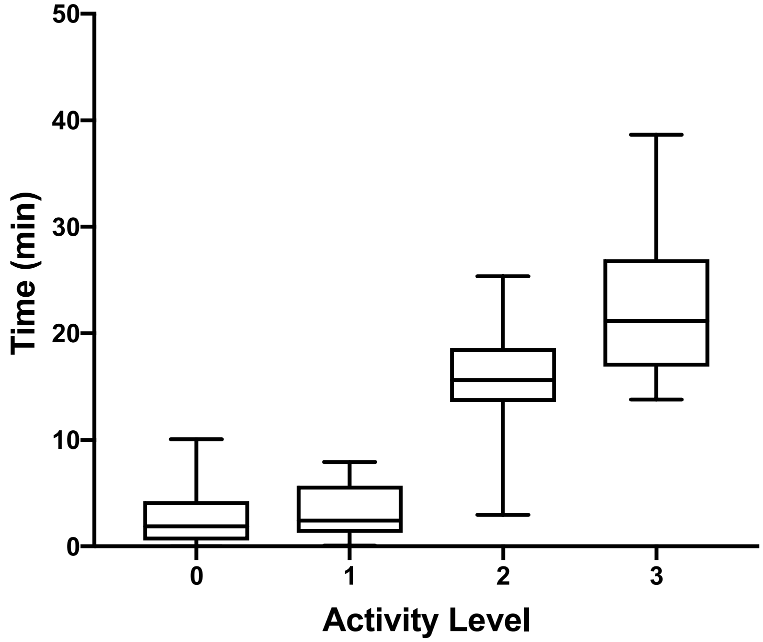

Figure 4. 2. Time spent on different activity levels in an exergaming session

4.4.3 MineBike Players Physiological Responses

4.4.3.1 HR Responses

All participants achieved study goal to exercise > 20min at a target heart rate > 120 bpm in an exergaming session of 40 min (Figure 4.3). The average time participants spent at the target heart rate at the different sessions was 26.35 min, 26.27 min and 21.08 min respectively (Figure 4.3).

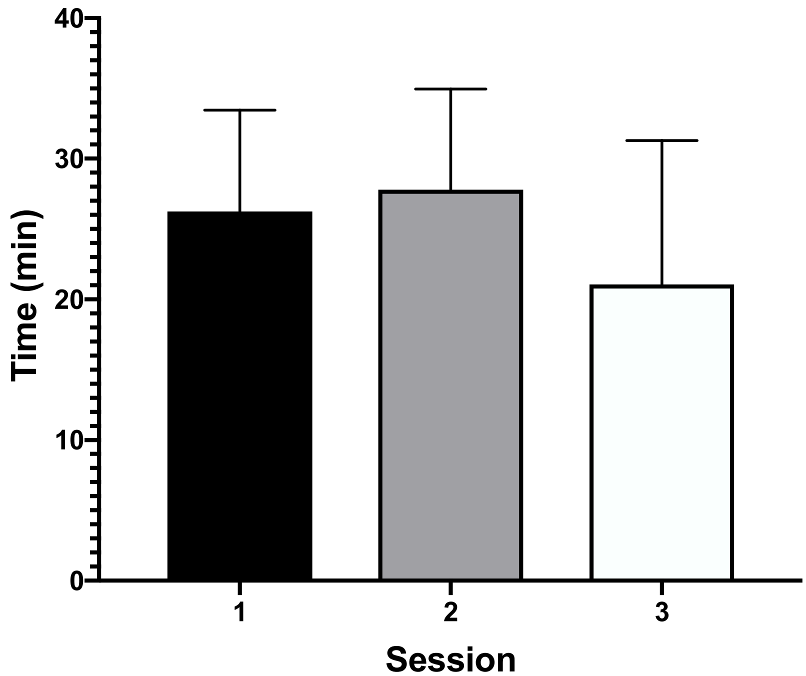

Figure 4. 3. Time spent at target heart rate (HR > 120 bpm) during MineBike exergaming sessions 1, 2 and 3

Figure 4.4. illustrates the heart rate responses at different activity levels. Higher activity level induced higher HR response. The averages heart rate at activity level 0 was 86 ± 11 bpm, activity level 1: 99 ± 16 bpm, activity level 2: 106 ± 15bpm, and activity level 3: 136 ± 16 bpm.

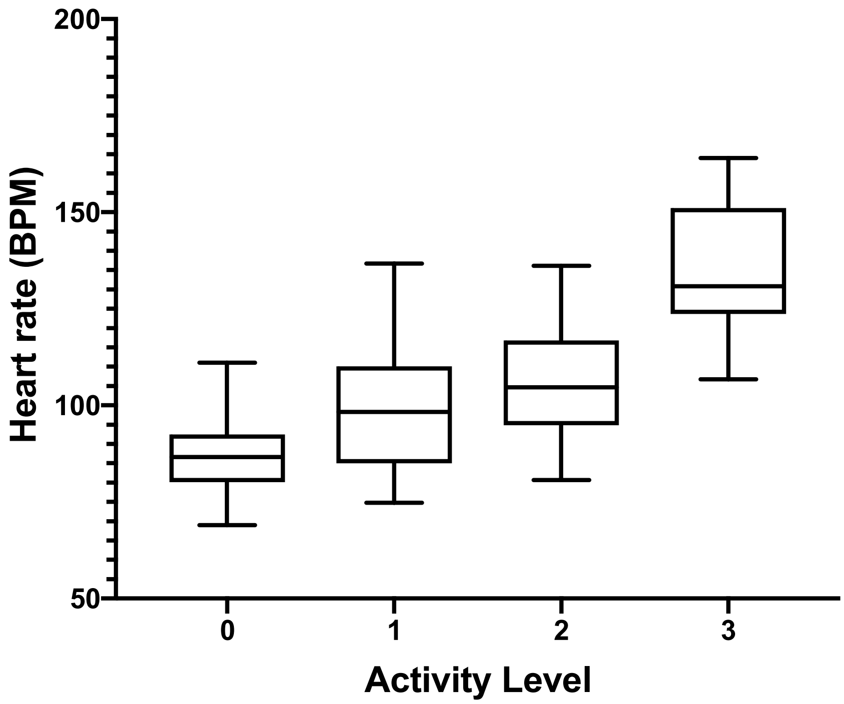

Figure 4. 4. Heart rate responses at different activity levels

Metabolic demands during the game were measured in session 2 or 3 using a metabolic cart. Participants played MineBike while breathing through a mouthpiece with a nose clip on, to measure gas exchange breath-by-breath. Oxygen uptake (VO2, VO2/kg) was measured during every activity level and Metabolic Equivalents (METS) was determined by dividing the VO2 (ml/kg/min) rolling average of each activity level by 3.5 [88].

As expected O_2 uptake increased with the increase in activity level (Figure 4.5). The averages of oxygen uptake were 8.80 ± 4.09 (mL/kg/min) at activity level 0, 13.42 ± 4.01 (mL/kg/min) at activity level 1, 22.35 ± 4.08 (mL/kg/min) at activity level 2, and 32.33 ± 4.36 (mL/kg/min) at activity level 3.

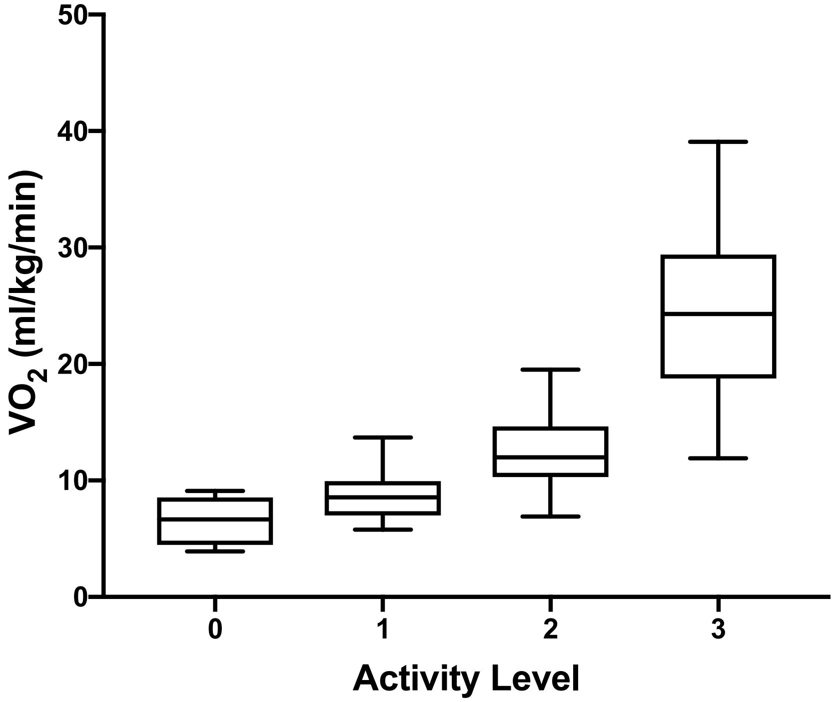

Figure 4. 5. Minebike Metabolic Demands at different activity levels

Figure 4.6 presents the participants' METS at the four activity levels. Activity level 0; 2.51 ± 1.17 METS, activity level 1; 3.84 ± 1.15 METS, activity level 2; 6.39 ± 1.16 METS, and activity level 3; 9.24 ± 1.24 METS.

