DESIGNING FOR EXERTION: USING HEART RATE POWER-UPS TO IMPROVE ENERGY EXPENDITURE IN EXERGAMES

by

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Abstract

By combining the joy of movement with digital games, exergames can encourage people to exercise. Unfortunately, current exergames may not inspire exertion levels that meet the exercise guidelines provided by the American College of Sports Medicine, and may not encourage long-term participation. In this thesis, we present a novel exergame mechanic, Heart Rate Power-ups that can be used to increase player exertion in exergames. Heart Rate Power-ups provide a benefit in the game when players reach a target exertion level.

We performed a user study to evaluate the efficacy of Heart Rate Power-ups at increasing players’ exertion and to assess their impact on player experience. This study compared player exertion and enjoyment of three games with and without the presence of Heart Rate Power-ups. We found that player exertion increased for two of the three games and that players responded positively to the addition of Heart Rate Power-ups. Our experience allowed us to provide design principles and applicability guidelines for the implementation of Heart Rate Power-ups.

Converting popular off-the-shelf games into exergames allows developers to provide content with less effort than creating games from scratch. Continually providing new content may renew player interest and positively influence players’ long-term commitment to exergames. We converted two popular games, Valve Corporation’s Half-Life 2 and Bethesda Game Studios’ Elder Scrolls V: Skyrim, into cycling based exergames with Heart Rate Power-ups. The conversion was achieved via modding interfaces provided by the games’ publishers. We performed a user study on the converted games comparing the traditional games with a straight cycling version and a cycling version with Heart Rate Power-ups present. The results confirmed our hypothesis that a straight cycling conversion would generate low exertion levels and using an off-the-shelf games modding interface to implement Heart Rate Power-ups improved exertion levels.

This thesis highlights the importance of designing exergames with exertion in mind and provides insight into a technique for those wishing to do so.
Co-Authorship


- The study mentioned in Chapter 4 is described in this paper.


- This paper’s focus is the initial evaluation of Heart Rate Power-up described in Chapter 3.
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Chapter 1

Introduction

The term ‘exergame’ refers to digital games that incorporate the movement of players’ large muscle groups into the gameplay. For example, Dance Dance Revolution is an exergame in which players accumulate points by matching footsteps on a floorpad to on screen patterns in time with musical rhythms [43]. Similarly, Dance Central is an exergame in which players mimic dance movements on screen in time with music and are rewarded points based on their performance [34]. There are exergames that have been designed for specific populations. For example, Liberi is a cycling-based exergame designed to be played by children with cerebral palsy [42]. Exergames gained commercial popularity when movement sensors such as Nintendo’s Wii Remote [64] and Microsoft’s Xbox Kinect [52] sensor became available to consumers, which enabled people to access and play exergames in their home. Nintendo’s Wii Sports suite affords players the opportunity to simulate the play of various sports from the comfort of their living room [62].

1.1 Problem Description

Exergames show promise as a way to encourage people to exercise because they are both fun and elevate players’ heart rates more than traditional digital games [44]. However, most exergames currently fail to elicit the moderate to vigorous activity levels associated with improved cardio-vascular health [9,69]. This has led to hesitation among health organizations in recommending exergames as a replacement for traditional physical activity [1]. The 2014 Healthy Kids Canada report card states that despite reviews that reveal exergames can elevate heart rates to light- and moderate-intensity they do not feel there is sufficient evidence to use exergames as a way of increasing daily physical exercise:

“Evidence from a comprehensive systematic review reveals that active video games (AVGs) may elevate heart rates by increasing light- to moderate-
Intensity physical activity among children and youth in the short term. However, available evidence does not show that AVGs lead to increases in energy expenditure over longer periods (e.g., 24 hours).” [1]

Approximately 54% of Canadians play video games [23]. If video games, which are currently classified as a sedentary activity by the Canadian Society for Exercise Physiology (CSEP) [15], were conducive to exertion levels that are recommended for exercise then those who play video games would have another avenue for improving their physical condition. Exergames’ combination of exercise and entertaining gameplay is promising as a motivator because people adhere better to an exercise regimen when the activity is engaging and enjoyable [90].

Many commercial exergames have been designed with a focus on entertainment rather than encouraging exercise. While games such as Wii Sports Tennis [62] or Dance Dance Revolution [43] incorporate physical motion, their design does not include a conscious goal of achieving and sustaining moderate to vigorous levels of exertion in their players. To illustrate this, we refer to Pasch et al.’s investigation into the movement patterns of Wii Sports games [67]. They discovered that players would use large gestures, which require higher exertion, during play with friends because players found it made the game more fun. However, when players were trying to do well they would use small wrist movements because it made the game easier. Thus the control’s design actually rewards the strategy that requires less exertion. Unsurprisingly, when players’ exertion levels are evaluated for Wii Sports, they fall short of the American College of Sports Medicine’s (ACSM) exercise guidelines [91]. According to Monedero and his team, making small adjustments to the gaming actions of the Wii Sport suite can have a positive effect on players’ exertion levels [54]. By augmenting the game play to incorporate more of the body, Monedero et al. were successfully able to increase the average exertion of players, thereby demonstrating the importance that a simple design decision can have on a players’ exertion level. Therefore, to elevate exergames to the point of being effective replacements for traditional physical activity, we argue that a focus on exertion must be actively incorporated into the design process.
Low exertion is not the only barrier preventing exergames from being considered as a suitable replacement for exercise. An important aspect of exercise is continued participation over time. The CSEP recommends 150 minutes of moderate to vigorous aerobic activity per week, in bouts of no less than 10 minutes at a time [15]. If exergames are to be a viable exercise tool, they need to be enticing enough that people choose to play them week after week. However, initial interest in an exergame often trails off quickly [6]. This is a common occurrence with traditional video games as well [75]. Players move away from games they have played in favor of new gaming experiences. One potential resolution for the issue of poor adherence to exergames is to ensure there is new content continually available to players [42].

Converting off-the-shelf games into exergames is one way to address the need for more exergames. The practice of converting off-the-shelf games into exergames provides benefits to both designers and exergame users. Namely, it affords users access to high-quality gaming content while requiring less design and implementation effort compared to creating an exergame from inception to finished product [79]. The ability of exergame users to access a large amount of content has the potential to combat the problem of exergame satiation over time, since new content has the capacity to renew player interest in the activity.

There are a few existing tools that can assist with the conversion of off-the-shelf games into exergames. For example, the PCGamerBike Mini pedaling device with the FitXF software allows players’ pedaling of a stationary bike to trigger a specified key press in the game, usually the key that is used to indicate forward movement [7]. This conversion allows players’ pedaling to move their character forward, which results in a black box style of conversion which means no changes are made to the game itself. Before our work, little was known about how well exergame conversions of off-the-shelf games work to encouraging players to exert themselves. We show that the black box conversion in which pedaling controls avatar movement did not encourage high exertion, since off-the-shelf games were not designed with exercise in mind. We argue that there is
a need to evaluate exertion levels of converted off-the-shelf games and to identify strategies that will help designers improve exertion levels in their converted games.

To address the issue of low exertion in exergames we evaluate the potential of a generic technique, Heart Rate Power-ups, to increase players’ exertion. We also investigate converting off-the-shelf games into exergames and the ability of Heart Rate Power-ups as a generic technique for those who wish to improve player exertion in a converted game.

1.2 Solution Part I: Heart Rate Power-ups

As a first step to aid those designing games for exertion, we introduce and evaluate a game mechanic, Heart Rate Power-ups, which can be applied to a wide range of exergames to encourage more vigorous play. Game mechanics, according to the Mechanics, Dynamics, and Aesthetics Framework, are “the various actions, behaviors and control mechanisms afforded to the player within a game context” [37]. Heart Rate Power-ups were inspired by the traditional game mechanic of a power-up which is an in-game object that can be activated by the player to provide benefits or that adds extra abilities to the game character. A Heart Rate Power-up is a game mechanic that motivates players to elevate their heart rate to a target zone by providing in-game rewards while the player is at or above their target heart rate. For example, in the Liberi Gekku Race racing game, players who maintain their target heart rate have access to a powerful weapon that slows down other players giving them an advantage. Heart Rate Power-ups calculate a player’s target heart rate based on a percentage of their heart rate reserve. Heart rate reserve is defined as the difference between a person’s resting and maximum heart rate [5]. Using a percentage of heart rate reserve allows us to set a target for each person that is considered the same relative intensity for different people (i.e. 50% of heart rate reserve) [5].

To begin investigating the potential of Heart Rate Power-ups as a generic technique for incenting higher exertion, we implemented Heart Rate Power-ups into the three existing exergames Dozo Quest, Biri Brawl, and Gekku Race. These games are part of the Liberi suite of exergames
To highlight the generic applicability of Heart Rate Power-ups, the games chosen are of different genres and have different average exertion levels. All three games require players to pedal a stationary bicycle to move their avatar, while simultaneously using a dual analog controller, similar to the Xbox [53] or Playstation [78] controller, for other game input. We used a heart rate monitor to determine when a player reached their target heart rate zone, activating the power-up.

To evaluate the effectiveness of Heart Rate Power-ups, we performed a within-subjects user study using the Dozo Quest, Biri Brawl and Gekku Race games, in which 20 participants played two versions of each game. In the experimental condition, the in-game power-ups were activated when the players’ target heart rate was reached. The control condition also provided power-ups that were awarded in specific areas or certain time intervals of gameplay for approximately half the game session. It was our goal to investigate and address the following three questions: Can power-ups assigned as a reward for reaching target heart rate encourage players to strive for and maintain a target percentage of heart rate reserve? If so, does the effectiveness of

Figure 1-1 Gameplay setup of Liberi cycling game.
Heart Rate Power-ups depend on players’ average exertion during the game? Finally, how does the presence of Heart Rate Power-ups affect players’ enjoyment of the game?

The study showed that Heart Rate Power-ups increased players’ average percentage of heart rate reserve, while at the same time contributing to their enjoyment of the game. It further found that Heart Rate Power-ups are particularly effective for games in which players’ average exertion is low, elevating the players’ exertion to levels close to those recommended for exercise.

1.3 Solution Part II: Convert Off-the-Shelf Games

We suspected that although converting off-the-shelf games into exergames has the potential to improve players’ adherence by continually renewing their interest, that the exertion levels during play of the converted games would be low. Given Heart Rate Power-ups promise as a generic technique for encouraging players to increase exertion during exergame play, we were interested in evaluating how successfully they could be applied when converting off-the-shelf games into exergames. Many game publishers provide “modding” interfaces for their games that allow the public to create extensions of existing games. We used these tools to convert games into exergames. These same tools allowed us to include Heart Rate Power-ups in the conversion.

In order to assess the potential of converting off-the-shelf games to high exertion exergames via the addition of Heart Rate Power-ups, we converted two popular action games: Elder Scrolls V: Skyrim [8] and Half-Life 2 [87]. The conversion was performed in two steps: the first mimicked existing black box techniques in which pedaling enables avatar movement. The second step used the games’ modding interfaces to implement Heart Rate Power-ups as an added incentive for exertion. Integrating Heart Rate Power-ups into the games was completed using the games’ modding interfaces combined with the use of Luke Walker’s Heart Rate Power-ups Manager Toolkit in the attempt to encourage higher exertion during the play of converted off-the-shelf games. Using the modding interface and Heart Rate Power-up Manager Toolkit requires more work than the black box conversion but still less than building a completely new game. Similar to
the gameplay setup in the previous study, participants pedal a recumbent stationary bicycle while holding a game controller needed to play the game. The game is displayed on a screen positioned in front of the participants.

We measured each of the 18 participants’ heart rates under three conditions: 1) playing the game while sitting on a couch, 2) playing the black box pedaling version and 3) playing the version in which Heart Rate Power-ups were implemented. In addition, we collected responses to the Intrinsic Motivation Inventory (IMI) questionnaire [73] after each condition, and performed a semi-structured interview after the study.

Our results show that the black box conversions of both The Elder Scrolls V: Skyrim and Half Life 2, in which pedaling drives avatar movement, lead to low levels of exertion. These off-the-shelf games include periods of gameplay that make it difficult for some players to keep a consistently high cadence throughout. Thus, this obvious way of converting games to cycling based exergames via pedaling for avatar movement is not successful as a tool for physical exercise. The Heart Rate Power-up conversion of the off-the-shelf games inspired higher exertion in players than the simple conversion. Although players average exertion levels were close to those set by exercise guidelines they will still require more research before being considered suitable as a replacement for exercise. The current exertion levels motivated by the Heart Rate Power-up conversion are considered suitable for an anti-sedentary activity. We found that aspects of the games pace and mechanics affected player exertion levels. Notably playing at a higher exertion level did not affect players’ enjoyment of either Half-Life 2 or The Elder Scrolls V: Skyrim.

1.4 Main Contributions

The main contributions of this thesis are:

- **Assessment of Heart Rate Power-ups as a generic technique**: We demonstrate Heart Rate Power-ups can be successfully applied to a variety of exergame styles to increase player exertion.
• **Guidelines for Heart Rate Power-up design**: We provide three design guidelines for exergame designers to use when crafting Heart Rate Power-ups for their games. Namely, power-ups effect should be clear, the activity should be coupled to the effect, and impact should be balanced.

• **Guidelines for the applicability of Heart Rate Power-ups**: We provide guidelines for identifying which exergames are best suited for Heart Rate Power-ups. Specifically, that a game’s motion control should support high exertion, players should have agency over their exertion and there should be a gap between the games’ average and potential for exertion.

• **Evaluation of player exertion during an exergame created via black box conversion**: We assessed player exertion during play of two off-the-shelf games converted to exergames via the black box conversion method.

• **Demonstration that an off-the-shelf game’s modding interface can be used to implement an exergame conversion that has Heart Rate Power-ups**: Our work confirmed that an exergame conversion performed via a games modding interface can successfully implement Heart Rate Power-ups to improve player exertion compared to a black box conversion.

Much of the work was performed in collaboration with and building on the work of other researchers. Heart Rate Power-ups were initially conceptualized and implemented by the EQUIS Lab’s Zi Ye, programmer of the Liberi suite of games. I built on his initial idea and implementation of the Heart Rate Power-ups by identifying design principles and modifying his implementations to align with them. I also identified the guidelines for the applicability of Heart Rate Power-ups. I performed the design, execution and analysis of the initial Heart Rate Power-up study described in chapter three.

The implementation of the Heart Rate Power-up conversions were performed using a Heart Rate Power-up tool created by an EQUIS Lab undergraduate research assistant, Luke Walker.
Walker also implemented the power-up mod for The Elder Scrolls V: Skyrim. I designed and implemented the power-up mod for Half-Life 2. I performed the design, execution and analysis of the second study described in chapter four.