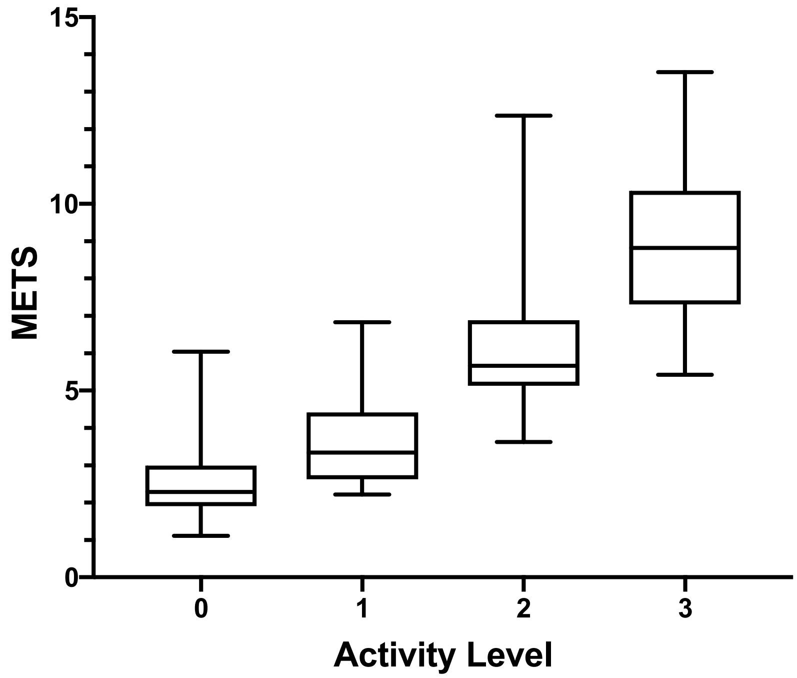

Figure 4. 6. METS measured at the four different activity levels

Figure 4.7 compares between MinBike METS at different activity levels and other exergaming titles. MineBike (activity levels 2 and 3) was able to induce higher METS than any other published exergame titles such as dance central, Kinect Sports Boxing and Kinect Adventures! Xbox 360 [89].

Figure 4.8 compares between MinBike METS at different activity levels and standard outdoor children activities' METS [90], [91]. For example, children ages 7-15 years old achieve 3 METS on average while walking at a comfortable pace [90] and 8 METS on average while jogging at a fast pace [91]. MinBike METS at activity level 0 is equivalent to walking at a comfortable pace, METS at activity level 1 are similar to fast pace walking, and METS at activity level 3 are higher than fast pace jogging [90], [91].

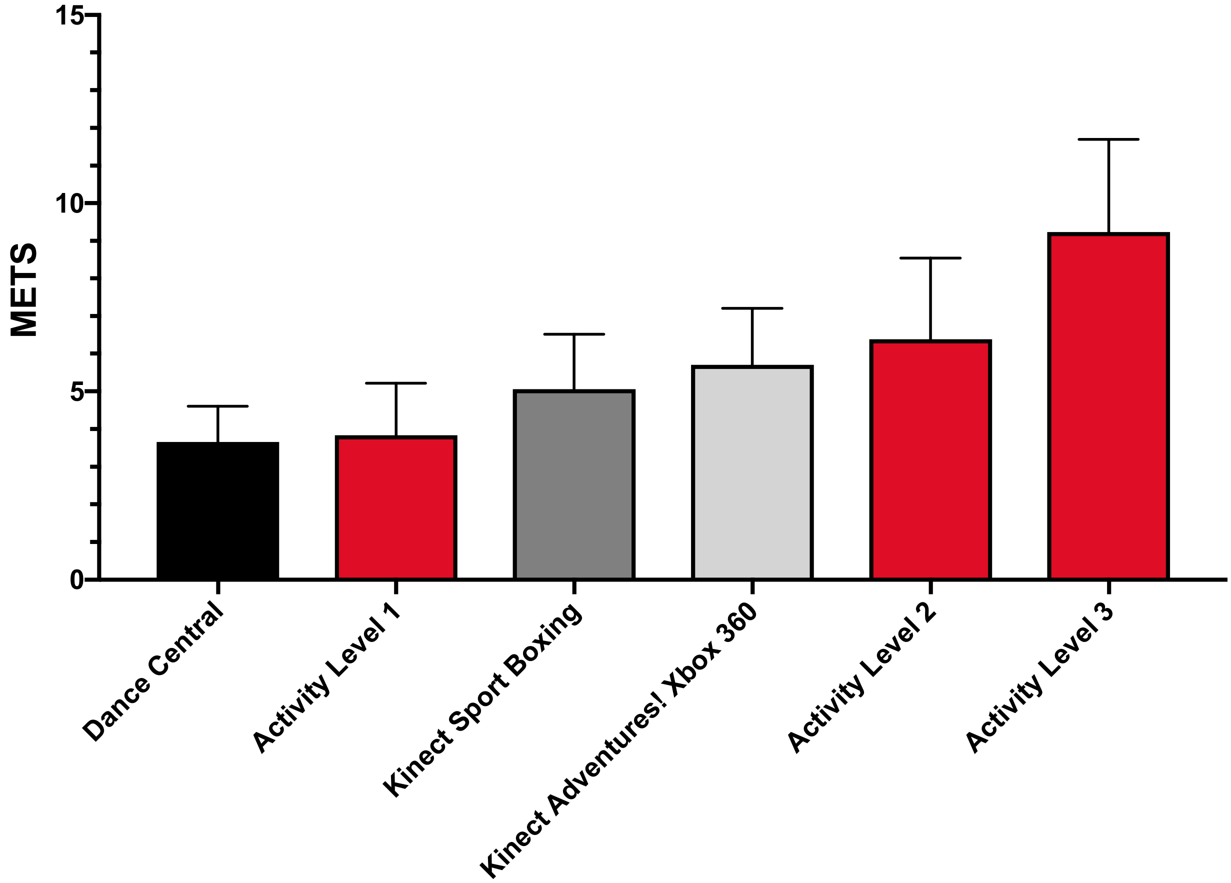

Figure 4. 7. MinBike and Other Exergaming Titles Metabolic Equivalents (METS)

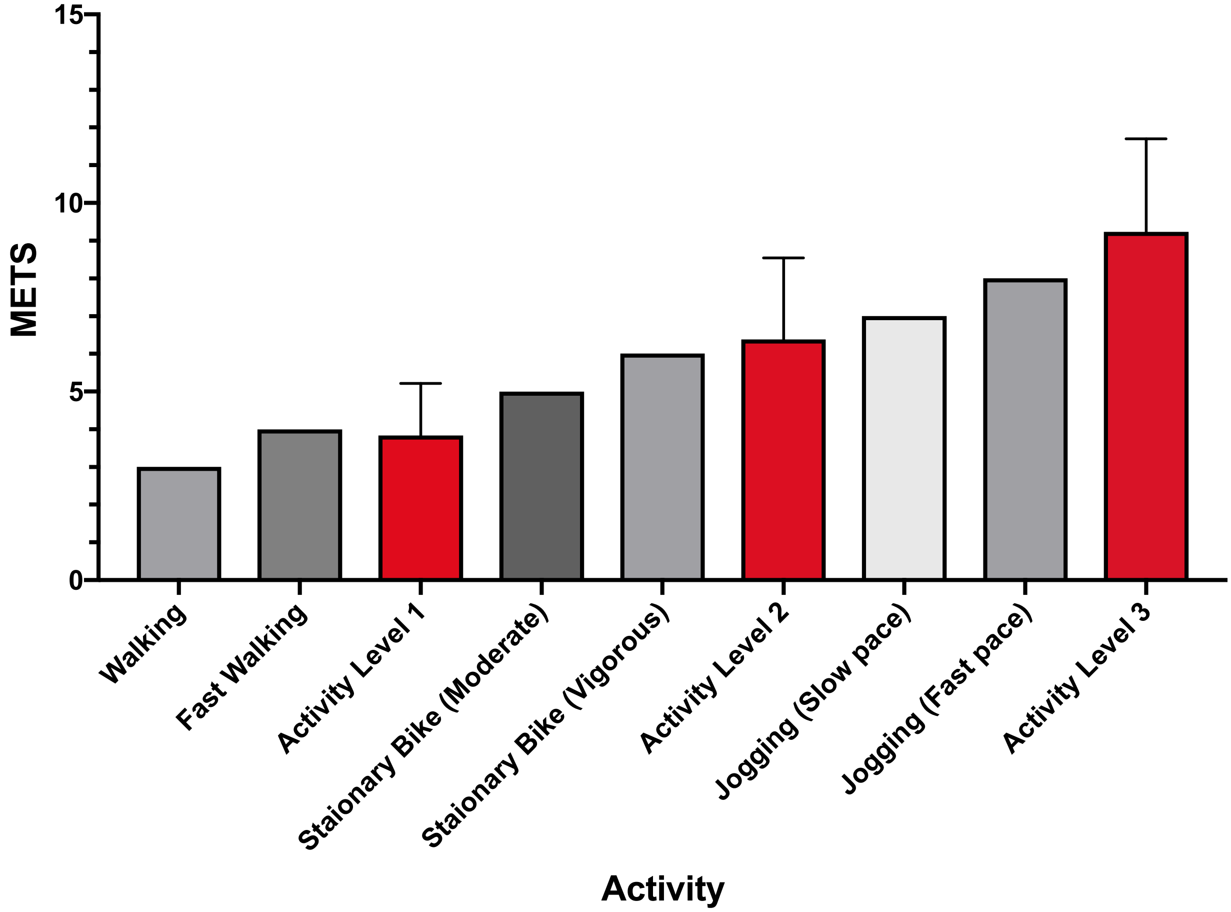

Figure 4. 8. MineBike and Other Typical Outdoor Activities Metabolic Equivalents (METS)

4.4.3.2 MineBike Physiological Responses: Age and Sex Comparisons

Heart rate and oxygen uptake responses at the four different activity levels were analyzed by sex and age. As shown in Figure 4.9, there are no significant sex differences in the HR responses in all 4 activity levels.

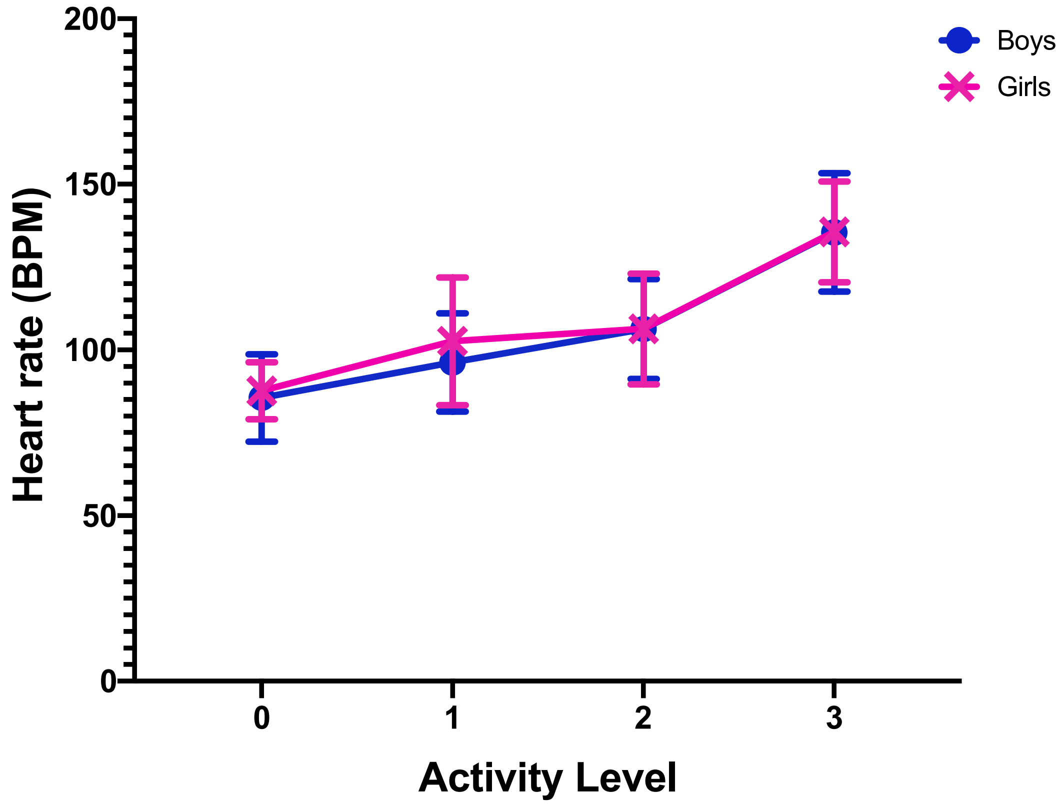

Figure 4. 9. Boys and girls increase HR with increased activity level with no sex differences

Figure 4.10 shows that both boys and girls increase oxygen uptake with increased activity level ($p<0.0001$) with on average higher VO_2/kg increase in boys ($p=0.0045$). Higher values of oxygen uptake per kg in boys can be explained by different body composition, meaning boys have more muscle mass compare to girls and/or boys playing higher monster levels (stronger thieves and monsters) that require higher metabolic demands.

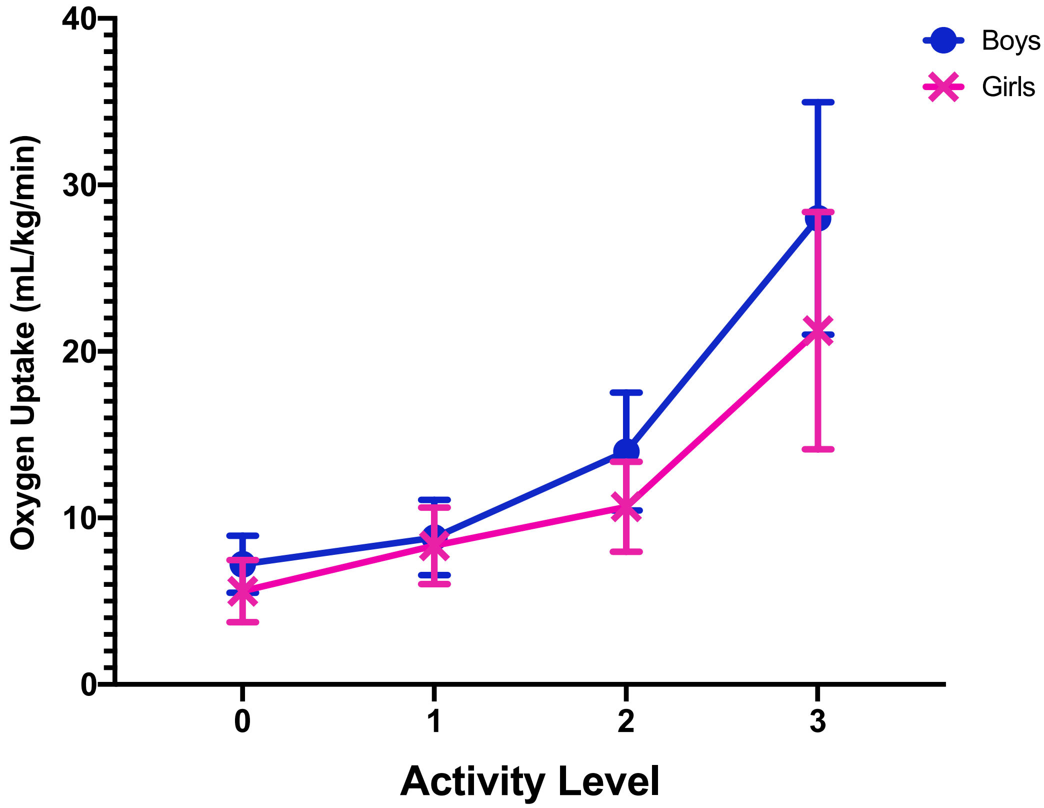

Figure 4. 10. Boys and girls increase oxygen uptake with increased activity level ($p<0.0001$) with on average higher levels in boys ($p=0.0045$)

Figure 4.11 shows no age differences in the HR responses to different MinBike activity levels.

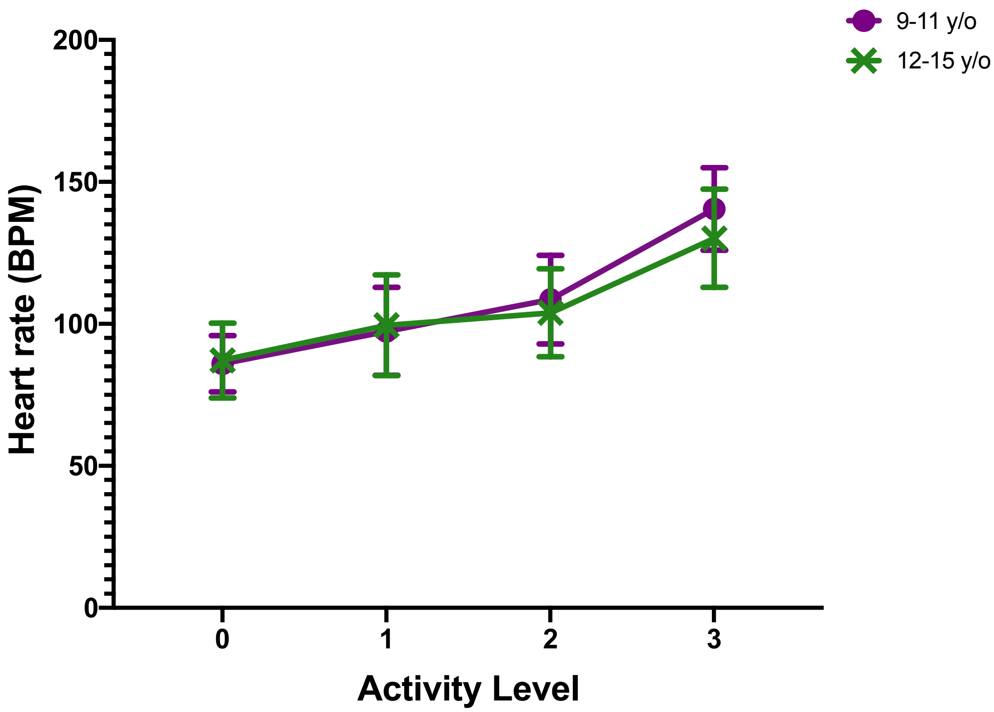

Figure 4. 11. HR Responses to Different MinBike Activity Level is Similar in Boys and Girls

Increase in oxygen uptake was observed with increase in activity level in both age groups (Figure 4.12). Younger children, on average exhibited higher VO2 (mL/kg/min). However, interaction was not significant.