This thesis is organized as follows; first we review related work including current techniques used to improve exertion in exergames, and exergame usage over time. We also review the current practice of converting off-the-shelf-games into exergames and survey existing techniques. Second, we describe in more detail the concept of Heart Rate Power-ups and provide guidelines for their design and applicability. Subsequently, we describe the details and findings of the initial study designed to evaluate the efficacy of Heart Rate Power-ups at increasing player exertion in exergames. Last, we describe our conversions of two popular off-the-shelf games into exergames and present the study we performed to evaluate the potential of converted games as a tool for exercise and Heart Rate Power-ups role in that.
Chapter 2
Related Work

In this chapter, we provide a discussion of related work to give context for the contributions of this thesis. The discussion begins with a sample of exergames chosen to clarify the concept and demonstrate the depth of experiences that exergames provide to players. We then review three prominent motives for the creation of exergames: rehabilitation, entertainment and exercise. Next, we address the question of how much exercise exergaming provides by reviewing studies of player exertion and approaches meant to increase it. Following this, we review studies of short and long term adherence of exergame players. Last, to provide background for our conversion of off-the-shelf games into exergames, we present three different approaches: Black Box Conversion, Source Code Modification and, the Modding Interface Approach.

2.1 Introduction to Exergames

The central difference between exergames and traditional digital games is the addition of the large muscle groups movement in exergames. Pulse Master Biathlon illustrates this key

Figure 2-1 Images showing a person playing Pulse Masters Biathlon [61]
differentiation as an exergame in which players aim to complete a virtual biathlon as quickly as possible using their heart rate as input and a motion controller [61], seen Figure 2-1. The game has an added twist that as players increase their heart rate their speed increases but the players’ ability to aim decreases due to decreased accuracy of the shooting component. Another example is Astrojumper, a virtual reality game that simulates moving through space [28]. Players must move their bodies in order to avoid colliding with the virtual planets they are moving past. Points are awarded for successfully dodging and score multipliers can be activated by reaching out to touch suns. PaperDude is a cycling game simulating a paper route [10]. Players wear a virtual reality head set while sitting on a bicycle. They pedal to move a paper delivery person on a bike through their paper route. To trigger the avatar to throw newspapers to the correct houses the player must perform large swinging motions with their arm.

Exergames introduce novel forms of interaction with digital games. Exergames designers have explored different ways of incorporating player movement into the game. For example, in the game Growl Patrol, players’ location is used as input to the game encouraging players to walk around their environment [45]. The gameplay requires players to listen to a stream of audio through ear phones that are attached to a handheld GPS device. The audio indicates different animals by playing a representative sound. Each animal’s proximity to the player is indicated via the volume; the closer an animal is to the player, the louder its sound is played, as seen in Figure 2-2. Players run around the physical world trying to catch friendly animals while avoiding predators. Growl Patrol is a good demonstration of how exergames have potential to provide a new type of experience beyond what traditional digital games can offer.

2.2 Categories of Exergames

We now provide examples of exergames. These examples are provided to demonstrate the depth of different interactions and experiences that are available via exergames. The examples are
organized into the following categories: audio, ubiquitous, running, social, casual, and distributed. It is possible for a single game to fall under multiple of these categories.

2.2.1 Audio Exergames

Audio exergames use auditory cues to instruct or give feedback to a player. This category of exergames can be used to help people with visual impairments to participate in physical activity. Pet-n-Punch is a “whack-a-mole” style game, meaning that it is a game in which elements move around and players are meant to hit them [56]. Players hold a motion-sensing controller in each hand and are provided solely with sound and vibrational cues as feedback. The cues are provided to help them achieve the goal of the game which is to rid a farmer’s field of rodents while avoiding hitting the pet cats in the field. Players remove a rodent by swinging down twice in quick succession. However, when they encounter a cat they are instead meant to pet it. Players can tell what kind of animal is present and whether they successfully performed the desired action through vibrations in the controllers and audio feedback. A study evaluating the game with 12 children who

Figure 2-2 Growl Patrol Gameplay. The top image is virtual overlay of animal positions on a map. The bottom indicates the player experience. [45]
have visual impairments found that the children had a strong interest in playing the game and were able to reach light to moderate levels of exertion. Other examples of audio exergames include the previously mentioned Growl Patrol and VI-Tennis, a tennis game designed for players with visual impairments [55].

2.2.2 Ubiquitous Exergames

Ubiquitous exergames are games in which the gameplay takes place over large areas, typically played on mobile devices. Often players are encouraged to explore the world around them during play as seen with GPS Tycoon, a mobile phone game [81]. In this game, the physical world is split into a virtual grid in which each square is a plot of land in game, as seen in Figure 2-3. Players can buy plots of land by going to the real world location and purchasing it using their phones. The goal of the game is to acquire more money than others in the region. In-game currency is awarded to the player each hour for each plot of land that is owned. Competing players can purchase each other’s plots of land, creating a deeper strategy where land will give enough hourly

![Figure 2-3 Screen captures from gameplay of GPS Tycoon [81]. The left shows the virtual land plots; The right shows a players status.](image-url)
payouts to make the investment worth it. Travelling to plots with less traffic results in less turnover and is more profitable. It is also possible for players to craft weapons in game to defend land or to attack neighbors.

Another ubiquitous game is UbiBall, an obstacle course completed using an electronic ball [24]. The ball is outfitted with a microcontroller that collects data to be used in a screen based game. Touch-Space is a mixed-reality ubiquitous game in which players wear head mounted displays and hold a digital wand in their hand that they use as input [18]. Players move around a room interacting with physical objects that are augmented on screen to solve mysteries and rescue a princess.

### 2.2.3 Running Exergames

In running exergames, the predominant physical activity is running. For example, in Swan Boat, teams of players compete with each other by collaboratively controlling the speed of their virtual boat through running on a treadmill [4]. Teams control the direction of their boat by synchronizing their arm movements, as seen in Figure 2-4. While the running activity in Swan Boat takes place on a treadmill, in running exergames it could also manifest as running on the spot or running outdoors. For example OnTheRun is a mobile game played while running outdoors [21]. The game uses adaptive route planning to guide the player through the city. As they follow the

![Figure 2-4 Left image is a screen capture of Swan Boat gameplay. The right image is a team steering their boat together [4].](image-url)
route the game audio leads the player through a fugitive storyline. Players must follow the route to complete missions and move the story forward.

### 2.2.4 Social Exergames

In social exergames, a large part of the gameplay focuses on social interactions with other players. I-dentity is a social game played by four players [31] who hold PlayStation Move Motion Controllers [77], hand held controllers that detect movement, vibrate and light up (Figure 2-5). Players assume the role of one of the three spies or the interrogator. The three spies hold a Move controller and one of the players is randomly selected to be the leader. When the leader moves their controller it vibrates to discreetly let them know their role and all three controllers light up. It is the goal of the interrogator to watch the spies moving the controllers and guess which spy is the leader. The interrogator can give action directions to the spies such as “jump up and down” which they must all perform while trying to conceal which person’s controller movement that causes them to light up. The teamwork and interactions that are necessary between players make for a unique social experience.

![Image of PlayStation Move Motion Controller and I-dentity gameplay.](image-url)

**Figure 2-5** The left image is a PlayStation Move Motion Controller [77]. The right is an image of i-dentity gameplay [31].
Age Invaders is designed to facilitate inter-generational play by providing content that can be enjoyed by both a child and their grandparent [41]. The game is played on an electronic game board fitted with LED lights that is placed on the floor. Players wear sensors in their shoes and use a Bluetooth enabled toy gun as input to the game. The goal is to collect the most points by triggering rockets to hit the other player and virtual enemies. Players must move around the board to avoid being hit by their opponent’s shots.

2.2.5 Casual Exergames

Casual exergames are defined as “games that players can learn easily and access quickly, using simple rules and special game mechanics, to motivate them to exercise at a moderate intensity for short periods of play” [30]. One example of a casual exergame is Grab Apple, a Kinect based game in which players move their hands around to control hands on the screen [30], see Figure 2-6. The goal is to use the virtual hands to collect apples and avoid bombs that are falling from the top of the screen. Grab Apple can be played in short bursts of ten minutes at a time to help people include more physical activity in their day.

Figure 2-6 Screen of GrabApple gameplay [30].
Teemo is a casual commercial exergame available for mobile phones [2]. Players can choose virtual adventures meant to be short enough to complete within small gaps of free time throughout the day. The adventures are completed by performing a small number of physical exercises specifically chosen for their compatibility with any space.

2.2.6 Distributed Exergames

Distributed exergames are played by multiple people over a network. Breakout for Two is an example of one such game. This is a two player version of the classic arcade game Breakout, in which a ball needs to bounce against bricks to break them, with the goal of removing all of the bricks. In Breakout for Two, players are in two different locations but can see life sized versions of each other projected on a wall to create the experience of being separated by a glass partition [58], as seen in Figure 2-7. Players kick a soccer ball against the wall to hit semi-transparent blocks that are overlaid on top of the video stream. The goal is to smash all of the blocks before the other player hits them.

The previous examples of audio, ubiquitous, running, social, casual and distributed gameplay illustrated the diversity of exergames. Categories are not exclusive, and often a single game is a combination of several types. For example, Zombies Run is a mobile audio, ubiquitous and running exergame in which players assume the role of a ‘runner’ for a compound of people who are collectively surviving after a zombie apocalypse [71]. Running throughout their physical neighborhoods players listen to audio that mimics a radio person from the compound instructing them on missions and supply runs. After each run, the players are rewarded in game with the supplies they collected on their run which can be used to build onto a virtual compound. These supplies can be used for purposes that include increasing hospitals, population and farming capabilities.
Exergames for Rehabilitation

Exergames can be used for several motives however, the most prominent are rehabilitation, entertainment and exercise. As well, exergame use is not limited to a single purpose. For example, the Nintendo Wii sports games were designed for entertainment but have been applied to post-stroke rehabilitation [57]. Mouawad et al. investigated the efficacy of Wii-based therapy with seven patients who were post-stroke and five healthy people for control. Participants played one hour of Wii games for 10 consecutive days while supervised in a laboratory. The supervised play was augmented with at home practice that lasted 14 days and progressed from 30 minutes up to 180 minutes on the 14th day. Participants’ mean performance on the standard assessment scales Wolf Motor Function Test and Fugl-Meyer Assessment both saw significant improvement.

Rehabilitation programs often require patients to perform repetitive physical movements that may become boring over time, resulting in low adherence to rehabilitation programs. Exergames have been used as a tool to encourage adherence to rehabilitation programs by transforming the repetitive activity into an input for a more engaging digital game. For example,
Burke et al. created the game Rabbit Chase as a treatment for stroke patients [14]. During Rabbit Chase, a rabbit appears in one of four locations on the screen and the player must correctly time moving their arm to the correct location in order to catch it. Burke and Morrow performed three case studies using this game along with two others. The games received positive feedback, and the authors concluded that exergames can increase patients’ engagement in their exercise.

Exergames for rehabilitation purposes face specific design challenges. First, some rehabilitation exercises require specific postures and movements to ensure that patients are receiving the greatest benefit. It can be challenging to find sensors that are not cumbersome to the player and correctly detect the fine differences in a person’s movement. The Kinect sensor provides body tracking but it is not always accurate enough to be trusted to evaluate the intricacies necessary to evaluate rehabilitation exercises. Obdrzalek et al. performed an evaluation of the accuracy and robustness of the Microsoft Kinect sensor at identifying joint positions in the context of coaching the elderly population [65]. They found that in a controlled body posture, such as standing, the sensor can be as accurate as motion capture; however, in general the accuracy can vary by about 10cm. This means game designers should ensure that patients are properly trained on how to perform the action before beginning play.

Another challenge of designing exergames as a tool for rehabilitation is that the exercises are often simple repetitive movements; it can be difficult to create an interesting game when the motions required are repetitive and predictable. For instance, rehabilitation exercises for spasticity require slow deliberate movements posing a challenge for designers. Abeele et al. have explored how to design exergames for spasticity and acknowledge that many typical game mechanics should be avoided, such as timed movements or any design that creates a rhythm or time pressure. Instead they suggest designing for ‘slow fun’ and have presented several games that evolved from their exploration [3]. One game presented is Catching Dishes in which players’ arms are tracked. The goal is to catch dishes from the edge of the screen and stack the dishes in the center. While this
game is more engaging than performing the exercise alone it is still a thin veil over the exercise being performed.

2.4 Exergames for Entertainment

Although exergames can have multiple aims identified as rehabilitation, entertainment and exercise the first and foremost purpose is to provide an enjoyable gaming experience for players. Lindley et al. investigated how the addition of movement affects players’ experience of digital games by comparing play of Donkey Konga Bongos using a traditional controller, to play with movement controllers [47]. They found that the addition of physical movement to the game increased both players’ social interaction and their levels of engagement.

For those endeavoring to create an exergame, Mueller and Isbister have provided a comprehensive set of guidelines for the design of enjoyable exergames [59]. They derived the guidelines by compiling themes and commonalities of academic works and achievements. The guidelines were then critiqued and refined by experts in exergame design from both commercial and academic settings. The resulting guidelines are as follows:

- **Embrace ambiguity** - Ambiguity arises from no two movements being the same and sensor data being noisy. Trying to force precision in players movement may frustrate players, instead make the uncertainty enjoyable

- **Celebrate movement articulation** – Players do not get the same feedback as with button-press games. It is important to provide feedback on movement quality moment-to-moment.

- **Consider movement’s cognitive load** - Moving can demand mental attention, creating high cognitive load, especially when learning new moves. Players can become distracted by too much feedback.

- **Focus on the body** - When designing player feedback focus on the body not just the screen. Audiences and players enjoy watching moving bodies. Do not distract from this focus.
- *Intend fatigue* - If you use fatigue as a game challenge, make it intentional rather than incidental.
- *Exploit risk* - Risk can provide a sense of thrill which can contribute positively to the experience, if exploited sensibly.
- *Map imaginatively* - Map movement to game meaning in imaginative ways.
- *Highlight rhythm* - Help players identify rhythm in their movements.
- *Support self-expression* - Support players in expressing themselves using their bodies.
- *Facilitate social fun* - Facilitate social fun by making movement a social experience.

Game design experts consulted by Mueller and Isbister welcomed these guidelines that focus solely on creating enjoyable exergame. For those who wish to create games that can be used as a replacement for traditional exercise, there remains a need for guidelines and techniques that specifically address how to encourage high exertion and lasting adherence over time.

### 2.5 Exergames for Exercise

Using exergames as a tool for physical exercise presents several challenges. Many people do not participate in enough physical activity to meet the recommended levels for physical activity. It is generally accepted that people often adhere better to exercise regimens when the activity is something they consider enjoyable [90]. Swan Boat uses the combination of sensor bracelets and a treadmill to allow players to control the speed and direction of their boat in a race against others [4]. The goal of this work was to counter the tedious nature of running on a treadmill by augmenting it into a more fun and social activity. Thus, combining exercise with the entertainment of video games offers the potential to motivate increased and continuing physical activity. In order for exergames to be a suitable substitute for exercise there are two necessary criteria that must be met:

- *Exertion* - Exergames by nature encourage movement; however, players need to perform enough movement to reach recommended exertion levels for exercise.
• Adherence - Exercise regimens are a commitment. In order for exergames to be suitable as an exercise replacement, they need to remain an engaging and enjoyable way to spend time in both the short-term and long-term.

The research community has been investigating how well exergames currently meet these criteria and what design decisions can be made to improve upon these aspects. For example, Grab Apple uses innovative techniques to integrate casual exergames into the work day with the goal of improving short term adherence [30]. The motivation behind casual exergaming identifies that for some people, exercising in multiple small chunks of time throughout the day is easier than setting aside one larger amount of time for exercise. This is an acceptable solution to address the main issue that the total amount of time spent exercising adds up to the recommended amount of 30 minutes a day [5].