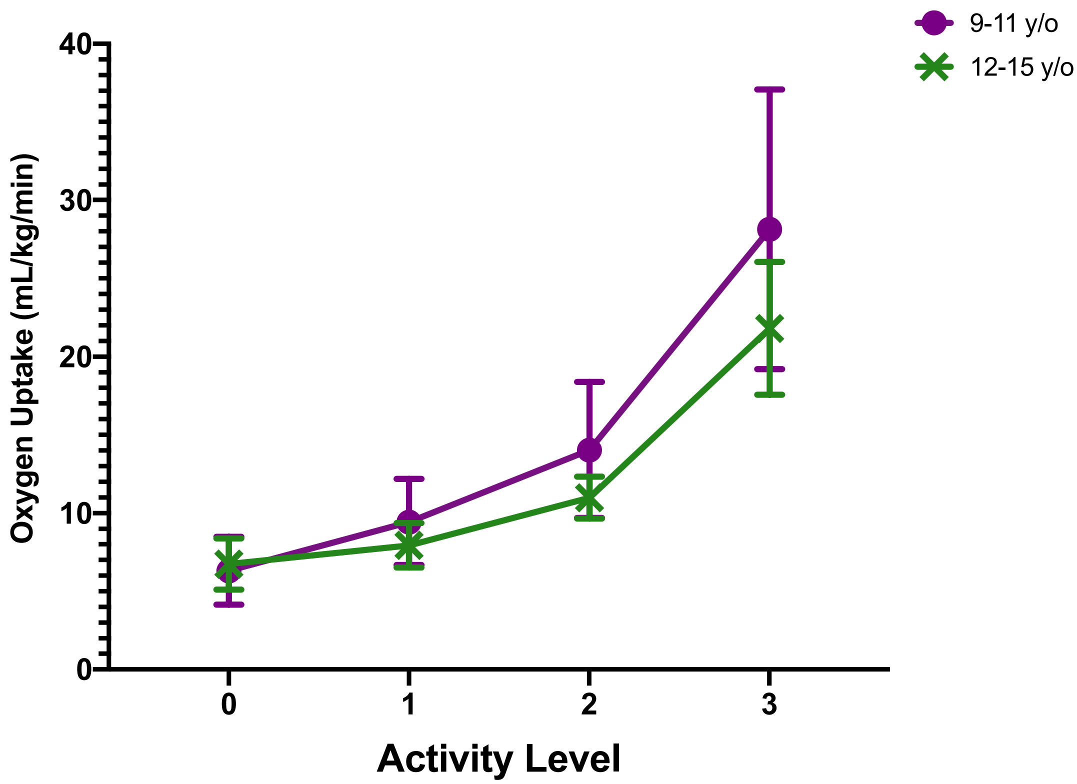

Figure 4. 12. On average younger children exhibited higher metabolic demands while playing Minebike

4.4.4 Correlation of game activity and physiological responses

Figure 4.13 summarizes MineBike different activity levels and their related physiological responses. As expected the higher the activity level is the higher the HR response and oxygen uptake are. Quantifying the physiological responses at a given activity level will enable us to personalize MinBike sessions based on each child fitness level and needs.

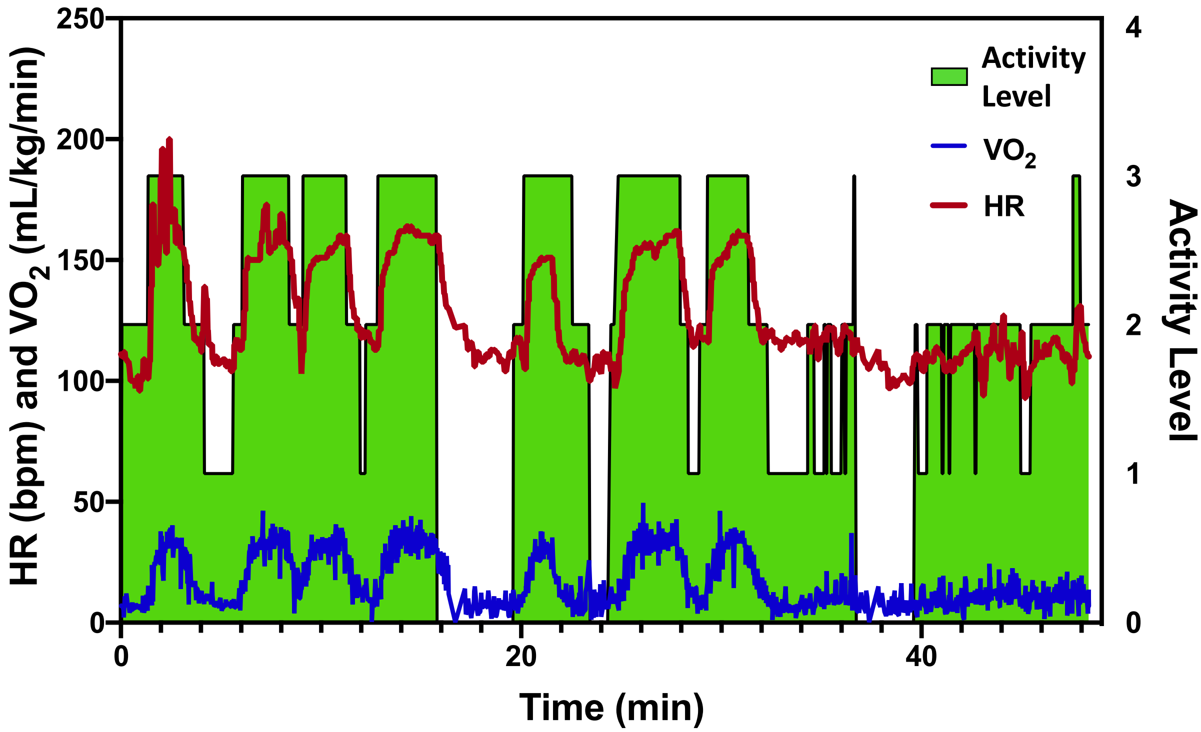

Figure 4. 13. Correlation of game activity and physiological output

4.4.5 Enjoyment and engagement evaluations

Activity Enjoyment Scale (PACES) and game satisfaction surveys where used to gauge the enjoyment and engagement levels.

4.4.5.1 Physical Activity Enjoyment Scale (PACES)

Figure 4.14 presents the average total score in sessions 1-3. Noted, that the participants' enjoyment levels slightly increased between the first and second session. Table 4 presents the individual PACES scores of all 16 questions in the three sessions. On average, participants reported 4.14 ± 0.16 out of 5 for all 16 questions.

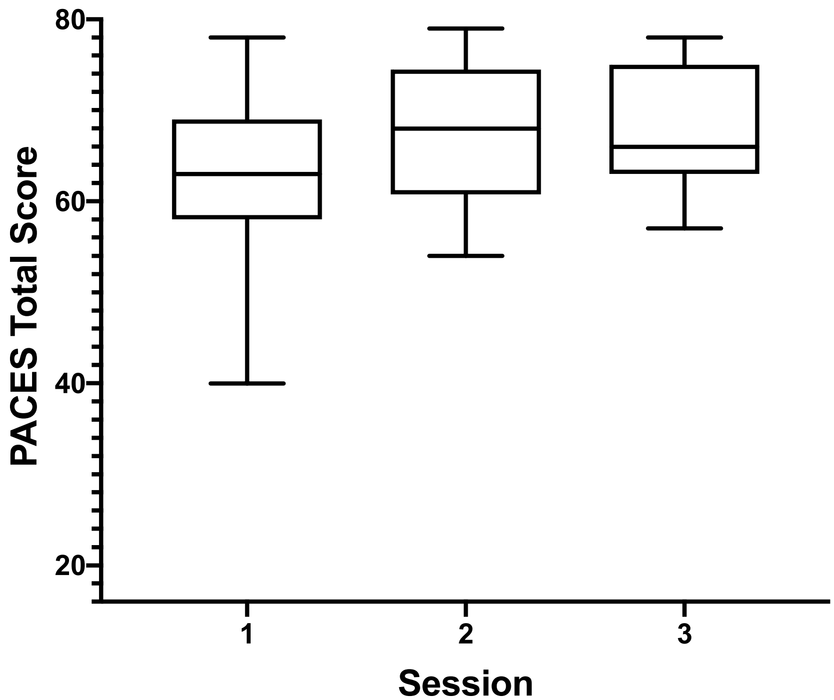

Figure 4. 14. Physical ACtivity Enjoyment Scale (PACES)

Table 4. PACES scores for sessions 1-3

Question	Score		
	Session 1	Session 2	Session 3
I enjoyed it	4.29 ± 0.56	4.5 ± 0.51	4.47 ± 0.51
I felt bored	3.95 ± 0.92	4.44 ± 0.62	4.47 ± 0.61
I disliked it	4.29 ± 0.72	4.5 ± 0.62	4.68 ± 0.48
I found it fun	4 ± 0.89	4.33 ± 0.59	4.42 ± 0.61
It was not fun at all	4.48 ± 0.6	4.78 ± 0.43	4.58 ± 0.61
It gave me energy	3.14 ± 1.11	3.61 ± 0.92	3.53 ± 1.02
It made me sad	4.57 ± 0.68	4.67 ± 0.49	4.68 ± 0.48
It was very pleasant	3.7 ± 0.8	3.89 ± 1.02	3.68 ± 0.89
My body felt good	3.48 ± 1.12	3.94 ± 1.11	4.05 ± 0.91
I got something out of it	4.1 ± 0.62	3.94 ± 0.73	3.95 ± 0.85

It was very exciting	3.9 ± 0.77	4.22 ± 0.88	3.95 ± 0.97
It frustrated me	3.43 ± 1.08	3.89 ± 1.13	4 ± 1.05
It was not at all interesting	4.33 ± 0.91	4.72 ± 0.46	4.63 ± 0.5
It gave me a strong feeling of success	3.95 ± 0.97	4 ± 0.77	4 ± 0.94
It felt good	3.95 ± 0.8	4.22 ± 0.73	4.21 ± 0.54
I felt as though I would rather be doing some	3.71 ± 0.96	4.06 ± 0.73	4.42 ± 0.61

Boys were rating higher enjoyment in all sessions compared to girls ($p=.0003$). No differences in ratings were found between two age groups.

4.4.5.2 Participant satisfaction survey

Participant satisfaction survey was used to gauge iXercise/MineBike usability and game pleasure. The survey includes 15 questions (Table 5) about enjoyment, clarity, operation and overall guidance during the game, which the participants answered on a Likert-type scale 1-5, three additional questions (see bullets below) and one question about general feedback.

Table 5. Game satisfaction survey responses on Likert-type scale

Questionnaire (Likert-type scale *)	Score Average *
Was this fun?	4.31 ± 0.15
Was it clear what you were supposed to do in the game?	4.28 ± 0.1
How easy was the bike/game to use?	3.56 ± 0.15
How easy was the exercise?	3.04 ± 0.63
Would you do this again?	4.27 ± 0.13
Was the audio feedback clear?	3.82 ± 0.35

Was the audio feedback helpful?	3.09 ± 0.33
Would you invite a friend to do this (exergaming)?	3.97 ± 0.11
Was the visual feedback clear?	4.36 ± 0.15
Was the visual feedback helpful?	3.6 ± 0.3
The amount of visual feedback I got was:	3.0 ± 0.0 **
The amount of audio feedback I got was:	3.08 ± 0.14 **

* Likert-type scale: 5-strongly agree, 4-agree, 3-neutral, 2-disagree, 1-strongly disagree
** Scale: 1- Definitely not enough, 2-Not really enough, 3-Just right, 4-Too much, 5-Definitely too much

Additional questions include:

- How long do you feel you exercised for?
- Would you prefer to exercise on the bike with or without playing the game?
- Would you prefer to play the game with or without the bike?
- What else would you like to tell us about your experience in this session?

Overall, participants reported they enjoyed playing the MineBike in all three sessions. They indicated the instructions to play the game were clear from the very beginning however they seem to become more familiar with MineBike over time. In addition, they answered that using the exercise bike with a gamepad was easy for gameplays. The participants mostly were enthusiastic on coming back for more gameplays. Participants reported that in-game feedbacks delivered messages clearly, but the feedback messages require to be refined a bit more to be even more helpful.

For the question: "How long do you feel you exercised for?" The participants estimated about 39.66 ± 6.24 min. This question/answer might not be valid since all participants were notified prior to the beginning of the session how long they will be exergaming and during the game the time was also shown on the screen.

For the question: Would you prefer to exercise on the bike with or without playing the game? Most participants answered they would prefer to exercise with Minebike (Table 6) with higher percentage among the boys (97%) compared to the girls (85%). This answer indicates that MinBike can be a promising platform to promote physical activity among children (both boys and girls) who like playing computer games.

Table 6. Number of participants answered they would prefer to exercise with MineBike

	Boys	Girls
Session 1	90 %	78 %
Session 2	100 %	88 %
Session 3	100 %	88 %
Overall	97 %	85 %

For the question: Would you prefer to play the game with or without the bike? About half of the participants answered they would like to play the game while exercising on the bike (Table 7), indicating that those participants enjoyed the game even more when it included the exercise component. Choosing exergaming as a gaming genre would promote physical activity in our target population and would benefit their health.

Table 7. Would you prefer to play the game with or without the bike?

å	Children answered with the bike
Session 1	50 %

Session 2	60 %
Session 3	50 %
Overall	52.94 %

At the end of each session, the participants gave their overall feedback; what else would you like to tell us about your experience in this session? They also answered additional open questions about what part of MineBike they liked, which part they least preferred, and which parts might be confusing. The full list of the overall feedbacks can be found in APPENDIX-G. Below are selected answers.

Minbike participants' affirmation:

- **Liked the 'epic' music. Adjusting sensitivity to controls was good.**
- **Liked how you can buy stuff + get stronger. Thinks of it as good exercise.**
- **It was very helpful- a special experiment. would like to play it many more times.**

Participants' suggestions on ways to improve MineBike:

- **Wanted to explore more than just missions. Also, wants to play with friends at the same time with headsets.**
- **Doesn't like the thief running away.**
- **Would like to play this game with a friend.**
- **Wants to do more secret stuff. Amount of exercise was just right. Wants to be able to explore more.**

- **Was a little boring because it's the same thing happening over and over again. Wanted to build/ explore more since it's Minecraft.**
- **Hard to learn controller. Also doesn't like she can't change resistance: 'exercising bikes normally allow you to change resistance'. Very challenging/ exhausted. Got very dizzy.**
- **Bike seat hurt. Once he got the hang of it, it meshed well. Would have been fun to explore more.**
- **Foot-straps coming off caused slight irritation.**
- **There should be a multiplayer option, and you should be able to talk to other people.**

Favorite / Least Favorite / Confusing parts

The full list of answers can be found in APPENDIX H and APPENDIX I.

Favorite parts (selected answers): good graphics, chasing thieves/monsters, defeating monsters, MineBike world exploration, running up the mountain in the MineBike world, and exchanging items at MineBike marketplace.

Least favorite parts (selected answers): controller (hard to use in the first session), too many different fights, obstacles spawned by monsters, uncomfortable bike seat, game crashes.

Confusing parts (selected answers): Overall the participants indicated it was confusing to figure out where and how to go up to the mountain, how to get to the market place or village gate, and how to choose “next mission”, “retry” or “exit” after each chasing mini game.

4.4.6 MineBike Gaming Performance Evaluation

There was a great variability in the gaming performance among participants which affected the speed of in-game progress. For example, more skilled gamers could clear MineBike chapters quicker than others, also they could defeat monsters more effectively and more efficiently. Throughout the analysis of game events tags, better gamers were significantly performed better in three categories: 1) maximum combo counts, 2) chasing level at the end, 3) damage per minute.

In order to win a chasing mini game, gamers are required to give damages on thieves/monsters. When they can make consecutive damages in a row within a short period of time, the combo counts increase, which results in damage increase per attack as shown in Figure 4.15. Therefore, giving a higher combo counts is a way to clear game quicker and more efficient.

Figure 4. 15. Example of Combo Count

As shown in Figure 4.16, participants' skills were improved by session. Also, in session 1 the girls' performance was lower than the boys their performance improved over time and in session 3 was nearly equal to the boys.

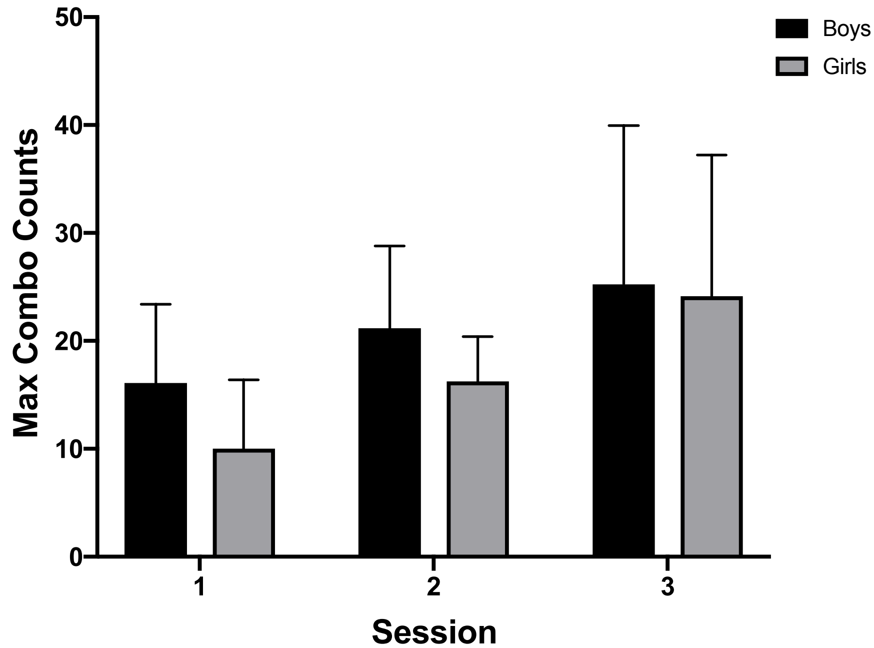

Figure 4. 16. Significant increase in max combo as session progress (p=.0068)

When the gamers can defeat each level of thieves, the level of the thieves/monsters increases as shown in Figure 4.17. The higher monster level at the end was observed when the participants were better at MineBike performance.