2.5.1 Typical Exertion Levels

Most available exergames are not a suitable substitute for traditional moderate to vigorous intensity physical activity. As a baseline, the ACSM recommends a minimum of 30 minutes of exercise five times per week at moderate intensity (40-59% Heart Rate Reserve), or 20 minutes three times a week at vigorous intensity (60-90% Heart Rate Reserve) [5]. Sedentary individuals, defined as those who do not participate in at least 30 minutes of moderate intensity activity three days a week for a 3 month period or more(1), will gain health benefits by just reducing their time spent being sedentary [5].

In a meta-analysis of 16 studies of energy expenditure in exergames, Peng et al. found that exergames increase players’ heart rates significantly, but that playing them is not enough to meet ACSM recommendations for vigorous intensity physical exercise [69]. Similarly, in a meta-analysis of 18 studies, Biddiss and Irwin concluded that currently exergames elicit moderate activity levels during play but should not currently be used as a replacement for vigorous physical activity [9]. The 34 studies reviewed by these meta-analyses performed 53 evaluations of games.
Of the 53 evaluations, 17 were of Wii Sports, and 10 were of Dance Dance Revolution. However, both of these games were designed with entertainment in mind, rather than physical exercise. To illustrate how the design of a game can affect a player’s exertion levels, we recall Pash et al., who demonstrated that in Wii Sports small wrist movements often lead to better scores than large, more realistic movements [68]. Thus, the game’s design penalizes play that leads to higher exertion rather than rewarding these high exertion actions.

Results of off-the-shelf games converted to exergames are unclear. Studies in the area do not usually focus specifically on exertion and those that are use different measures to evaluate exertion levels. For example Chatta et al. use the mean of participants’ maximum heart rates to evaluate whether there is an increase in exertion between conditions [17] while Guo and Quarles use the mean of participants’ average heart rate [33]. Without information such as participants’ age and resting heart rate neither of these measurements are helpful in determining whether participants are able to reach recommended exertion levels for exercise. Nevertheless, it is possible for digital activities to lead to higher intensity of physical activity. For example, the Free Run program included in Nintendo’s Wii Fit can prompt exertion equivalent to traditional moderate-intensity aerobic exercise [22]. It should be noted, however, that this program is a running simulator rather than a game.

2.5.2 Current Techniques for Increasing Exertion in Play

At their core, all exergames promote exertion by requiring physical movement to play. Increased exertion typically results in improved game performance. For example, in Growl Patrol mentioned previously, players hear animals overlaid on the physical world through head phones and must collect certain animals while avoiding others [45]. This requires that the player must run faster than the animals they are chasing or being chased by and are therefore rewarded for more physical movement. In Frozen Treasure Hunter [93], a two player game, one player pedals a bike and steers using a game pad while another swats at enemies using a Wii Remote. Pedaling the
bicycle faster increases the speed of the player’s avatar, allowing the team to collect treasure at a faster pace. While the movement inherent in the play of such games is a form of physical activity, this activity is as we have seen, often insufficient to sustain elevated heart rate. To combat this, a small number of techniques have been proposed for raising the level of exertion in exergames.

2.5.2.1 Increasing a Game’s Pace

The most basic approach is to increase the game’s pace. In the Interaction Tempo balloon-bursting game [46], a projector-camera system, balloons are projected onto a wide slide and players must slide over the projected balloons to pop them. Landry and Parés demonstrate how increasing the rate of appearance of balloons encourages players to move faster climbing up the slide to get the next set of balloons, resulting in an increase in players’ heart rates. This was an effective strategy in their game but not all games have an obvious pacing mechanic that can be sped up. Thus there is a need for more generic techniques designers can draw upon and apply to their own games regardless of the game’s genre or style.

2.5.2.2 Modifying Movement

Another technique involves changing the movements required during gameplay to those that will encourage higher exertion of players. Mondéro et al. modified the movement pattern performed by players of Wii Sports Tennis and Wii Sports Boxing [54]. The games were augmented so that players were required to take large steps in addition to upper body movements already required to, for example, swing a tennis racquet. This change led to an increase in energy expenditure from light to moderate intensity levels. This technique is generic enough to be applied to many styles of exergames. We argue that it is necessary for several generic techniques to be available for designers to draw upon, giving them the freedom to choose those techniques that would integrate best into their games.
2.5.2.3 Rewarding Exertion

Another approach is to improve players’ game experience when they attain target levels of exertion. Boyd et al. have created a mobile game in which players carry a handheld device with a screen and GPS tracker [12]. As players walk around the real world, a virtual world is created on the screen. Players’ exertion directly impacts the qualities the virtual area has when it is created. For example, high exertion creates lush environments while low exertion generates impoverished territories. Similarly, in Wylie and Coulton’s Health Defender, a game based on Space Invaders, attaining a designated heart rate threshold rewards players with in-game bonuses [92]. If players reach heart rate thresholds, their weapon gains various bonuses. Though this technique was used in Health Defender as a way to motivate higher exertion, its ability to do so was not validated. As well, Wylie and Coulton demonstrated a potential danger in designing for exertion. Namely, that the control scheme in a game that leads to the highest level of exertion may not necessarily be enjoyable to players. Similarly to the last two exergames discussed, Webz of War [60] also uses player heart rate as an input to modify the players’ game experience. As players’ heart rates increase, they become more powerful in the game. However, no work has been conducted to evaluate the success of these implementations at increasing players’ heart rates nor are there any guidelines as to how to apply this in game benefit approach as a generic technique.

2.5.2.4 Motivational Techniques seen in Interactive Fitness Systems

Numerous techniques have been designed to increase exertion in interactive fitness systems, which are digital systems that support traditional exercise. We review this area to identify any motivational techniques that could be applied to exergames. TripleBeat is a mobile system that provides runners with personal awareness of their heart rate [66]. This system provides feedback to runners regarding what zone their current Heart Rate Reserve is in, as well as providing a feature that facilitates competition between users, as seen in Figure 2-8. Players are assigned a score based on what heart rate zone they are in and how long they remain in that zone. Players are able to select
competitors and are shown how their score compares with their competitors’ scores during their run. The Strava platform uses GPS to track users’ runs or bike rides [94]. Enabling participants to check their progress against others to compare, compete and participate in challenges. Users can select challenges such as to climb 1,200 meters over a month of running, which will earn them a badge on their profile.

Other techniques used by interactive fitness systems include digital opponents and ghost guides. For example, the Expresso stationary bicycle shows a digital rendering of a track on a screen in front of the bike [39]. A pace bike is displayed on the screen as another cyclist, allowing users to compare visually how well they are maintaining a goal speed. Similarly, the ghost guide shows an opponent whose speed matches one of the user’s past workouts. This can help provide motivation to improve over earlier performances. Many of these techniques focus on the aspect of competition that is inherent in numerous types of games; however, there is no validation for these techniques, and it is unclear how they can be applied to different types of exergames.

2.5.3 Adherence

In addition to physical exertion exergames must produce a degree of commitment expressed as player adherence to be considered as a suitable substitute for traditional exercise

Figure 2-8 Display screen of TripleBeat [66].
programs. As mentioned previously, the enjoyable aspects of exergames are intended to increase a person’s adherence to an exercise regime [90]. Evaluating the efficacy of exergames to improve adherence is two-fold, in that there is both short-term and long-term adherence measure. Often initial enthusiasm declines and the use of the system dips [6].

2.5.3.1 Short-Term Adherence

Exergames can successfully encourage people to increase their physical activity in the short-term. For example, Mark and Rhodes followed a group of families over a six week randomized in home trial comparing the use of a GameBike to traditional stationary bikes [49]. They found that initially usage was significantly higher for children who were in the GameBike group when compared to the group using traditional exercise bikes. However, they saw no significant difference in usage between the two groups for parents. Usage declined over the six weeks for adults and children in both the GameBike and stationary bicycle group.

2.5.3.2 Long-Term Adherence

Long-term adherence to exergame play has proven to be elusive. A systematic review of nine exergame studies performed by Barnett et al., determined that for most players, frequency of play declines over a short time [6] of usually one to two weeks. Notably, Barnett et al. highlighted this area as one that could benefit from better quality studies. Reduced engagement with video games over time is not unique to exergaming; for example, the video game Red Dead Redemption was named Game of The Year in 2010 by several publications including GameSpot [29], and GameSpy [84], and yet the game was only completed by 10% of the users [75]. Few techniques for increasing long-term adherence have been published and this remains an area where game designers could benefit from further inquiry.

One approach that has been used to increase long-term engagement is to continually provide new and compelling content to users to maintain their interest over time. Liberi, an exergame for children with cerebral palsy, employs this strategy to maintain players’ interest by
releasing new content over time [42]. In an eight week trial the expected decline in play time was not seen. In addition to releasing new content over time Liberi facilitates social interaction. It is unclear which of these factors was the primary contributor to the improve adherence.

2.6 Converting Off-the-Shelf Games into Exergames

A promising strategy for providing exergame users with new content is to convert existing off-the-shelf games into exergames. The addition of an exercise component to existing games allows developers to provide exergames that have the deep storylines and high quality assets that are typical of well-funded commercial games with less effort and expense [79]. Currently there are three different approaches for converting off-the-shelf games into exergames, which we term black box, source-code modification and modding interface approach.

2.6.1 Black Box Conversion

A black box conversion approach uses a software tool to convert inputs from an exercise device to game inputs without requiring modification to the game itself. For example, the FitXF software provided with the PCGamerBike Mini pedaling device can be configured to inject the keystroke of choice (usually the key that is used for forward movement) into a game whenever the player pedals, leading the game to move the player’s avatar forward [7]. This allows players to move their avatar by pedaling while using a controller for the remaining input. The black box conversion technique is also used by Sportal, an exergame adaptation of the popular game Portal 2 [89]. Walther-Franks et al. used the Kinect SDK [52] and a virtual game controller vJoy [25] to map players’ walking movements to avatar movements; the player walking forward moves the character forward. They realized that the off-the-shelf game would probably not encourage high exertion and so built custom levels using the Valve Hammer Editor [85] that is provided with the game. These custom levels were designed to encourage more exercise than the original game levels.
2.6.2 Source-Code Modification

A second technique for converting off-the-shelf games into exergames is to modify the source code of the game. There are two toolkits that have been developed to support such conversions: the Flexible Action and Articulated Skeleton toolkit (FAAST) [82] and the General Active Input Model (GAIM) toolkit [13]. Guo and Quarles performed a source-code conversion of a driving video game using the FAAST toolkit [33]. FAAST interprets body positions using a Kinect, which were then mapped to the acceleration of the car in the game’s code. Participants performed the exercise with greater frequency when playing the game, but their maximum heart rates were significantly higher when performing the exercise without the game. Chatta et al. used FAAST to convert Sonic All Stars Racing Transformed to an exergame [17]. In Sonic All Stars Racing Transformed, players race against each other using characters from various Sega franchises. Players were told to perform leg lifts while playing the game and received feedback regarding their performance of the exercise through a visual overlay on the game. If players did not perform the leg lifts correctly or at a fast enough frequency, a flashing overlay blocked players’ views of the screen. The GAIM toolkit has been used to convert the XNA Racing Game [13] so that the player’s car is powered by cycling or jogging on the spot. It was also used to convert the game Spacewar [13] so that players lean their bodies to control the direction of their spaceship, and perform a “hammering” gesture to fire its weapons.

A pure black box approach requires less of a knowledge barrier than source code modification but does not allow designers to adapt the game to the addition of exercise. Source-code modification can work well to convert off-the-shelf-games into exergames, but is limited to games whose code is available to developers.

2.6.3 Modding Interface Approach

The third approach for converting games into exergames: the use of the modification (or “modding”) programming interface provided by many games. This approach provides the benefit
of being able to modify gameplay to suit an exergame while not requiring access to the game’s source code.

In 2014 alone, 30 games with modding interfaces were released on the Steam digital store [80], supplementing an existing robust catalogue. A significant and growing base of games are therefore available for conversion into exergames, potentially helping with the problem of player satiation with games over time.

There are a range of modding interfaces that provide developers with different levels of access to modify the game. For example, the game publisher Bethesda provides an extensive modding tool, the Creation Kit [76]. This can be used to create mods for the popular game The Elder Scrolls V: Skyrim. It consists of a graphical user interface with a render window and a reference list to all objects within a game cell (Figure 2-9). Users can create and manipulate objects through this interface. The Creation Kit allows users to modify existing game areas or create completely new ones. Scripts, using a library provided for the programming language Papyrus, can
be attached to game objects as a way of defining behaviors. The tool creates plugins for the game that are loaded on top of the game’s master file.

A simpler modding interface is provided for the game Cities: Skylines [16]. A scripting API is provided and developers are able to create C# scripts to implement custom behaviors. The UnityEngine namespace is included, allowing developers to draw upon the Unity scripting API as well. When the game starts, it compiles the scripts and creates a .dll file that is loaded at runtime.

Game modding has become a popular activity with significant impact. The popular mod sharing site Moddb.com has seven and half million monthly visitors and over one petabyte in downloads per month [38]. Counter-Strike [86], a modified version of a first person game Half-Life [87], is iconic as one of the most successful mods to date. It has become a competitive e-sport with professional teams competing in high-level tournaments and a fan base numbering in the millions [27]. Given the benefits and the potential to reach a large audience, we decided that identifying successful techniques for modifying existing games into exergames is a worthwhile pursuit.

2.7 Conclusion

This chapter provided background on the research to date that targets improving exergames suitability as a substitute for exercise. We reviewed some exergame categories including audio, ubiquitous, running, social, casual and distributed. As well as purposes for exergames namely rehabilitation, entertainment and exercise. We discussed the criteria for an exergame that is to be used as a replacement for exercise and what the current state is for each of those criteria. We identified a need for more generic techniques that can improve player exertion, and long-term adherence. Finally, we provided a review on the current work being done in the area of converting off-the-shelf games. This review outlined three approaches for the conversion and the benefits and limitations those approaches, which are black box, source-code modification and the modding interface approach.
Chapter 3

Heart Rate Power-ups

This chapter introduces Heart Rate Power-ups: a generic technique that can be implemented in exergames as a way of increasing players’ exertion levels. We begin with an explanation of Heart Rate Power-ups and their implementation in the exergames: Dozo Quest, Biri Brawl, and Gekku Race. Following this, we provide guidelines for the design and applicability of Heart Rate Power-ups in exergames. We then report a study that investigates the effectiveness of Heart Rate Power-ups at increasing player exertion and the results of that study. Power-ups are a common mechanic used in commercial video games, including, for example, the Super Star power in Nintendo’s Super Mario Bros, which grants players temporary immunity to enemies [63]. Fabricatore described power-ups as a satellite mechanic that enhances existing activities [26]. Building on this mechanic, Heart Rate Power-ups provide in-game rewards to players who attain a target heart rate while playing. Upon reaching a specified target heart rate zone, players receive a reward: for example, their avatar may have a stronger attack, may heal more quickly, or may simply take on an appealing appearance. Heart Rate Power-ups derive from the use of heart rate to improve player experience in earlier games. Unlike earlier approaches, Heart Rate Power-ups are a generic technique that can be applied to a wide range of games.