Figure 4. 17. Chasing Thieves Levels

As shown in Figure 4.18, both boys and girls were able to progress in the game over time (p<.0.0001). There was a significant difference in sex at each level. Boys was able to reach a higher monster level than the level girls reached (p<0.0001). Figure 4.19 shows that there was a significant difference in age; older participants cleared higher level monsters than younger participants (p=0.0002).

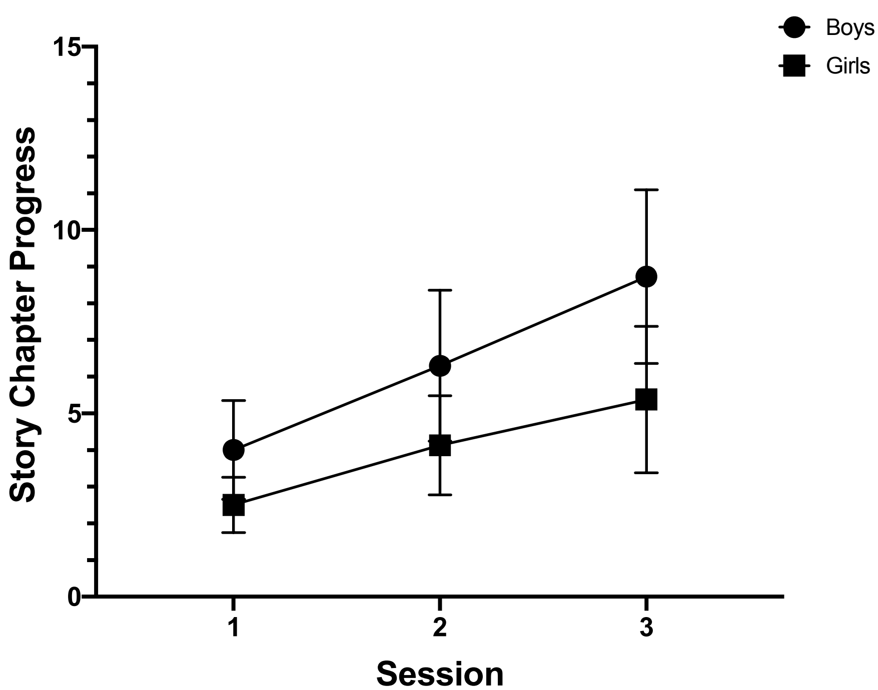

Figure 4. 18. Boys tend to reach higher in-game level

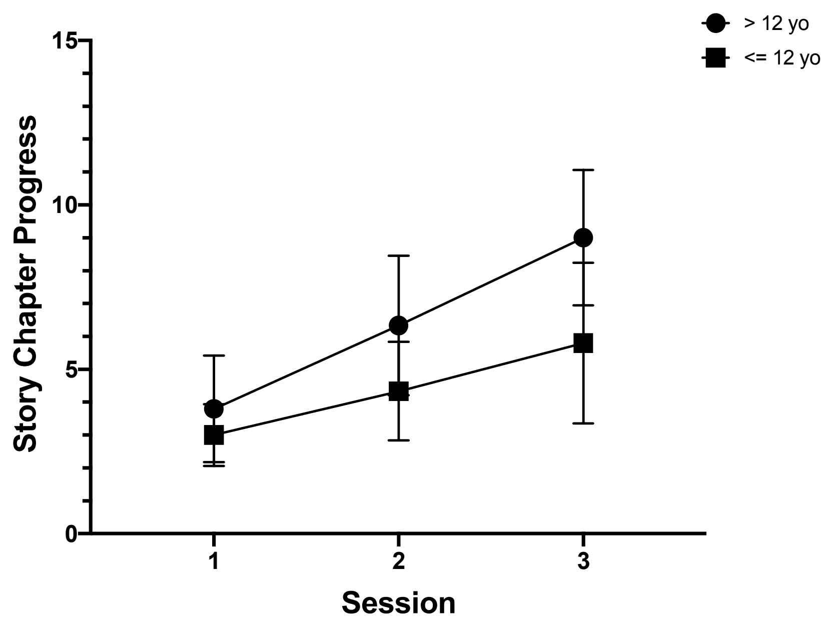

Figure 4. 19. Older participants tend to reach higher in-game level

In addition, the better gamers were able to 1) make higher combo counts, 2) equip with better weapons, 3) maintain aiming more precisely, and 4) understand level-up system. Getting ready for gears and gaming skills made higher Damage Per Minute (DPM) possible. As shown in Figure 4.20, older participants tend to cause more damage per minute (DPM). All participants improved DPM on average (p=0.0318). Also, the older age group showed more improvement than younger group showed (p=0.0417).

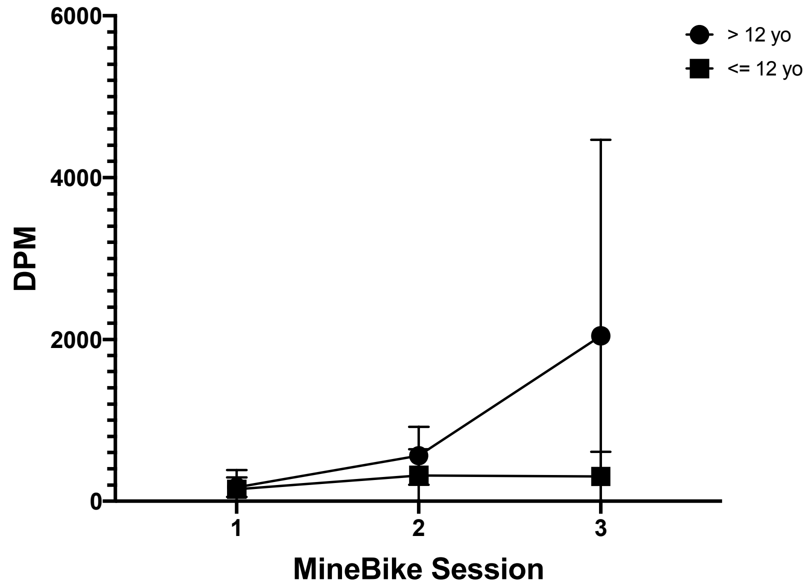

Figure 4. 20 Older participants tend to cause more damage per minute (DPM)

Chapter 5

5. Discussion

The exergame industry has yet to create quality games that players want to play for sufficient amounts of time to achieve long term fitness benefits.

While it makes sense to adapt existing games and fitness equipment, successfully integrating these together into a quality exergame is a challenge. Both the equipment and the game have to be adapted to create an environment that is a natural fit and achieves the desired goals of exercising. This is where our platform simplifies development considerably. Our embedded system and associated client middleware provide the technology backbone for bringing the game and equipment together for an authentic exergame experience.

The exergame industry has been struggling to create quality games that players want to play for sufficient time to achieve fitness benefits. Traditional approaches to exergame development require (1) the development of a video game that players find fun and engaging for extended periods of time, (2) the creation of exercise equipment that can function as controls for the video game, and (3) the successful integration of these systems into an exergame, with all the challenges that hardware and software entail. We have developed a platform that bypasses steps (1) and (2) by adapting available products instead of designing new ones, and simplifies step (3) by providing an easy-to-use technology platform for complete integration. By adding a cloud service, we bring new functionality to exergaming, effectively centralizing game serving, data collection, and allowing supervision by medical service providers.

For our prototype, we picked one of the best-selling affordable stationary bikes and added a few parts. We created a high-quality exergame interface quickly and for low cost.

Currently, we have a working prototype that is capable of reading sensors and delivering data to games to affect game play. Also, the game is interactive with the real environment therefore encouraging sustained interest. The prototype includes the following features.

- Quadrature sensor and encoders provide precise rotation measurement.
- Arduino Firmware reads sensors, applies resistance motor changes, and communicates with a PC.
- Middleware is capable of reading sensor values and writing resistance change. Also, the middleware connects to the game to record and store values.
- The middleware is also capable of logging each user's heart rate, within the local system.

MineBike reads the sensor data and moves the main character in the game accordingly. Also, the MineBike makes resistance changes, based on changes in the game environment.

We used an existing and popular game "Minecraft". The game is played by over a million people, and game modification is allowed for free. Minecraft's reputation as an “addictive” game makes it ideally suited for adaption to exergaming, as it is capable of holding player attention for long sessions.

In developing MineBike we were able to isolate the game tasks that were suitable for physical activity. In addition, we found that to encourage consistent exercise intensity, modification of the tasks was required.

In our prototype MineBike, we successfully introduced a chasing sequence task, which consistently increased exercise intensity over multiple game sessions. We also prototyped a tutorial to educate the gamers on how to use the system and included an easy to access help menu.