3.1 Implementation

To evaluate how well the addition of Heart Rate Power-ups in a game work to increase player exertion we have implemented them in three existing games that represent both a range of game genres and a range of average exertion levels. Dozo Quest is a platformer game, Biri Brawl is a fighting game and Gekku Race is a racing game. These three games were chosen for two reasons. First, we chose games of different genres to highlight how Heart Rate Power-ups are applicable to a variety of game genres. Second, we suspected that each game incented different
levels of exertion and wanted to gain insight into the interaction between the efficacy of Heart Rate Power-ups and the exertion levels in different games. For example, we were curious whether Heart Rate Power-ups would be as effective in games that do not typically encourage high exertion as those that do. All three games are played on a recumbent bicycle where the player is outfitted with a wrist-mounted heart rate monitor connected wirelessly to the computer on which the game is running, as illustrated in Figure 1-1.

The physical action of pedaling the bicycle directly moves the in-game avatar; the faster the player pedals, the faster the avatar moves. A standard game controller, similar to an Xbox [53] or PlayStation [78] controller, is used to control the avatar’s direction and to launch special abilities such as attacks. Players use the analog stick highlighted in Figure 3-1 to steer their avatars and press the green A button to issue other commands, such as attacks or special moves. We introduce these games below, and describe the Heart Rate Power-up implemented in each of the three games, Dozo Quest, Biri Brawl and Gekku Race as well as describe the benefit it provides to players.

3.1.1 Dozo Quest

Dozo Quest is a platform game which means the player controls a character jumping or climbing between solid platforms. The player controls a red spiked ball in a desert maze containing obstacles that must be jumped, climbed or knocked down (Figure 3-2). Throughout the maze there

![Figure 3-1 Logitech game controller used as input to Dozo Quest, Biri Brawl, Gekku Race [48].]
are enemies that the player can choose to attack or avoid as part of their gameplay strategy and checkpoints that mark significant points along the maze. If a player’s health becomes fully depleted the avatar returns to the last checkpoint. The speed of the ball is determined by the player’s pedaling speed. Pedaling also fills an action bar at the bottom of the screen that once full allows the players to use a dash move to race up ramps, jump between platforms, break cacti, attack enemies, and smash walls in their path. The objective is for the player to collect as many cactus pieces as they can. As we shall see in section 3.5, Dozo Quest is typically played at a low level of exertion as players are not obliged to move quickly and may pause to decide how best to approach the next part of the platform maze.

When a player reaches their target heart rate, the power-up is awarded. Visual feedback is the avatar turning into a black ball with larger, more intimidating spikes. The avatar’s health regenerates, allowing recovery from injuries. Attacks become stronger, aiding in combat and allowing walls to be destroyed in less time.

3.1.2 Biri Brawl

![Figure 3-2 Dozo Quest Gameplay](image)

Figure 3-2 Dozo Quest Gameplay. The image on the left indicates gameplay without the power-up enabled. The image on the right indicate changes that occur when the power-up is enabled. Note the avatar is black with bigger spikes when powered-up and the heart rate indicator is also bigger (and pulses in actual gameplay).
Biri Brawl is a fighting game in which players control a “Biri” jellyfish underwater (Figure 3-3). As with the Dozo Quest, players pedal to move their avatar, steering the jellyfish with the analog stick on their game controller. Players are able to attack each other in the game by pressing a button on the controller triggering their biri to punch. The objective is to knock out as many other Biris as possible in the time allotted by swimming up to them and punching until their opponents’ health runs out. Once Biris are knocked out they are deactivated for a short period and then respawn at full health. To increase their longevity, players can acquire floating booster packs that provide extra health, short bursts of extra speed or stronger attacks.

Performing well in the game necessitates good aim, successful timing of hits, as well as being able to disengage from fights that are going poorly. Like Dozo Quest, Heart Rate power-ups are awarded to players in Biri Brawl when they reach their target heart rate. Active power-ups are visually indicated to the player through green plus symbols floating around the player’s biri avatar. Power-ups provide the player with faster health regeneration which speeds recovery from combat interactions. Biri Brawl, as we will see in section 3.5, encourages players to reach moderate levels of exertion because players must pedal quickly to engage in combat or to escape if they are losing.

Figure 3-3 Biri Brawl Gameplay. Image on the left is play without the power-up enabled. Right image is with power-up enabled. Note the plus signs on the powered-up biri that indicate health regeneration and the indicator in the bottom left of each image.
However, there are opportunities for players to pause when they are recovering, before engaging in the next combat, or during the respawn time.

### 3.1.3 Gekku Race

Gekku Race is a racing game in which players pedal to move their avatar along a track (Figure 3-4). The use of an analog stick, located on their game controller, enables the player to steer their Gecko avatar. As with Dozo Quest and Biri Brawl, the faster the player pedals, the faster their gekku character moves. The objective of the game is to be the first player to get their gekku avatar to the top of a track. As players pedal, a small energy bar located at the bottom of the screen fills up. Once the energy bar is full, the player is able to shoot cashews or fireballs at other racers. When a gekku is hit with a cashew, it is stunned for a short period of time, preventing it from moving higher up the wall. If a Gecko is burned by fire, it turns black and falls a short distance down the wall before being able to begin climbing again.

Gekku Race, as we will see in section 3.5, typically inspires high levels of exertion as players are continually trying move their avatar faster than the others. When a player’s heart rate reaches the target range, their gekku avatar glows a bright green (Figure 3-4), indicating that the

![Gekku Race gameplay](image)

**Figure 3-4 Gekku Race gameplay.** Left shows play without power-up; Right is with power-up. The powered-up gekku is lighter green and has a more visually impressive attack.
power-up is active. With the power-up, players’ attacks become stronger: the cashew attack shoots three cashews rather than one, and the fire attack changes from a small ball to a long stream of fire that is able to burn multiple opponents. The powered-up attacks are visually and aurally satisfying to the player, while providing a modest increase in avatar power. Heart Rate Power-ups in Gekku Race are designed to be visually obvious (through the green glow and the visual effects of the attacks), and desirable through the appealing visual and audio presentation of the attacks. If and when the player’s heart rate drops below the target range, the power-up is lost.

3.2 Applicability

Dozo Quest, Biri Brawl and Gekku Race share characteristics that make them strong candidates for the application of Heart Rate Power-ups. All three games are based on cycling, a physical activity that can be performed vigorously. In all three games players are able to increase the intensity level of the exercise they are performing without reducing their effectiveness at the game. The combination of these factors makes the games well-suited to Heart Rate Power-ups, in that it is possible for players to raise their heart rates if they are incented to do so. However, not all active games have these properties. We identify three properties required by an active game to be suitable for the application of Heart Rate Power-ups those are: agency over exertion, motion controls supporting exertion and a gap between the game’s potential and average exertion.

3.2.1 Agency Over Exertion

A player’s agency over exertion refers to the amount of freedom the player has to change their level of exertion in the game without penalty. For example, in Dance Dance Revolution, players perform dance moves at a pace dictated by the game [43]. If a player attempts to increase their level of exertion by dancing faster, they lose points for failing to match the beat of the game. Dance Dance Revolution, therefore dictates the player’s level of exertion by restricting the players’ agency over exertion. It is worthwhile to note that agency is not an all-or-none game element but may change at different points throughout a game. For example, many games use a cut scene
mechanic in which the gameplay suspends and an animation plays to move the story forward or provide an explanation. During cut scenes players stop playing or during a turn-based game, players may be inactive while waiting for their turn.

Our three games Dozo Quest, Biri Brawl, and Gekku Race provide players with agency over exertion. The games have no pauses that require the players to stop pedaling, and if players increase their cadence they do not receive any negative influence on their performance. If players are discouraged or penalized for increased exertion during gameplay, they will not be incented to exercise more vigorously in order to earn a Heart Rate Power-up. Therefore, a high degree of player agency over exertion is necessary for Heart Rate Power-ups to be used successfully in games.

3.2.2 Motion Controls Support Exertion

A game can facilitate exertion only to the degree that players can raise their heart rates by performing the game’s physical motions. We define the potential exertion of a game as the maximum exertion level a player can achieve via the game’s motion controls. For example, the potential exertion of Wii Sports Bowling is limited by the game’s core activity of slowly swinging one’s arm to throw a virtual ball. Dozo Quest, Biri Brawl and Gekku Race are games based on cycling input, which has been designated a vigorous activity by the ACSM [5], indicating high potential exertion. While the presence of high potential exertion does not guarantee that players will reach target heart rates during gameplay, it does ensure that players’ exertion is not limited by the game’s motion controls.

3.2.3 Large Gap Between Average and Potential exertion

A game’s average exertion level refers to the exertion level that is experienced during a typical gameplay session. Average exertion can be measured as the average of a representative set of players’ exertion levels during gameplay (section 3.4 reports average exertion for our three games). The difference between a game’s average and potential exertion indicates whether there is room for players to increase their level of activity. Dozo Quest, Biri Brawl and Gekku Race share
a high potential exertion, but – as we shall see – differ in their average exertion. In our experience, a game with a large difference in potential and average exertion is better suited for the implementation of Heart Rate Power-ups.

Heart Rate Power-ups are therefore most applicable to games that allow players agency to modify their level of exertion without penalty in game, include motion controls that support high levels of exertion, and differ in players’ average and potential levels of exertion. This implies that a wide array of game genres have potential for application of the technique, such as those presented in this thesis: platformer, racing and fighting games as well as shooter and role-playing games. Games that have rigid pace (like Dance Dance Revolution) or whose controls do not significantly increase heart rate (like Wii Sports Bowling) are poor candidates for the technique.

3.3 Design Principles

Dozo Quest, Biri Brawl and Gekku Race illustrate that Heart Rate Power-ups can be applied to three different genres of games (racing, platformer and fighting games) as well as three different levels of average exertion. While the power-ups provided in each game are different, they share a similar approach in that all power-ups provide a change in the avatar’s appearance and directly cause one or more improvements to the avatar’s power. The design of these power-ups followed three principles: (1) the effect of the power-up should be clear, (2) the impact of the power-up should be balanced, and (3) the player’s activity should be coupled to the power-up’s effect. These principles are described in greater detail in the following sections.

3.3.1 Effect Should Be Clear

It must be clear to the player when the power-up is in effect, how close they are to attaining their target heart rate, and what effect the power-up has on their avatar. For example, in Biri Brawl, the player’s jellyfish is surrounded by green floating health symbols when it is powered-up, making it clear that the power-up is active and regenerating the avatar’s health. In all games, a heart rate indicator is shown at the bottom left of the screen (Figure 3-5). This indicator provides players with
enough information to compare their current heart rate to their target heart rate. As we shall see in section 3.5.1, participants commented that this indicator helped motivate them to work harder to obtain and maintain the power-up.

Clarity is important for two reasons. First, if the player’s heart rate is close to the target, the power-up may be activated and deactivated frequently. It should be clear when the effect is lost to help motivate the player to increase their exertion level to regain it. Second, the player must be convinced that the power-up is worth the literal effort required to activate it. It is therefore important that they are able to immediately see what advantage the power-up gives them in gameplay. For example, Gekku Race’s loud and visually exciting attacks clearly indicate the benefit of having the power-up. Similarly, the dangerous looking avatar in Dozo Quest immediately conveys that the power-up increases the player’s power.

3.3.2 Impact Should Be Balanced

It is tempting to design power-ups with excessive capabilities and overwhelming power in order to increase players’ desire to activate them. However, this should be avoided as overly powerful power-ups place the game at risk of being too easy and ultimately boring for the player. Equally, the game must be playable without the power-up to avoid losing players who have not reached their target heart rate. For example, piloting of an early version of Dozo Quest indicated that both parts of this principle had been violated: without the power-up, it was difficult to complete

Figure 3-5 Heart rate indicator displayed at bottom left of the screen in Dozo Quest, Biri Brawl and Gekku Race. The left indicates the player is at rest. As the player increases their heart rate the interior heart grows until they reach their target, seen on far right.
the game without being killed by the enemies. Meanwhile, the power-up rendered the player essentially invincible, removing all challenge from the game. In the final version of Dozo Quest, the game’s difficulty was reduced in standard play, and the effect of the power-up was reduced to retain challenge in the game.

### 3.3.3 Activity Should Be Coupled To Effect

When players expend the necessary energy to meet their target heart rate, they should see the benefit of the power-up immediately and continuously as long as their heart rate remains above the target. Not only should it be clear that the power-up is active (our first principle), but the positive effect of the power-up should be immediately available. For example, in Gekku Race, players must pedal to charge up the Gekku’s cashew and fire attacks. To ensure the game’s difficulty is balanced (ie neither not too hard or too easy) these attacks are not constantly available. It was necessary to tune this recharge time so that the player did not need to wait overly long to receive the benefit of the power-up. In the final game, the charging time is six seconds.

Traditional power-ups often grant an ability that can be used in the future, illustrated in Nintendo’s Mario Kart Series [74] where players can obtain a banana that can be used later to slow down an opponent. Our guidelines capture that power-ups must be tied to the player’s present exercise level so that obtaining a power-up for later use does not provide an excuse to slow down or reduce effort. We applied these three principles of clarity of effect, balance of impact and coupling of activity through the iterative design and pilot testing of our three games. The iterative testing involved having multiple people play the games and give feedback on their experience with and without the power-up. Afterwards we adjusted the game’s difficulty and the effects of the power-up. This was repeated until we were satisfied the guidelines were met. Each game adheres to the guidelines in the following ways:

- Effect should be clear
- *Dozo Quest*: Players’ avatar has larger spikes and appears more intimidating while in the powered-up state to indicate that it is more powerful with stronger attacks and health regeneration.

- *Biri Brawl*: Players’ avatar has green plus signs floating around it while powered-up to indicate it has a faster health regeneration.

- *Gekku race*: While powered-up the gekku avatar glows green and the visual effect of an attack is more impressive to indicate its potential to do more damage.

- Impact should be balanced:
  - *Dozo Quest*: Enemies and barriers present enough of a challenge that they can be defeated without the power-up and still require precise aiming and do equal damage to the player while players are powered-up.
  - *Biri Brawl*: Having a faster regeneration time does not make defeating enemies trivial but allows players to win a one on one fight more easily. Players must still be careful not to draw too many attackers at once.
  - *Gekku Race*: Being able to slow down more enemies at once makes it easier for players to pass other gekkus, however when players are ahead the power-up does not make remaining in first place trivial.

The guideline effect should be clear is observed in the same way for all three games - the effect of the power-up is only available while players are maintaining a heart rate above their target.

### 3.4 Evaluation

To evaluate the effectiveness of Heart Rate Power-ups, we performed a within-subjects user study using the games Dozo Quest, Biri Brawl and Gekku Race described above. We wished to address the following three questions: Can power-ups assigned as a reward for reaching target heart rate encourage players to strive for and maintain their target heart rate? If so, does the effectiveness of Heart Rate Power-ups depend on the difference between average and potential
exertion levels of the game? And how does the presence of Heart Rate Power-ups affect players’
enjoyment of the game?

3.4.1 Participants

We recruited 20 participants from Queen’s University comprised of 11 males and 9 females
ranging from 18-26 years of age. The recruitment process was achieved through postings placed
on the Queen’s University Paid Research Opportunities Facebook group. We used the Physical
Activity Readiness Questionnaire (PAR-Q) [20] to screen for health issues that would make
physical exercise inadvisable. All participants were comfortable using a game controller and
operating a recumbent bicycle. On the initial demographic questionnaire, 13 participants reported
playing games daily and five of the remaining seven reported having been frequent gamers in the
past. As well, 11 of the 20 participants reported activity levels at the recommended ACSM level.
During the study, automated data collection failed for one participant, therefore results are reported
for 19.

3.4.2 Setup and Apparatus

The study was conducted using a PCGamerBike Mini pedaling device as input to the
games, shown in Figure 1-1. This device provides cycling cadence information via a USB
connection. Participants wore a Garmin heart rate monitor to provide real-time heart rate
information to the game and used a Logitech game controller to move their avatar. The games were
displayed on a 55” wall-mounted television.

3.4.3 Measures

Data was collected through log files generated by the games and questionnaires filled out
by participants once they completed each game. Once per second, the game recorded the player’s
heart rate and cadence as well as game events. A custom log-file analysis tool was used to compute
average percent of heart rate reserve and the time spent within their target heart rate range. The test
to find people’s maximum heart rate is the VO2 max [19] which requires bringing people to their limit. We instead chose to use a standard formula which estimates players maximum heart rate based on their age. Participants’ maximum heart rate was estimated by inserting each participant’s age into the formula:

$$HR_{\text{max}} = 206.9 - (0.67 \times \text{age}) \ [32]$$

Target heart rate was calculated by inserting players’ maximum and resting heart rates into the Karvonen formula:

$$HR_{\text{Target}} = \left( (HR_{\text{Max}} - HR_{\text{Resting}}) \times \%_{\text{Intensity}} \right) + HR_{\text{Resting}} \ [5]$$

We chose a target intensity of 60% of heart rate reserve, representing the moderate-to-hard intensity level recommended by the ACSM for people who regularly exercise at moderate-to-high intensity [5]. This target is significantly higher than that sought in the exergaming meta-reviews cited earlier; we chose this ambitious exertion level to convincingly assess the potential of a game with Heart Rate Power-ups as a viable substitute for traditional exercise.

3.4.4 Procedure

Participants completed two sessions occurring on different days. At the beginning of the first session, participants were asked to read and sign a consent form and a debriefing letter. They also completed a demographic questionnaire and the PAR-Q to screen for health issues, which cleared all participants to safely participate in exercise. Once the questionnaires were completed, participants put on a heart rate monitor and were asked to lay on a couch for five minutes to obtain a baseline resting heart rate.

The difference between session one and session two was the condition being tested. In one session, participants played all three games with the Heart Rate Power-ups present; in the other they played the control condition of all three games. The control condition involved the power-ups being awarded outside the players influence. Specifically, in Dozo Quest and Gekku Race, segments of the track were selected as regions in which the player automatically received the
power-up. In Biri Brawl, the power-up was awarded during predetermined time periods. In the control condition of all three games the power-ups were awarded during 50% of the playtime. We chose to award the power-ups for 50% of the playtime because piloting determined that was about the amount players were reaching their target. Thus, in both conditions, players received the same power-ups; the conditions differed only in how the power-ups were awarded. In the experimental condition, the power-up was activated when the player met or exceeded their target heart rate. In both conditions, a heart rate indicator located at the bottom left of the screen informed players how close they were to their target heart rate, seen in Figure 3-5.

Both sessions followed the same format. Each participant completed a three minute warm up on the recumbent bicycle followed by a five minute break. Upon completion of the break, participants played each of the three games for seven minutes with a rest period between games to reduce cross-over of elevated heart rate levels from earlier play. The game and the power-ups were explained immediately before each was played to ensure that players understood the objectives and specifics of the games. The rest period between each game was a minimum of five minutes and was extended as necessary until the participant’s heart rate fell below moderate intensity levels. During the rest period that followed each game, participants filled out a Likert scale questionnaire regarding their experience in the game they just finished. The power-up condition questionnaire had additional statements that pertained specifically to the mechanic itself. Ten participants played the Heart Rate Power-up condition first and ten played the control condition first. The order in which the three games were played was chosen according to a Latin square, which ensures each ordering of the games is completed an equal number of times over the course of all participants. This was done to counter any learning effect. Because heart rate typically reaches a steady-state within one to two minutes following an increase in exercise intensity [40], the first two minutes of data from each game were considered to be warm-up, and were removed from analysis. This left
five minutes of data for analysis in each trial. Once participants had completed both conditions they
filled out a final questionnaire and participated in a semi structured interview that was recorded.

3.5 Results

We present results as they address our three questions about the effectiveness of Heart Rate
Power-ups. The results are based on our gameplay logs and questionnaire responses. Questionnaire
results are summarized in Table 3-1, Figure 3-8, Figure 3-9, and Figure 3-10. Player responses to
Likert Scale questions that were asked only once are in the form of a diverging stacked bar graph
to show which percentage of players chose a specific response [35]. We report significance at the
alpha=.05 level and marginal significance at the alpha=.07 level. Effect size is indicated by Cohen’s
d [83], where a value of 0.2 is considered a small effect, 0.5 medium and 0.8 large. Data from one
of the 20 participants is excluded due to a failure of that participant’s heart rate sensor.

3.5.1 Q1: Can Heart Rate Power-ups encourage players to reach and maintain their target
heart rate?

Figure 3-6 Average amount of time players spent at or above target heart rate during
play with and without a Heart Rate Power-up for Dozo Quest, Biri Brawl and Gekku
Race. Effect size is labeled. Hats indicate a significant difference.
The average amount of time participants spent at or above their target heart rate during each game expressed in minutes is depicted in Figure 3-6. For each game, we performed a one-way paired-samples t-test comparing time at or above target heart rate and applied Bonferroni correction to the results. Time above target heart rate was significantly higher in the Heart Rate Power-up condition for Dozo Quest (t=3.22, p=.002), Biri Brawl (t=2.82, p=.006) and Gekku Race (t=3.22, p=.021).

Figure 3-7 shows participants’ average percentage of heart rate reserve while playing the games. A one-way paired-samples t-test on player’s average percentage of heart rate reserve between conditions showed significant differences for Dozo Quest (t=4.40, p<.001) and Biri Brawl (t=2.82, p=.006), and no significance for Gekku Race (t=1.58, p=.06).

When asked the question “I was focused on the heart rate indicator during the game”, a Wilcoxon Signed-Rank test indicates player responses agreed significantly more in the Heart Rate

![Average Percent of Heart Rate Reserve](image)

**Figure 3-7** Players' average percentage of heart rate reserve during play with and without Heart Rate Power-ups for Dozo Quest, Biri Brawl and Gekku Race. Effect size is labeled where applicable. Hats indicate a significant difference.
When asked “I tried to reach and maintain my heart rate during gameplay,” significant differences were found between the Heart Rate Power-up and control condition for Biri Brawl and Dozo Quest, but not for Gekku Race. Table 3-1 shows the results of the Wilcoxon Signed-Rank test on the responses to statements that were present after each condition. Figure 3-8 shows that most players believed trying to get the power-up motivated them to pedal harder.

**Q1: Interpretation of results**

<table>
<thead>
<tr>
<th>Questions asked in after each game</th>
<th>Gekku Race</th>
<th>Biri Brawl</th>
<th>Dozo Quest</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1) The game was physically tiring</td>
<td>z=-1.933</td>
<td>z=-1.134</td>
<td>z=-3.035</td>
</tr>
<tr>
<td></td>
<td>p=.53</td>
<td>p=.257</td>
<td>p=.002</td>
</tr>
<tr>
<td>S2) I was good at achieving the game’s objectives</td>
<td>z=-1.732</td>
<td>z=-.212</td>
<td>z=-0.359</td>
</tr>
<tr>
<td></td>
<td>p=.83</td>
<td>p=0.832</td>
<td>p=.719</td>
</tr>
<tr>
<td>S3) I was focused on the heart rate indicator during the game</td>
<td>z=-2.359</td>
<td>z=-3.362</td>
<td>z=-3.572</td>
</tr>
<tr>
<td></td>
<td>p=.18</td>
<td>p=.001</td>
<td>p&lt;.001</td>
</tr>
<tr>
<td>S4) I tried to reach and maintain my target heart rate during gameplay</td>
<td>z=-2.575</td>
<td>z=-3.327</td>
<td>z=-3.099</td>
</tr>
<tr>
<td></td>
<td>p=.10</td>
<td>p=.001</td>
<td>p=.002</td>
</tr>
<tr>
<td>S5) Playing this game was a vigorous workout</td>
<td>z=-2.333</td>
<td>z=-1.265</td>
<td>z=-1.786</td>
</tr>
<tr>
<td></td>
<td>p=.002</td>
<td>p=.206</td>
<td>p=.074</td>
</tr>
</tbody>
</table>

Table 3-1 Results of a Wilcoxon Signed-Rank test comparing participant responses to questions S1-S5 after the control condition and after the Heart Rate Power-up condition of each game.

Power-up condition for Biri Brawl and Dozo Quest, but not for Gekku Race. When asked “I tried to reach and maintain my heart rate during gameplay,” significant differences were found between the Heart Rate Power-up and control condition for Biri Brawl and Dozo Quest, but not for Gekku Race. Table 3-1 shows the results of the Wilcoxon Signed-Rank test on the responses to statements that were present after each condition. Figure 3-8 shows that most players believed trying to get the power-up motivated them to pedal harder.

![Figure 3-8 Participant responses to the statement "Trying to get the the power-up motivated me to pedal harder" after they finished playing Dozo Quest, Biri Brawl, Gekku Race in the Heart Rate Power-up condition.](image)
Our study reveals that players maintain a higher heart rate when games use a Heart Rate Power-up. Player responses to S8 (seen in Figure 3-9) reveals that all participants felt encouraged to pedal harder by the presence of the Heart Rate Power-ups. In an interview, one participant stated: “it’s more motivating to get your target heart rate when you get a power-up. [In] the [control condition] you just ignore your heart rate and play the game”. This quote along with the Wilcoxon Signed-Rank test results for S3 in Table 3-1 indicate that the addition of the Heart Rate Power-ups can work to improve players’ mindfulness of their exercise level, in turn increasing their exertion levels. The average amount of time players spent in their target heart rate zone increased for Dozo Quest, Biri Brawl and Gekku Race, as did the players’ mean average percentage of heart rate reserve for Dozo Quest and Biri Brawl.

3.5.2 Q2: Does the effectiveness of power-ups depend on the average exertion level of the game?

We measured each game’s average exertion via the players’ mean average percentage of heart rate reserve during play of the control condition. We chose the exertion from the control condition to measure each game’s average exertion because players will be playing the games

![Figure 3-9](attachment:image.png)

**Figure 3-9** Player responses to S8 - S10 presented after participants completed Dozo Quest, Biri Brawl, Gekku Race in the Heart Rate Power-up condition.
without incentive to modify their exertion. These exertion values are summarized in Table 3-2. A one-way within-subjects Analysis of Variance (ANOVA) indicated a significant effect of game on players’ average percentage of heart rate reserve (F(1.90, 34.21) = 15.58, p<.001). One-way paired-samples t-tests with Bonferroni correction indicate that the mean exertion of Dozo Quest (M=44.55, SD=12.86) is significantly lower than the mean exertion of Biri Brawl (M=49.95 SD=10.54, t(18)=2.79, p=.006, d=.46); the mean exertion of Biri Brawl is significantly lower than the mean exertion of Gekku Race (M=56.25 SD=12.17 t(18)=2.72, p=.007, d=.55), and the mean exertion of Dozo Quest is significantly lower than the mean exertion of Gekku Race (t(18)=5.80, p<001, d=.93). Therefore, Gekku Race is the game that produces the highest average exertion while Dozo Quest is the game with lowest average exertion, and Biri Brawl lies between them. Therefore, we conclude that there is a difference in average exertion between the three games.

This difference in average exertion impacted the effect of Heart Rate Power-ups where the slower the pace of the game, the larger the impact that was seen on both time spent above target heart rate and players’ average percentage of heart rate reserve. Specifically, the effect of Heart Rate Power-ups on the average minutes players spent over target heart rate is greatest for Dozo Quest (d=.72), then lower for Biri Brawl (d=.65) and smallest for Gekku Race (d=.5), all are considered medium effect sizes. The effect of Heart Rate Power-ups on average percentage of heart rate reserve follows the same ranking, of Dozo Quest (d=.89) with a large effect size and Biri Brawl (d=.58) with a medium effect size.

<table>
<thead>
<tr>
<th>Game</th>
<th>Average % of Heart Rate Reserve</th>
<th>Effect of Heart Rate Power-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dozo Quest</td>
<td>44.5%</td>
<td>d = 0.89</td>
</tr>
<tr>
<td>Biri Brawl</td>
<td>49.9%</td>
<td>d = 0.58</td>
</tr>
<tr>
<td>Gekku Race</td>
<td>56.2%</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Table 3-2 Players’ average exertion in the control of each game and the effect of adding Heart Rate Power-ups measured by Cohen's d.
Q2: Interpretation of results

Power-ups were more effective at increasing player heart rate in the games with lower average exertion. One explanation for this trend is that during the games with high average exertion, players were already close to their target heart rate in the control condition, and therefore required less additional effort to attain the power-up. Not surprisingly, players’ responses to the statement “Trying to get the power-up motivated me to pedal harder” (Error! Reference source not found.) show that players were more motivated by the power-ups during the games with lower average exertion.

A major finding from these results is that it is possible to improve heart rate in games with low average exertion. In Dozo Quest, players have lots of opportunities to pause, rest and reflect. The Heart Rate Power-up was successful in motivating players to skip these opportunities.

3.5.3 Q3: How does the presence of Heart Rate Power-ups affect players’ enjoyment of the game?

Several statements were presented as a Likert questionnaire after each game was finished being played during both conditions. In response to the statement “I found the game to be physically tiring”, players reported the games to be significantly more tiring when power-ups were dependent on heart rate in Dozo Quest and saw an increase with marginal significance in Gekku Race. In response to the statement “Playing this game was a physical workout” (S5 in Error! Reference source not found.), players agreed significantly more during the Heart Rate Power-up condition of Gekku Race and marginally significantly higher values for Dozo Quest.

Upon completion of both conditions for Dozo Quest, Biri Brawl, and Gekku Race, participants responded to specific statements designed to assess the impact of Heart Rate Power-ups on players’ experience. In response to the statement “The games were more fun when power-ups were dependent on reaching target heart rate” (S9 in Figure 3-9). 18 participants responded with “Neutral, “Agree” or “Strongly Agree”, while one responded with “Disagree”. In response to
“Pedaling hard is more rewarding when the power-ups were based on heart rate” (S10 in Figure 3-9), all participants agreed or strongly agreed.

Most players agreed with the statement that “Using the power-up made it easier to complete the game’s objectives” for Dozo Quest and Biri Brawl and approximately half agreed for Gekku Race, seen in Figure 3-10.

Q3: Interpretation of results

Despite concerns that increasing the exertion level of the games could reduce players’ enjoyment [92], we found the opposite to be true. Players overwhelmingly reported the Heart Rate Power-up version of the game to be more fun, and reported the physical exercise to be more rewarding. One player described how Dozo Quest changed with the power-up: “the power-up made it go faster and faster is more fun”. Being able to pedal hard to obtain the power-ups adds a new form of challenge to the games, likely an important factor of the increased enjoyment.