Throughout the platform evaluation, we were able to observe that MineBike was able to achieve physiological goals increasing participants’ heart rate to the target heart rate (120 bpm) for the target time for at least 20 minutes. Our game was also induced the recommended moderate- to high- intensity exercise. Throughout the data analysis, we found that MineBike successfully creates an effective correlation of in-game activities to physiological responses. The survey results were universally positive. The participants enjoyed MineBike experience, they answered that they prefer to exercise with MineBike exergaming experience than without.

Now that we have shown that one can consistently increase the level of exercise for given periods of time with quests, we can focus on creating more gameplays to create a stronger staying power for exergame users. For staying power, a variety of design elements must be developed, such as an epic storyline with a range of challenges that are well suited for physical activity, and social interaction through online communities.

Besides platform development, we planned to design an intelligent module that transcribes the prescribed weekly training program into behavior game quests that target the set exercise goals (heart rate, workload, etc.) for each patient. The strenuousness (or resistance) levels of the physical equipment are adjusted to the patient's fitness profile to maintain a pleasurable experience for all levels of physical strength.

Serving games online enables multiple players to play the exergame together, either cooperating or competing with each other in the game world. By tapping into the ability of multiplayer online gaming to create a strong sense of community and participation, we hope to encourage regular exercise in patients, who have difficulty engaging in physical activity due to medical complications.

As mentioned above, we have tested the system in a pilot population of healthy 9 – 15-year-old boys and girls to assess the viability of our approach. The results showed that children take well the integration of exercise and gaming. With the collaboration of the Pediatric Exercise and Genomics Research Center (PERC), we plan to conduct supervised exergaming intervention study in healthy children. In addition we plan to test the iXercise platform on a group of children with clinical condition (e.g., children with cystic fibrosis and/or children who have survives cancer) to study the effectiveness of the iXercise concept over a 12-16 week rehabilitation period (typical duration of an intervention program). We expect that this live testing will validate our predictions on its appeal to that specific population, showing sustained patient interest in exercising with the anticipated outcome of meeting the desired goals in physical health.

Chapter 6

6. Summary and Conclusion

In this dissertation, I presented how iXercise cloud platform is designed to deliver a customized exergaming experience, and how MineBike is designed to motivate exercise routine through exergaming content.

In Chapter 2, I described iXercise cloud platform system design. In order to facilitate the workflow of the trainers, the platform is required to track the participant's performance continuously and create outcome reports. To support the functionalities, the system needs to provide 1) remote exercise program updates, 2) participant tracking and data visualization via web, 3) exercise and game statistics analysis. The iXercise platform was prototyped with system components, including embedded systems, middleware software, logging system, web application, and mobile application. The embedded systems (Arduino and Raspberry pi) was developed to interface sensors attached on exercise bikes. Also, the middleware software was created for coordinating data flow between embedded systems, logging system and game content. Logging system was prototyped to store game state and physiological progress data. The web interface provides an easy accessibility for trainers to view all logged data.

In Chapter 3, MineBike game design is introduced. The goal of MineBike is to encourage users to participant in exercise routines to 1) achieve recommended exercise goal, 2) maintain users' motivation, and 3) create staying power. In order to reach the goal, the exergaming content should be able to distract users from exercise burden while engaging the gamers in immersive game challenges over long periods of time. To create an enjoyable exergaming experience, game content should have 1) clear in-game goal, 2) proper rewards, 3) in-game incentives from the usage of workout equipment, 4) engaging game experience to distract gamers from exercise burden, and 5) proper in-game feedback. In order to create an engaging game experience, we prototyped MineBike with a variety of game elements such as 1) chasing quest, 2) chest hunting, 3) story, and 4) refined aesthetics on top of Minecraft. The chasing quest in MineBike is a mini game that has a theme of chasings and fleeing. The goal of the mini game is to defeat a thief or a monster that runs away from users on a virtual world. The thief or the monster runs on the steady speed, which makes gamers pedal fast and makes gamers perform moderate- to vigorous-intensity physical activity. Also, MineBike provides different types of game challenges such as obstacles, puzzles and chest hunting, so that gamers can be challenged continuously. Storyline and aesthetics of Minecart were also refined to create an epic game experience.

In Chapter 4, I describe the iXercise platform evaluation. The iXercise platform was evaluated based on the following measurements such as exercise workload (rpm x resistance), physiological responses (HR and VO_2), time at target HR, and enjoyment and engagement levels. Healthy 9-15 year-old boys and girls participated in the evaluation over three visits. Over the three sessions, we recorded several forms of data such as heart rate, VO2, rpm, wattage, and game event tags. Also, to evaluate enjoyment and engagement, we used different questionnaires such as Physical Activity Enjoyment Scale (PACES), Rating of Perceived Exertion (RPE), and Participant Satisfaction Survey. Through the data analysis, we found that MineBike was able to successfully achieve target time (at least 20 min) at the target heart rate (120 bpm). Also, we found that MineBike successfully induced moderate-to vigorous- intensity exercise. From the survey questionnaires, we found that the participants enjoyed MineBike universally and engaged in the game experience. The iXercise platform is a promising new approach to promote exercise in children. The platform allows personal exercise prescription and enjoyable experience. This approach might prove to be useful in enhancing the use of exercise as therapy in children with clinical conditions.

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APPENDIX A: iXercise Flyer

PERC
UC Irvine

The Pediatric Exercise and Genomics Research Center (PERC) at the University of California Irvine is seeking children to participate in a research study to evaluate a new

Exergaming Platform Minecraft

The purpose of this research study is to evaluate a new exergaming platform to promote physical activity in children.

The study includes up to 3 sessions of exergaming and questionnaires (~ 60-75 min each session).

To participate, volunteers have to be:

- Healthy boys and girls
- Age 7-15
- Able to perform simple game tasks

Volunteers will be compensated up to $55 for completion of all 3 study visits.
Although there is no direct benefit anticipated for the subjects, participants will exercise at each exergaming session which is designed to promote fitness.

Location:
UC Irvine Pediatric Exercise and Genomics Research Center (PERC)

FOR ADDITIONAL INFORMATION PLEASE CALL:

Julia Kim
Study Coordinator
(949) 824-6650
Juliaak2@uci.edu

Lead Researcher: Shlomit Aizik PhD. Department of Pediatrics

Title of Study: "Immersive Exercise Computer Game (iXercise) to Promote Fitness in the Pediatric Population – A Pilot Study to Evaluate the Platform"

APPENDIX B: Gaming Habits Questionnaire

Gaming Habits Questionnaire

Study ID: ______________ **Date:** ______________ **Time of Day:** ________
DOB: __________ **Age:** _____ **Gender:** M / F
School: ___________________________________ **Grade:** ____

1. Do you like video games (any games)?

Very Much Somewhat Not Really Not at all Never-Played

If you answered either Not Really, Not at all or Never-Played, skip remaining questions.

2. How often do you play games (any games)?

Daily 1-2 times/week 3-4 times/week 5-6 times/week On occasion

3. Do you play the game Minecraft?

Yes No

If answered no, skip remaining questions.

4. How often do you play Minecraft?

Daily 1-2 times/week 3-4 times/week 5-6 times/week On occasion

5. Do you know what a Minecraft mod is?

Yes No

If answered no, skip remaining questions.

6. Do you enjoy the mods?

Very Much Somewhat Not Really Not at all

Additional Notes:

APPENDIX C: PACES

Participant #: ____________
Day: ____________
POST

Please rate how you feel at the moment about the activity you just did.

How do you feel right now?	Disagree a lot	Disagree	I am not sure	Agree	Agree a lot
1. I enjoyed it	1	2	3	4	5
2. I feel bored	1	2	3	4	5
3. I disliked it	1	2	3	4	5
4. I found it fun	1	2	3	4	5
5. It was not fun at all	1	2	3	4	5
6. It gave me energy	1	2	3	4	5
7. It made me sad	1	2	3	4	5
8. It was very pleasant	1	2	3	4	5
9. My body feels good	1	2	3	4	5
10. I got something out of it	1	2	3	4	5
11. It was very exciting	1	2	3	4	5
12. It frustrated me	1	2	3	4	5
13. It was not at all interesting	1	2	3	4	5
14. It gave me a strong feeling of success	1	2	3	4	5
15. It feels good	1	2	3	4	5
16. I feel as though I would rather be doing something else	1	2	3	4	5

APPENDIX D: Feeling Scale (FS)

Feeling Scale (FS)
(Hardy & Rejeski, 1989)

While participating in exercise, it is common to experience changes in mood. Some individuals find exercise pleasurable, whereas others find it to be unpleasant. Additionally, feeling may fluctuate across time. That is, one might feel good and bad a number of times during exercise. Scientists have developed this scale to measure such responses.