The responses to the statement “using the power-up made it easier to complete the game’s objectives” indicate that we successfully followed our design principle of impact should be balanced for both Dozo Quest and Biri Brawl. Players were aware of the benefit of the power-up
while still enjoying the game, indicating that players found the game neither boring nor frustrating. Player responses for Gekku Race provide another possible explanation for the lack of statistical significance in players’ exertion between conditions of Gekku Race. Perhaps players were not incented to activate the Heart Rate Power-up in Gekku Race because the benefits were not noticed by all players.

### 3.6 Discussion and Implications for Design

The success of Heart Rate Power-ups demonstrates the potential of designing for exertion in exergames. We now explore the implications of our experience with Heart Rate Power-ups on the design of exergames.

#### 3.6.1 Exergames as a Form of Exercise

While the presence of Heart Rate Power-ups successfully increased players levels of exertion for two of the games observed in our study, Dozo Quest and Biri Brawl, our central question remains as to whether they are sufficient to turn exergames into viable alternatives to traditional physical activity. In our study, we adopted the highest levels of the ACSM recommendation, 60-80% of heart rate reserve, intended for people who regularly exercise at moderate-to-high intensity. To place this choice in context, the ACSM recommendation for people of low levels of conditioning is 40-59% of heart rate reserve. This may have been more appropriate for the self-reported level of activity of 11 of our 20 participants. As we have seen, in Gekku Race, players spent 52% of their time at or above target heart rate with the addition of Heart Rate Power-ups. When the data is reinterpreted using the lower ACSM recommendation of 40-59% as a target heart rate, players spent 88% of their time at or above target heart rate in Gekku race. In Biri Brawl, players spent 88%, and in Dozo Quest 79% of their time at or above 40% of Heart Rate Reserve. These levels indicate that exergames employing Heart Rate Power-ups are more than adequate for reaching the lower end of the ACSM guidelines for exercise prescription, and on the boundary of being suitable for the higher level of recommendations.
A limitation of our study is that to avoid fatigue between conditions, we limited the exergaming segments to seven minutes in length. While further study is required to test longer play sessions, these results indicate that games using Heart Rate Power-ups have the potential to provide exercise consistent with ACSM recommendations, particularly for people with low levels of conditioning.

3.6.2 Heart Rate Power-ups Can Increase Player Enjoyment

When asked to respond to the statement “The games were more fun when the power-ups were dependent on reaching a target heart rate” only one of 19 participants disagreed. When interviewed, most participants expressed that they felt stronger or more powerful in the game when power-ups were present. Participants also reported enjoying that the power-ups added an extra goal to the game, and that obtaining the power-up gave them a sense of accomplishment. One participant described this saying “the power-ups made the games easier so by getting the power-up from working hard it felt like you accomplished it”. No participants cited the higher exertion required to play the game with Heart Rate Power-ups as negatively impacting their enjoyment.

3.6.3 Applicability of Heart Rate Power-ups

Our study provides evidence that, at least among the games tested, Heart Rate Power-ups have a larger effect in games where there is a large difference between average and potential exertion. Games with a high average exertion such as Gekku Race or game actions with a low potential for exertion (such as Wii Sports Bowling) provide players with limited opportunity to increase their exertion level through gameplay. Developers should consider whether their games have a high potential exertion with a gap between the potential and average exertion before implementing Heart Rate Power-ups.
3.6.4 Visible Heart Rate Power-ups Motivate Players

Our experience highlights the importance of the Heart Rate Power-ups being visually clear. One participant stated in reference to their Gekku Race avatar: “I just wanted to get the power-up so if it wasn’t glowing I would try to get it to glow”. Another commented on his reaction to a visualization, saying “Once I saw the gekku burst the giant flame, I was like ‘Okay! I want to do that again!’”. Players’ found the visual presentation important in knowing when the Heart Rate Power-up was in effect, and found the visuals motivational in of themselves.

3.6.5 Heart Rate Power-ups Create a Risk of Overexertion.

Heart rate has a delayed response to load increase which must be factored into game designs that use Heart Rate Power-ups as a method of increasing participant motivation based on the potential risk to overload players. Without direct feedback to participants that quantifies their heart rate in relation to target levels they may continue to exert themselves reaching unsafe heart rate levels in an attempt to avoid dropping below their target rate. To address this element that can impact safety and game enjoyment, all three games included in our study were designed to flash a warning message on the screen if the participant reached 90% Heart Rate Reserve while engaged in gameplay, to identify that they were exerting themselves too hard. Of the 19 participants, three surpassed the vigorous intensity exertion range and were shown the warning message. There are existing techniques to discourage players from over exertion that are more immersive than our approach of flashing a warning on the screen, as shown by Schneider et al. who included intuitive feedback to negatively impact players’ in game performance when they over exerted themselves [72].

In this chapter we described our evaluation of Heart Rate Power-ups, design and applicability guidelines and the implications of designing for exertion. With the addition of Heart Rate Power-ups, we saw a 50% to 100% increase in players’ average time spent over their target heart rate during seven minutes of play. Knowing the capacity of Heart Rate Power-ups to increase
player exertion in exergames, we decided to evaluate this technique in the context of exergames converted from off-the-shelf games. The exertion levels during play of off-the-shelf games is not well known, and we hypothesized earlier that because the design is not focused on exertion it would result in low levels. The following investigation consists of implementing Heart Rate Power-ups into converted off-the-shelf games and comparing the exertion levels of these converted games to that of games altered using an existing black box style of conversion.
Chapter 4

Converting Off-the-Shelf Games Into Exergames

This chapter outlines our conversion of two off-the-shelf games into exergames. Converting off-the-shelf games into exergames is a way of providing exergame content to users with less development work than would be required to create an exergame from scratch. Given the success of Heart Rate Power-ups to increase player exertion in exergames we wanted to explore whether they would be able to improve player exertion in converted exergames as well. We performed a conversion and implemented Heart Rate Power-ups by taking advantage of the modding interfaces that accompany the off-the-shelf games. With the converted games we performed a user study to evaluate the efficacy of the Heart Rate Power-ups at improving player exertion in converted off-the-shelf games.

We begin by describing the games we chose and the reasons behind that decision. Next we describe the conversions of each game and the method of conversion. We end by describing our evaluation of the converted games and the implications of our findings.

4.1 Performing the Conversions

We elected to convert two popular games, Valve Corporation’s Half-Life 2 and Bethesda Game Studio’s The Elder Scrolls V: Skyrim into exergames where the player’s avatar is powered by pedaling a stationary bicycle. These games were chosen because there are modding interfaces available for them, they have a first person viewpoint, and the avatar controls naturally map to pedaling. These reasons will be expanded upon in section 4.1.1. The Elder Scrolls V: Skyrim is an action role-playing game set in an open world in which players have the freedom to participate in crafting, combat, looting, bartering, and questing. It is the fifth installment in The Elder Scrolls series of games. The main storyline of the game centers on the player’s character and their effort to defeat the dragon Alduin. As players perform in-game actions, they are able to level up skills
and improve their armor and weapons. The Elder Scrolls V: Skyrim provides both a deep story line and game world for players to interact with and learn about, including the ability to interact with non-player characters by engaging them in conversation, marrying them or killing them. The Elder Scrolls V: Skyrim has been well-received by the gaming public, scoring an 8.4/10 on metacritic.com, a popular review site for video games [51].

Half-Life 2 is a fast-paced first-person shooter game interlaced with environmental puzzles that is a sequel to the game Half-Life. The storyline revolves around the player’s character Gordon Freeman who is awoken to discover that the world he lives in has been taken over by an alien compound. Collaborating with members of a human resistance group, Gordon and the others work together to save the world from attacking aliens that wish to harvest the Earth. Players are required to use weapons and periodically make use of props from the environment to solve physics problems to kill enemies and advance the plot. Half-Life 2 was also well-received by the gaming public with a user score of 9.2/10 on metacritic.com [50].

We performed the conversion of The Elder Scrolls V: Skyrim and Half-Life 2 to exergames in two stages. The first stage was a black box conversion in which we add pedaling to enable avatar movement, similar to the conversions enabled by the PCGamerBike Mini and FitXF [7]. We hypothesized that black box conversion would not incent high exertion in players since the off-the-shelf games incorporate no incentives for exertion and do not attempt to match gameplay activities with the pace of physical exercise. The second stage of conversion uses the games’ modding interfaces to augment the pedal-based control with Heart Rate Power-ups. These power-ups benefit the player, giving them an advantage in the game for reaching and maintaining target heart rate levels, adding an explicit incentive for exertion not present in the black box conversion. Our conversions demonstrate how the modding approach to off-the-shelf exergame conversions offers the designer the ability to adapt game elements for exertion, providing an important advantage over the black box approach.
4.1.1 Identifying Which Off-the-Shelf Games to Convert

Before beginning the process of conversion, we needed to identify which off-the-shelf games would be best suited for conversion into exergames. We used guidelines provided by Walther-Franks et al. on selecting a suitable off-the-shelf game to adapt for exercise [89]. They suggest using character-based action games because movement input can be directly mapped to avatar movement. First-person games are also recommended because they increase a player’s sense of presence. Both The Elder Scrolls V: Skyrim and Half-Life 2 meet this criteria as they are first-person games that involve significant action. In addition to following these guidelines, we required games with rich modding interfaces to allow the addition of the Heart Rate Power-ups. Finally, we selected games from different genres in the hope that it would give insight into how elements of a game might affect players’ exertion. These considerations led us to choose Half-Life 2 and Elder Scrolls V: Skyrim for conversion to exergames: both are action-oriented first-person games, representing the two genres of first-person shooter and role playing games respectively, and both provide rich modding languages. The converted games were renamed Thighrim and Calf-Life.

4.1.2 Customizations of Games via Heart Rate Power-up

We performed the conversion of The Elder Scrolls V: Skyrim and Half-Life 2 using each game’s modding interface. A custom tool created by Walker is used in both conversions to record a player’s heart rate and pedaling cadence in real time. The values are sent wirelessly from the heart rate monitor and a cadence sensor on the pedal. Once the heart rate and cadence values are received, the tool calculates the player’s target heart rate as a percentage of their heart rate reserve. Next, keystrokes are injected into the game to communicate these values. For example, if the player’s heart rate is at their target, then the tool injects a “.” keystroke. The games have been modified so that the character enters a powered up state while a “.” keystroke is detected. The tool also provides an overlay displaying a heart rate indicator, similar to what was used in the Liberi games’ power-ups to provide feedback to the player on their heart rate levels (Figure 4-1).
For each game, we created a custom mod that responds to the injected keystrokes associated with target heart rates and cadences. In both games, the mod allows the player to move their avatar only when the pedaling cadence is above a threshold of 20 revolutions per minute (RPM). The threshold was implemented because we didn’t want players to be startled if their avatar moved on screen due to slight unintentional movements of the pedal. We chose 20 RPM because after testing we decided it allowed players to pedal at as slow a pace as they would feel comfortable without being falsely detected. Power-ups are enabled when the keystroke is injected to indicate that the player has reached their target heart rate. Players receive an in-game advantage when their power-up is active, such as acquiring the ability to effect more damage during attacks or to be able to heal more quickly than normal.

![Figure 4-1 Heart Rate indicator used in the Calf-Life and Thighrim exergames. Far left image is displayed when player’s heart rate is at resting level. The interior red heart increases in size until the player reaches their target heart rate at which point the far right heart is displayed.](image)

### 4.1.3 Base Conversion: Pedaling to Move Avatar

In both Thighrim and Calf-Life, the physical action of pedaling is used to enable avatar movement. Both of the original games use the first person convention for dual analog controllers in which one joystick moves the player’s camera and another moves their avatar. This allows players to look forward while moving sideways or backwards, or to look behind them as they run forward. In our custom cycling-based exergames, pedaling simply moves the avatar in its current direction, whereas in our converted games, the player must both pedal and use a joystick to specify
the direction of movement. Typically in custom cycling-based exergames, avatar movement speed is based on the speed of pedaling; however, off-the-shelf shooter and role-playing games typically support only one or two movement speeds of walking, and sprinting. Therefore in Thighrim and Calf-Life, a pedaling cadence threshold is used to enable movement. If the player pedals faster than the threshold, the avatar moves at a constant speed.

As we shall see, both of these decisions impact the effectiveness of the games as exergames. More involved conversions, as would be possible with source code-level conversions, could allow the exergames to adopt control schemes closer to those used in custom exergames.

4.1.4 Enhanced Conversion: Heart Rate Power-ups

Based on the applicability guidelines identified during the previous study of the Liberi games, we hypothesized that Heart Rate Power-ups would indeed be suitable in these off-the-shelf games, and would incent higher exertion levels than the black box conversions. The results of our study were consistent with this hypothesis and will be discussed in more detail in section 4.3.

During play of Calf-Life and Thighrim the player is provided with both visual and audio cues that indicate when they are approaching or have attained their target heart rate. Figure 4-2 and Error! Reference source not found. demonstrate visual feedback provided in each game. Both of the games chosen for conversion have a range of activities present. Power-ups were designed to motivate players during all game activities, not just specific ones such as high action combat. We will now describe in more detail the converted games and the Heart Rate Power-ups present in each.

4.1.4.1 Thighrim

When the power-up is active in Thighrim, players’ attacks are 50% more effective, and take less time, and player health regenerates faster. Additionally, the power-up allows players to activate sprinting (by pressing a button on the controller) without draining their stamina resource. Attack and health related benefits are intended to incent players during combat by increasing their
power to fight against enemies. Allowing sprinting without depleting stamina can reduce the tedium of travelling long distances between cities. The stamina benefit of the power-up is intended to incent players to reach their target heart rate even in low action periods. To ensure that players understand when the power-up is active, we added visual feedback: on activation, there is a bright flash followed by a tornado effect surrounding the players’ weapons. The bright flash is accompanied by a loud thunder sound. When the power-up is deactivated, the swirling effect disappears. Additionally, the heart rate overlay from the power-up manager signals how close players are to their target heart rate. Figure 4-2 shows the player’s display with and without the power-up.

4.1.4.2 Calf-Life

When the power-up is active in Calf-Life, players may sprint without using auxiliary suit power, players’ health regenerates over time, and players’ ammunition is unlimited. Similarly to Thighrim, the benefits are designed to increase players’ effectiveness in combat, and reduce the cost of travelling. On activation, a visual cue in the form of a swirl of blue particles around the player indicates the activation of the power-up. As long as power-up is active, a border overlay is

Figure 4-2. Image of Skyrim gameplay. The right image shows player feedback when the Heart Rate Power-up is active. Note the heart indicator and whirlwind effect over the weapon.
visible, and text mimicking the games’ heads-up display shows “Power-up Active”. Again, the heart rate overlay from the power-up manager signals how close players are to their target heart rate. Figure 4-3 shows Calf-Life when the power-up is (bottom) and is not (top) active.

It was important for each game’s power-up to be sufficiently rewarding for players to strive for them, but not so powerful that they trivialized game play. In order to attain this balance, several rounds of playtesting and adjustment were necessary.

Figure 4-3. Image of Half-Life 2 gameplay. The bottom image shows the visual feedback when the player has the power up. Note the heart rate indicator, the blue border and the text at the bottom of the screen.
4.2 Evaluation

We performed a study to address the following three questions: (1) Does mapping avatar movement to pedaling, as is done in black box conversions, solicit sufficient activity from the player? (2) How effective is the inclusion of Heart Rate Power-ups in encouraging players to raise their exertion in converted games? (3) How well do the mechanics and play styles of typical off-the-shelf games lend themselves to conversion into exergames?

We recruited participants to play The Elder Scrolls V: Skyrim, Half-Life 2, and the two exergame conversions using the black box and Heart Rate Power-up approaches. Participants attended two one-hour sessions, each scheduled on different days. During each session, we measured participants’ energy expenditure and player experience, and followed up with a semi-structured interview. As we shall see, core results revealed that black box conversions of both games required low levels of exertion to play, and Heart Rate Power-up versions required higher exertion levels. Neither version was a suitable substitute for traditional physical exercise. However, the Heart Rate Power-up version met requirements for anti-sedentary activity. Both games had design elements that made it difficult for players to attain high levels of exertion, indicating that to attain exercise levels as set by the ACSM, custom-designed exergames may be necessary.

4.2.1 Participants

The target users of converted off-the-shelf games are people who enjoy videogames but do not perform recommended levels of exercise on a weekly basis. As such, we recruited 18 participants between the ages of 18 and 35 who had played first-person games for at least 100 hours using an analog game controller. In addition, we required that the participants be involved in less than one hour of vigorous intensity exercise per week, yet were confident that they could cycle at a moderate pace for 25 minutes. We administered the PAR-Q [20] to ensure that it was safe for each participant to perform exercise. In a demographic questionnaire, 16 of 18 said they currently play video games, at an average of two hours weekly. Eight of the 18 participants were familiar
with Half-Life 2, having played it previously, and 11 of the 18 had played The Elder Scrolls V: Skyrim. Of the 18 participants, five were female and 13 were male.

4.2.2 Setup and Apparatus

As shown in Figure 4-4 players used a Vision R10 recumbent bicycle. A cadence sensor was used to transmit cadence information to the game in real time. Participants wore a Garmin Premium heart rate monitor to provide real time heart rate information to the game. Additionally, players used a Logitech game controller to control the game. The games were displayed on a 55” display positioned in front of the bike.

4.2.3 Conditions

We tested three conditions of each game. The control condition was the unmodified game played while sitting on the couch. The pedaling condition was the black box conversion, played on the recumbent bicycle. Participants pedaled to enable avatar movement and used a game controller to perform all other game input. The power-up condition was the extended pedaling condition including the Heart Rate Power-ups. The power-up implemented in each game is described above.

In all three conditions, a screen overlay provided a visual representation of players’ heart rates. As seen in Figure 4-1, players’ heart rate is represented by the size of a heart image. The

Figure 4-4 Left image shows the play setup for Thighrim and Calf-Life gameplay. The right image shows the games from the player’s perspective.
image size is a percentage of an outlined heart that represents their target heart rate. As players’ heart rates increase, the image grows until the player reaches their target heart rate, at which point the outline is full. As players’ heart rate decreases the image size decreases proportionally.

In order to fight the effect of players becoming uninterested in playing the same section of game three times (once per condition), we identified three segments of similar gameplay. The order in which participants played the conditions was decided based on a Latin square. The game segment matched to each a condition was rotated. Pilot testing with four participants ensured that each game segment was of similar length and difficulty. Half of the participants played The Elder Scrolls V: Skyrim on their first day’s session and Half-Life 2 during the second session, and half played in the other order.

4.2.4 Measures

During each second of gameplay, the player’s heart rate and cadence and the state of the power-up were logged to a file on the testing computer. A custom log analysis tool was used to calculate players’ average percentages of heart rate reserve. Participants’ maximum heart rates were calculated by inserting participants’ ages into the mathematical formula:

\[ HR_{\text{max}} = 206.9 - (0.67 \times \text{age}) \]  

Target heart rate was calculated by inserting players’ maximum and resting heart rates into the Karvonen formula:

\[ HR_{\text{Target}} = \left( (HR_{\text{Max}} - HR_{\text{Resting}}) \times \%_{\text{Intensity}} \right) + HR_{\text{Resting}} \]

We chose a target heart rate based on the guidelines of the ACSM [5]. We piloted the games with a target heart rate reserve of 60%, but players found that intensity difficult to maintain while concentrating on playing the game. With this feedback, we chose the target range to be moderate intensity at 40-59% of heart rate reserve to prevent players from becoming frustrated and having a bad experience in the case they were unable to obtain the power-up. After the first combat section in each gameplay scenario, we showed players the Borg rate of perceived exertion scale
and asked them to rate their exertion from 6–20. The Borg rate of perceived exertion scale is commonly used as a tool to evaluate a person’s perceived exertion during exercise. We chose to include this scale because we were interested whether players perceived a difference in their exertion between the pedaling and power-up condition. After playing each game segment, players completed the IMI questionnaire to gauge their game experience [73]. At the end of the second session, we performed a semi-structured interview regarding the players’ experience with the game conversions.

### 4.2.5 Procedure

Before beginning the first day’s session, participants filled out a consent form, demographic questionnaires regarding their physical activity levels and video game usage, and the PAR-Q to ensure players could safely participate in exercise. At the beginning of the first day’s session, participants performed three-minutes of light cycling that served as a warm up and allowed participants to find a comfortable cycling resistance. At the beginning of the second session, participants cycled for three minutes at the resistance chosen during the previous session as a warm up. Each session, before participants began any of the conditions we allowed them to play the games while cycling until they felt comfortable with the controls to minimize any learning effect that may accompany playing a new game or an old game with the addition of pedaling.

In each hour-long session, participants played three segments of the game each under a different condition. The control, pedaling and power-up conditions were played for seven minutes each with a five-minute rest between conditions to reduce crossover of heart rate levels from the preceding condition. The first two minutes of data from each game was considered to be acclimatization time, and was not included in the analysis. This left five minutes of data for analysis. Following each condition, participants completed the IMI questionnaire. At the end of the second session participants participated in a semi-structured interview that pertained to their experiences with the converted games.
4.3 Results

We first report participants’ exertion levels and perceived exertion for each condition and then present participant responses to each section of the IMI. In the following section, we interpret these results with respect to our three research questions.

4.3.1 Exertion

Figure 4-5 shows participants’ average percentage of heart rate reserve for the three conditions. Participants’ exertion was highest in the Heart Rate Power-up condition and lowest in the control condition for both games. A 3x2 within-subjects ANOVA revealed a significant effect of condition (Control, Pedaling, and Power-up) on average percentage of heart rate reserve, F(2,34)=87.0, p<0.001. Post-hoc tests using Bonferroni correction revealed that players’ average percentage of heart rate reserve was higher in the pedaling condition (M=26.3, SD=2.7), p<.001 and power-up condition (M=35.5, SD=2.5), p<.001, versus the control (M=8.0, SD=1.4), and the power-up condition was higher than the pedaling condition (p<.001). A within-subjects ANOVA

![Bar chart showing participants' average percentage of heart rate reserve](image)

**Figure 4-5.** Participants' average percentage of heart rate reserve while playing Half-Life 2 and Skyrim. Vertical bars show standard deviation. Horizontal lines indicate statistical significance.
also showed an effect of game (Half-Life 2 and The Elder Scrolls V: Skyrim) on average heart rate reserve, F(1,17)=7.7, p=.013. Players had a higher average percentage of heart rate reserve in The Elder Scrolls V: Skyrim (M=24.9, SD=2.1) than in Half-Life 2 (M=21.5, SD=2.1), p=.013.

The interaction between the game and the condition was significant F(2,34)=3.3, p=.048. During the Heart Rate Power-up condition, there was a significant difference in player exertion between The Elder Scrolls V: Skyrim and Half-Life 2. The investigation consisted of performing three paired t-tests on participants’ average percentage of heart rate reserve between the two games for each condition. There was no significant difference between the average percentage of heart rate reserve in the Half-Life 2 control condition (M=6.7, SD=5.2) and The Elder Scrolls V: Skyrim control condition (M=9.2, SD=7.9), t(17)=1.8, p=.09. There was no significant difference between participants’ average percentage of heart rate reserve in the pedaling condition of Half-Life 2 (M=25.3, SD=11.9) and the pedaling condition of The Elder Scrolls V: Skyrim (M=27.3, SD=12.2) t(17)=1.3, p=.23. There was a significant difference in participants’ average percentage of heart rate reserve between the power-up condition of Half-Life 2 (M=32.6, SD=11.0) and the power-up condition of The Elder Scrolls V: Skyrim (M=38.3, SD=10.8), t(17)=3.6, p=.002. Cohen’s d=0.52 indicates a medium effect.

Our analysis of players’ rates of perceived exertion revealed that in both games, participants were aware of their changes in exertion between each condition. Players mean rates of perceived exertion can be seen in Table 4-1. A one-way repeated measures ANOVA was conducted on the rate of perceived exertion responses collected during the three conditions of both Skyrim and Half-Life 2. The ANOVA performed on the Skyrim data indicates significant difference between players perceived exertion over the three conditions, F(2,16)=111.6, (p<.001). The ANOVA performed on participants’ rate of perceived exertion in Half-Life 2 also indicated a
significant difference over the three conditions $F(2,16)=70.9, p <.001$. The results of post-hoc tests using Bonferroni correction revealed significant differences of players’ perceived exertion between all conditions, seen in Table 4-2.

### 4.3.2 Player Experience

During the interviews, we asked players to rank the conditions from their favorite to least favorite for both games. For The Elder Scrolls V: Skyrim, 12 of 18 participants ranked the pedaling condition as their least favorite, while 14 of 18 ranked the power-up condition as their favorite. The results are similar for Half-Life 2, with 11 of 18 ranking the pedaling condition as their least favorite and 14 of 18 ranking the power-up condition as their favorite.

### Table 4-1. Participants’ mean rates of perceived exertion (M) and the standard deviation (SD) of the responses.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Pedaling</th>
<th>Power-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Half-Life 2</td>
<td>M = 6.8</td>
<td>M = 11.5</td>
<td>M = 13.8</td>
</tr>
<tr>
<td></td>
<td>SD = 1.4</td>
<td>SD 2.1</td>
<td>SD = 2.6</td>
</tr>
<tr>
<td>The Elder Scrolls V: Skyrim</td>
<td>M = 7.0</td>
<td>M = 11.6</td>
<td>M = 13.9</td>
</tr>
<tr>
<td></td>
<td>SD = 1.4</td>
<td>SD 1.8</td>
<td>SD = 2.0</td>
</tr>
</tbody>
</table>

### Table 4-2. Results of the post-hoc t-tests on players’ rates of perceived exertion responses. All tests saw significant differences and all effect sizes are large.

<table>
<thead>
<tr>
<th></th>
<th>Control vs. Pedaling</th>
<th>Control vs. Power-up</th>
<th>Pedaling vs. Power-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Half-Life 2</td>
<td>$p &lt;.001$</td>
<td>$p &lt; .001$</td>
<td>$p &lt;.001$</td>
</tr>
<tr>
<td></td>
<td>$d = 2.6$</td>
<td>$d = 3.4$</td>
<td>$d = 1.0$</td>
</tr>
<tr>
<td>The Elder Scrolls V: Skyrim</td>
<td>$p &lt; .001$</td>
<td>$p &lt; .001$</td>
<td>$p = .002$</td>
</tr>
<tr>
<td></td>
<td>$d = 2.9$</td>
<td>$d = 4.0$</td>
<td>$d = 1.2$</td>
</tr>
</tbody>
</table>
A one-way within subjects ANOVA was completed on each section of the IMI used to evaluate the effect of condition on player’s experience. Participants’ average scores on each subscale can be seen in Table 4-3.

4.3.2.1 Competence

No significance was found for the competence subscale scores of the IMI for Half-Life 2, $F(2,16)=.14$, $p=.87$ or for The Elder Scrolls V: Skyrim, $F(2,16)=.4$, $p=.70$.

4.3.2.2 Importance

A significant effect was found for the importance subscale scores for Half-Life 2, $F(2,16)=7.61$, $p=.005$. Post-hoc tests using Bonferroni correction indicate an increase in players’

<table>
<thead>
<tr>
<th>Subscale</th>
<th>Control Condition</th>
<th>Pedaling Condition</th>
<th>Power up Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest/Enjoyment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Half-Life 2</td>
<td>5.38</td>
<td>5.55</td>
<td>5.63</td>
</tr>
<tr>
<td>Skyrim</td>
<td>5.17</td>
<td>5.33</td>
<td>5.52</td>
</tr>
<tr>
<td>Perceived Competence</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Half-Life 2</td>
<td>4.14</td>
<td>4.21</td>
<td>4.19</td>
</tr>
<tr>
<td>Skyrim</td>
<td>4.62</td>
<td>4.68</td>
<td>4.80</td>
</tr>
<tr>
<td>Effort/Importance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Half-Life 2</td>
<td>4.21*†</td>
<td>5.04*</td>
<td>5.29†</td>
</tr>
<tr>
<td>Skyrim</td>
<td>3.66*†</td>
<td>4.64*</td>
<td>5.07†</td>
</tr>
<tr>
<td>Pressure/Tension</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Half-Life 2</td>
<td>2.30*</td>
<td>2.68</td>
<td>3.24*</td>
</tr>
<tr>
<td>Skyrim</td>
<td>2.03</td>
<td>2.50</td>
<td>2.51</td>
</tr>
</tbody>
</table>

Table 4-3 Average IMI subscale scores. Values in a row sharing a * or † symbol are significantly different ($\alpha=.05$).

71
importance score between the control (M=4.2, SD=1.0) and pedaling conditions (M=5.0, SD=1.1),
p=.013, with a large effect size (d=0.9). There is also a statistically significant increase in players’
score from the control condition (M=4.2, SD=1.0) to the power-up condition (M=5.3, SD=1.0),
p=.003 with a large effect size (d=1.1). There is no statistically significant difference between the
pedaling and power-up conditions, p=.67.

A one-way within-subjects ANOVA for the importance subscale scores of the IMI during
The Elder Scrolls V: Skyrim indicates a significant effect, F(2,16)=16.8, p<.001. Post-hoc tests
using the Bonferroni correction indicate there is a statistically significant increase in players
importance subscale score between the control condition (M=3.7, SD=1.1) and the pedaling
condition (M=4.7, SD=1.0) in The Elder Scrolls V: Skyrim, p=.003, with a large effect (d=0.9). There
was also a statistically significant increase in players’ importance subscale scores from the
control condition to the power-up condition (M=5.1, SD=1.0), t(17)=5.9, p<.001, with a large effect
(d=1.3). There was no statistically significant difference of the importance subscale scores between
the pedaling and power-up conditions for The Elder Scrolls V: Skyrim, p=.11.

4.3.2.3 Interest

A one-way within-subjects ANOVA over the interest subscale scores for the Half-Life 2
session showed no statistically significant effect, F(2,16)=.95, p=.41. Similarly, a one-way within-
subjects ANOVA for the interest subscale scores for the The Elder Scrolls V: Skyrim session
showed no statistically significant effect, F(2,16)=2.2, p=.14.