+5 Very good

+4

+3 Good

+2

+1 Fairly good

0 Neutral

-1 Fairly bad

-2

-3 Bad

-4

-5 Very bad

APPENDIX E: Rating of Perceived Exertion (RPE)

Rating of Perceived Exertion

6	
7	Very, very light
8	
9	Very light
10	
11	Fairly light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very Hard
18	
19	Very, very hard
20	

APPENDIX F: Participant Satisfaction & Feedback Survey

Participant Satisfaction & Feedback Survey

Study ID: _______________ **Date:** ____________ **Visit #**:_______

Exergaming Level:____________ **Session start time:** __________ **End time:** __________

1. Was this fun?

   Very Fun   Fun   OK   Somewhat   Not at all

2. Was it clear what you were supposed to do in the game?

   Very Clear   Clear   OK   Somewhat   Not at all

3. How easy was the bike/game to use?

   Very Easy   Easy   OK   Somewhat   Not at all

4. How easy was the exercise?

   Very Easy   Easy   OK   Somewhat   Not at all

5. How long do you feel you exercised for? (circle one)

5 minutes	40 minutes	1 hour 30 minutes
10 minutes	45 minutes	2 hours
20 minutes	1 hour	More than 2 hours
30 minutes	1 hour 15 minutes	

6. Would you do this again?

Definitely Not No Maybe Yes Definitely Yes

7. Would you prefer to exercise on the bike with or without playing the game?

With the game Without the game

8. Would you prefer to play the game with or without the bike?
With the bike Without the bike

9. Was the audio feedback clear?

Very Clear Clear OK Somewhat Not at all

10. Was the audio feedback helpful?

Very Helpful Helpful OK Somewhat Not at all

11. The amount of audio feedback I got was:

Definitely not enough Not really enough Just right Too much Definitely too much

12. Was the visual feedback clear?

Very Clear Clear OK Somewhat Not at all

13. Was the visual feedback helpful?

Very Helpful Helpful OK Somewhat Not at all

14. The amount of visual feedback I got was:

Definitely not enough   Not really enough   Just right   Too much   Definitely too much

15. Would you invite a friend to do this (exergaming)?

Definitely Not   No   Maybe   Yes   Definitely Yes

16. What else would you like to tell us about your experience in this session:

____
____
____
____

a) What was your favorite part?

____
____
____
____

b) What was your least favorite part?

____
____
____
____

c) If there was any part of the game that was confusing, please specify.

APPENDIX G: What else would you like to tell us about your experience in this session

Session 1

- Wanted to explore more than just missions. Also, wants to play with friends at the same time with headsets
- At first it was hard but they got used to it. During the exercise, could not feel legs but it was not bad. No suggestions, they would leave the game as is.
- It was frustrating but exercising to a game was interesting
- Better if stopped crashing. Make pedaling limit higher. Very exciting: straightforward/
- Liked the 'epic' music. Adjusting sensitivity to controls was good.
- Liked how you can buy stuff + get stronger. Doesn't like the thief running away. Thinks of it as good exercise.
- Controls were a little confusing.
- Prefers the dancing game. Hard to learn controller. Also, doesn't like she can't change resistance: 'exercising bikes normally allow you to change resistance'. Very challenging/ exhausted. Got very dizzy.
- The participant liked when she caught the thief. She also felt as though the thief was too fast. She also mentions how there is a good amount of both exercising and exploring
- Said 'it was fun'
- The participant said they liked everything about the game, found it to be a little bit too hard though. She had mentioned that her father had been stressing her out, but felt that it was a good workout with a good amount of exploring and challenges
- It was very helpful- a special experiment. would like to play it many more times.
- Didn't feel like it was just 40 min of exercising, felt as though it was longer. He was still aware that he was exercising while playing the game, but mentions that the game was easy, but pedaling was difficult.
- Mentions that it was fun and did not notice he was exercising
- He mentions that the experience makes him feel energetic

- She had mentioned that she wishes there was more to the game
- When she got the weapon, it did less damage than she was hoping, but it was fine because it made her exercise more. Wanted to do more exploring. This made her want to play more Minecraft.
- Bike seat hurt. Once he got the hang of it, it meshed well. Would have been fun to explore more.
- Foot-straps coming off caused slight irritation.

Session 2

- This session was a lot harder than the others. Also, would like to play this game with a friend
- They had liked the challenges, for example the power ups. Would want to play with a friend. It was tiring. Do not think any improvements need to be made to the game.
- The game was updated so it was more fun. More exciting because there was a story
- Pretty fun, but better if you get to keep items when you die. Exciting to defeat all big bosses. Liked secret passageways. Good amount of exercise.
- Got used to playing the game. Did not like the foot pedal. Liked the exploring part. Also liked that she outran the thief, so she gets a break.
- Liked the challenges the most. Disliked that it's easy to die.
- It was easier to catch the thieves, but still challenging. Likes the game; nothing specific. Good amount of exercising/ exploring.
- Suggests that players should be able to make their own avatars 'to feel more represented.' Killing the Thief was very fun. Should have speech bubbles for the thief. Last time she was nervous (so didn't pedal well), but now she is more confident b/c she knows how to play.
- The participant liked climbing up the stairs very fast. The participant did not like how the thief was running too fast.
- The participant mentioned that she had felt more tired playing this time than yesterday (had her first visit the day before this one)
- The participant mentioned that it is tiring to pedal but it was fun

- N/A
- Wants to do more secret stuff. Amount of exercise was just right. Wants to be able to explore more
- More tired this session because of school P.E., ran 2.1 miles.
- Was harder than the last session. Was a little boring because it's the same thing happening over and over again. Wanted to build/ explore more since it's Minecraft.
- Felt easier compared to first session - more adjusted/ prepared. Good balance b/w exploring/ exercising.

Session 3

- It was kind of uncomfortable because of the mouth and nose piece. There should be a multiplayer option, and you should be able to talk to other people.
- Likes how the game motivates you to run faster and kill. Likes the challenge mode the most. Made a suggestion to include more challenges
- It was fun, the nose clip was very uncomfortable. It was a good level of difficulty. Liked how you use the bike to control the game. Said he was exercising and didn't even feel it. Liked the exploring part of the game. Said that if tired would rather just play the game but if he wants to exercise would like to bike and play the game
- It was very fun. Would be better if the swords did more damage. Better with different stages of the game; had more goals to complete.
- Fun searching outside of the city. Breathing tube did not bother him.
- Bike was really easy to use. Game controls were easier also. Game was too short- story should be longer. Medium difficulty- not too hard, not too easy (exercise)
- Same as last 2 sessions. Difficult to bite mouthpiece because she lost a tooth- mouth hurts. No suggestions.
- The participant likes the exploring more than the challenges. She was frustrated about the thieves running in multiple direction, she said to maybe just keep them running in one direction
- The participant had mentioned that this was the hardest visit, and that her nose clip caused her pain

- Participant had mentioned she would rather exercise without the game because it is much harder to exercise while playing a game. The participant also mentions how they wish they could explore more in the game. Mentions that it is really hard to pedal because her legs had to be stretched and the pillows and towels used to allow for better reaching were uncomfortable.
- My nose hurts (nose clip) - Couldn't see the screen because the nose piece was blocking it, - Nose piece was heavy/ big mouth piece = uncomfortable in mouth.
- Enjoyed it more this time because finally got the hang of the bike so more fun because easier.
- Repetitive: maybe a different game would be better suited for the bike.
- Today was difficult because legs were sore from lunges. Increase speed of thieves as they run away to incentivize player - thieves should get faster.

APPENDIX H: What was your favorite part?

Session 1

- Liked stealing/ crafting items. Liked the things you weren't supposed to do.
- Favorite part was the fighting/chasing the thief
- Favorite part was chasing down thieves
- Favorite part was chasing the monsters down
- Did not have a favorite part
- Killing the thieves because she felt it was a good achievement.
- Liked the graphics (really good) - what had been built in the world.
- Said all way equally enjoyable.

Session 2

- Favorite part was the amount of exploring and exercising
- Playing in the challenge and finding stuff
- Enjoys running up the mountain
- Finally defeated the thief.
- Liked the market system. Catching the thieves.
- All very enjoyable

Session 3

- When he got all the items to exchange sword.
- Finding the hidden Easter egg, finding the key for it and opening it.
- Felt good to get the guy. Liked the world.
- Likes the system of chasing after people.

APPENDIX I: What was your least favorite part?

Session 1

- The aiming was difficult. Hard to get into the door. Controller should be like a wheel so that it's easier to move.
- Least favorite part was that there were too many different fights
- Least favorite part was when the monsters began to box and he had to jump over
- Least favorite part was when the monster placed blocks in front of her while she was chasing him
- When she got trapped behind the blocks during the challenges. Wants the swords to do more damage.
- Having to run after the thieves.
- Doesn't ever use a remote (a console) so difficult to use.

Session 2

- Getting inside the door was the least favorite. (Door wasn't allowing him to walk through)
- Getting a handicap because he was too good at the game
- How long it takes to defeat the guy.
- Having to bike- seat was uncomfortable.
- Certain parts unclear

Session 3

- All the zombies that attached him every 2 min while he was expanding. Game crashed few times.
- Computer crashing
- Having to bike. Nose clip hurt.
- Missing all the jumps b/c haven't used console before.

APPENDIX J: If there is any part of the game that was confusing, please specify

Session 1

- Was confused on where and how to go up to the mountain.
- He felt confused when it was time to chase the monster because he was unsure where to go
- there was nothing confusing about the game
- Didn't know how to get to the marketplace.
- Straightforward.

Session 2

- no part of the game
- N/A (Easier 2nd time).
- Leaving the village was confusing - unable to even though directions said so.

Session 3

- After defeating monster was confused on whether to press next mission, retry, or exit.