4.3.2.4 Tension

A one-way within-subjects ANOVA scores for the pressure/tension subscale during the
Half-Life 2 session indicated a statistically significant effect, F(2,16)=8.8, p =.003. Post-hoc tests
using the Bonferroni correction indicate there is a statistically significant increase in players
pressure and tension scores from the control condition (M=2.3, SD=.8) to the power-up condition
(M=3.2, SD=1.2), p=.004, with a large effect (d=0.9). There was no statistically significant increase
in pressure and tension subscale scores from control condition (M=2.3, SD=.8) to pedaling condition (M=2.7, SD=1.1) p=.223, nor from the pedaling condition (M=2.7, SD=1.1) to power-up condition (M=3.2, SD=1.2), p=.28. A one-way within subjects ANOVA for pressure/tension subscale scores during the The Elder Scrolls V: Skyrim session showed no statistically significant effect, F(2,16)=1.59, p=.24.

4.4 Analysis and Discussion

Our results provide promising insight into the prospect of converting off-the-shelf games into exergames. One concern regarding converting off-the-shelf games into exergames is that the exertion required may negatively affect player enjoyment. The players’ increase in their rate of perceived exertion (Table 4-2) and the IMI subscale scores (Table 4-3) for effort and importance indicates that they were aware of their increased exertion in the mods. Despite their awareness, players’ level of enjoyment saw no negative effects. The interest and enjoyment subscale scores did not see a statistically significant difference. Participant feedback during the interviews was generally positive. Participant 18 stated “I think it’s really cool to be honest, if they did have these exercise games available, I think it’d be pretty popular.”

We will now discuss the results above in terms of our three questions.

4.4.1 Q1: Do black box conversions solicit adequate activity from the player?

Although players’ average percentage of heart rate reserve increased with the addition of pedaling, the average exertion levels recorded for the pedaling condition of both Calf-Life and Thighrim failed to meet the lowest ACSM recommendations for cardio-respiratory exercise. The average exertion for the pedaling condition of Calf-Life was 25% of heart rate reserve and for Thighrim it was 27% of heart rate reserve; both are substantially lower than the recommended 40% of heart rate reserve. The low exertion levels we experienced does not seem to be a result of the chosen exercise but rather something inherent to the game. We will expand on this in section 4.2.3
4.4.2 Q2: How well does the addition of Heart Rate Power-ups work to increase players’ exertion?

Players’ exertion levels increase in the Heart Rate Power-up condition when compared to the pedaling condition. In the power-up condition the average percentage of heart rate reserve was 32.6% for Calf-Life and 38.3% for Thighrim, close to but still below the minimum recommendation of 40% of heart rate reserve. We found that players’ percentage of heart rate reserve increased by 7 points during Calf-Life and 11 points in Thighrim with the presence of Heart Rate Power-ups. This increase is in line with the 6 – 11 point increase we saw when we added Heart Rate Power-ups to Dozo Quest, Biri Brawl, Gekku Race. However, the base exertion level for the converted games with pedaling was lower than the Liberi exergames and as a result, the increase is still not enough to encourage the recommended levels of exertion.

However, the exertion levels seen in this study indicate the exergame conversions of off-the-shelf games are suitable as an anti-sedentary activity and show promise as a replacement for exercise. Converting off-the-shelf games to exergames allows people who enjoy playing video games the opportunity to avoid a sedentary lifestyle while participating in an activity they enjoy. Some of the benefits of spending less time being sedentary for children aged five to 17 are listed by the Canadian Society for Exercise Physiology as maintaining a healthy body weight, doing better in school, and improved self-confidence [70]. If off-the-shelf games are to be converted to exergames that can be used as a substitute for traditional cardio-respiratory exercise, more work is required to incent and permit higher levels of exertion.

During the interview, players indicated that the pedaling condition was the overall least favorite, with power-up condition being the most favored. When questioned about why they ranked the games in this order, participant 3 stated “Because I found the pedaling distracting, but when I got a power-up from it, it was worth it.” Participant 13 explained the pedaling condition was their least favorite by stating “I felt like I was pedaling for like no reason”. The same participant claimed they liked the power-up condition because “I felt like I actually put some effort in”. These
participants valued the pedaling aspect when it led to a gameplay reward, but otherwise found it to be a chore. The addition of Heart Rate Power-ups was valuable not only as a tool for increasing exertion but also as a tool for improving players’ perceptions of adding exercise to off-the-shelf games.

4.4.3 Q3: How well do the mechanics and play styles of off-the-shelf games lend themselves to conversion of exergames?

As we have seen, our converted exergames failed to motivate levels of exertion meeting the ACSM guidelines for cardiorespiratory exercise. These results contrast with our earlier research that showed using Heart Rate Power-ups can motivate players to achieve an average heart rate reserve of 60%.

These results hint that some design aspects of off-the-shelf games may conflict with the requirements of exergames. Existing guidelines for the design of exergames will not have been followed during the design of off-the-shelf games such as The Elder Scrolls V: Skyrim and Half-Life 2. As described in section 2.4, Mueller et al. recommend consideration of movement’s cognitive load [59], a guideline which would not have been relevant to the design of a game intended for play using a keyboard or game controller. The results together with interview comments provide hints of where the design of off-the-shelf games may conflict with exercise. We describe below the suspected conflicts, which are the control scheme and the pacing of in game activities.

4.4.3.1 Control Scheme

Thigrim and Calf-Life both use a movement control scheme based on pedaling and the use of dual analog joysticks. The avatar moves in the direction specified by the left analog stick only while the player pedals. Since the games support only the two movement speeds of walking and sprinting, pedaling faster does not cause the avatar to move faster. For some players, this created a disconnection between pedaling and avatar movement. For example, some players
continued to pedal even when their players were not moving. Participant 6 described their approach to playing: “pedaling to me was the least important thing so I just, you keep pedaling at a constant rate regardless of what you were doing and then you play the game.” Perhaps if the pedaling were tied to avatar movement speed this would be a big enough benefit to pedaling that players would place more value on the exercise component. Other players forgot to pedal when they wanted to move their avatar after they had stopped. Participant 15 admitted that in Calf-Life, “I was more engaged [causing me to] forget sometimes to pedal.” Thus, the fact that role-playing and first-person shooter games such as The Elder Scrolls V: Skyrim and Half-Life 2 support only one speed of movement and require a joystick to specify direction of movement weakens the natural mapping of pedaling to avatar movement found in pedaling-based exergames.

The two games differ during combat. In The Elder Scrolls V: Skyrim/Thighrim, players were provided with a melee weapon and a spell. In Half-Life 2/Calf-Life, they were able to choose between different guns and a crowbar. To aim in The Elder Scrolls V: Skyrim, players need to turn the character’s body roughly in the direction of the target, while in Half-Life 2, precise aiming with a targeting reticle is required. This may have contributed to the significant difference we saw for the pressure and tension subscale scores of the Half-Life 2 game between the Power-up and Control condition (Table 4-3). Participant 2 noted a difference in their ability to raise their heart rate in Calf-Life saying, “I think in Skyrim, because it wasn’t as hard as Half Life 2, I ... reached that heart rate and just kind of coasted along but in Half Life I was like struggling”. Participant 6 described how the addition of pedaling affected their ability to aim: “It was harder to move into certain positions so I could aim. A lot of times when I aim it's not just with the aiming reticle it's also the movement along with the aiming reticle.” Participant 16 described how the addition of pedaling affected their gameplay: “it was harder for me to play Half Life 2 because of like the aiming whereas in Skyrim you like don't have to aim.” It is unclear whether participants’ difficulty with aiming and pedaling simultaneously stems from the physical challenge of trying to make fine
movements with the analog stick while pedaling, or from trying to split their focus between pedaling and aiming. One possible tactic for future conversions of off-the-shelf games that require aiming would be to implement aim assistance to reduce the difficulty of aiming while pedaling, for example using algorithms suggested by Vicencio-Moreira et al. [88]. Perhaps reducing the precision required to aim would decrease the level of focus that is required from players.

4.4.3.2 Pacing and In Game Activities

We intentionally chose fast-paced games because we hoped the fast pace in the game would encourage rapid pedaling. Interestingly, for some participants, the pace of the game may have had the opposite effect. Participant 18 indicated that the faster pace distracted from pedaling stating that in “...Half Life 2 because it's more fast-paced you don’t get to think of the pedaling as much.”

One reason the slower-paced The Elder Scrolls V: Skyrim may allow for higher exertion levels is that the cognitive load for players might be lower. Half-Life 2 has environmental puzzles, which are not present in The Elder Scrolls V: Skyrim. For example, one section of game play in Half-Life 2 leads players to a closed gate. Players are required to assess the environment and realize that a flammable barrel is located below a beam that if knocked over will cause the gate to open. Players must shoot the barrel to trigger the events that will open the gate. Participant 6 noted that splitting their concentration between tasks in Half-Life 2 was a problem: “it’s hard to concentrate on pedaling and moving and the game.”

Both games include slow-paced activities such as looting, moving between areas and cut scenes. These activities are more prevalent in The Elder Scrolls V: Skyrim and one participant indicated that this allowed them the chance to focus on their pedaling. “Skyrim made me pedal faster because it had more walking in the game, like I had to go through the map and the area and search for stuff within this game.” The difference in pace and cognitive load may have contributed to the higher percentage of heart rate reserve seen in the power-up condition of The Elder Scrolls V: Skyrim. By using the modding interface of a game, a developer could lower the required
cognitive load either by providing more tasks that require less cognitive load, such as looting, or by adding assistance for cognitively demanding tasks. For example, the developer could add signifiers to indicate what a player should do next rather than requiring them to assess each situation. In the scenario that requires players to realize they must shoot the barrel to open the gate the designer could make barrel glow or flash as a hint to players they will need to interact with these objects. Interesting future work will be to assess whether the presence of such assistance affects players’ exertion levels.

Over all, our study has revealed that the off-the-shelf games Half-Life 2 and The Elder Scrolls V: Skyrim are not designed in a way that is conducive to high exertion exergaming despite being chosen as promising candidates. The simple black box conversion elicits low exertion levels because the design of the games did not incent exertion. Heart Rate Power-ups improved the level of exertion in players by providing incentives in game for exertion but was not enough to reach recommended exertion levels for exercise. More work is required to discover how off-the-shelf games can be converted in a way that raises the exertion to a level higher than anti-sedentary levels.

In this chapter we have begun an investigation into the suitability of off-the-shelf games as high exertion exergames. To gain insight, we performed a two-step exergame conversion on: The Elder Scrolls V: Skyrim and Half-Life 2. We evaluated players’ exertion levels while they played an exergame conversion in which pedaling moves their avatar similar to existing techniques and during a power-up conversion in which players received in game rewards for reaching target heart rate levels. We found that adding pedaling to enable avatar movement does increase exertion above rest, and that the addition of Heart Rate Power-ups increases exertion higher still. However, none of the average exertion levels of players during the different conditions are satisfactory for exercise. The exertion levels are appropriate for anti-sedentary activity. Additionally, we have identified aspects of off-the-shelf games that may have inhibited players’ ability to reach high exertion during play. We conclude that conversions of off-the-shelf games are appropriate for anti-sedentary
activity but more work is required to find techniques that will motivate players of converted games to reach an exertion level that can be recommended for exercise.
Chapter 5

Conclusion

This thesis has introduced and described the Heart Rate Power-up as a generic tool that can be included in exergames to incent increased exertion during play. We investigated its effectiveness using three games of varying play-styles and differing typical exertion levels. We also explored converting off-the-shelf games into exergames using a game’s modding interface and how the inclusion of Heart Rate Power-ups in the converted game effects player exertion and experience.

In order to investigate the ability of Heart Rate Power-ups to encourage player exertion, we implemented them into three games that exhibited very different play styles. They were chosen deliberately in order to investigate the effectiveness of Heart Rate Power-ups across a variety of genres and hopefully to demonstrate its viability as a general tool for exergames. The three games that were selected were Dozo Quest, a platformer game, Biri Brawl, a fighting game, and Gekku Race, a racing game. We ran a user study to investigate if the addition of heart rate based power-ups successfully increased player exertion levels, and if so, how does the efficacy of Heart Rate Power-ups change with the game’s average exertion level. We also explored the questions of whether and how heart rate power-ups affected players’ enjoyment.

Our in depth analysis of the results from the user study reveal that with the addition of Heart Rate Power-ups players’ exertion levels increase when playing the games. The largest increase in players’ average percentage of heart rate reserve that we observed was from 44 to 55 percentage, seen in Dozo Quest. We also find that player exertion finds the greatest increase when the Heart Rate Power-up is applied to games of lower typical exertion. Players’ responses to the addition of Heart Rate Power-ups were generally positive, they found the games more fun when the power-ups were dependent on heart rate even though they found them more tiring.
In addition to presenting the study, we also included guidelines for those deciding whether Heart Rate Power-ups are a good candidate for their game. Through our experience with Heart Rate Power-ups we identified that their potential to increase player exertion is sensitive to three qualities of an exergame. Firstly, the game must ensure that players have the agency to increase their exertion without suffering from excessive deterioration to accuracy and finesse. Secondly, the movement controls should be conducive to the player reaching high exertion and there must be a gap between players’ current exertion levels during play and the exertion the motion controls can incent. To aid developers who wish to implement Heart Rate Power-ups we propose three design principles, they are: the effect of the power-up should be clear, the impact of the power-up should be balanced, and the player’s activity should be coupled to the power-up’s effect. Our exploration of Heart Rate Power-ups demonstrates that they have potential to increase player exertion and enjoyment when playing exergames. It has also provided us with a good understanding of how and when to apply Heart Rate Power-ups.

Moving forward from our first investigation, we began looking at the possibility of converting off-the-shelf games into exergames. Some of the more popular games are shipped with modding capabilities and interfaces which allow their players and fan base to customize and extend the game experience. We identified this tool as a potential new direction for the conversion of off-the-shelf games, which is to use an existing games modding interface to implement the conversion. With this in mind we selected two popular games, The Elder Scrolls V: Skyrim and Half Life 2, to convert into exergames. The level of exertion elicited by exergames that use the current conversion methods was unknown but we suspected it was would be poor. It was doubted that by merely adding an exercise component without modifying the game to inherently include any incentive for exertion would result in high player exertion. To address these concerns we added Heart Rate Power-ups to our conversions as a way to incentivize players.
We used our conversions in a study that compares player exertion and experience over three different conditions: the games without modification, a conversion that uses the existing black box approach, and a conversion that includes Heart Rate Power-ups. The purpose of the study was twofold: Firstly, to gain a deeper understanding of how well the current black box approach for converting off-the-shelf games works as a tool for exercise, and; Secondly, to explore a new approach for conversion and to evaluate whether Heart Rate Power-ups can successfully be applied to off-the-shelf games as an effective means to promote rigorous exercise in their players.

Our analysis of data from this study confirmed our suspicions that the existing conversion technique did not solicit high enough exertion to be considered adequate for exercise as recommended by the ACSM. The games modified to include the Heart Rate Power-up, resulted in an increase of players’ exertion and enjoyment compared to the black box conversion. Players’ percentage of heart rate reserve saw an 11 point increase between the two converted versions of Half-Life 2, which is in line with the increase seen in Dozo Quest. Players indicated that they not only enjoyed the games more when Heart Rate Power-ups were present but that they also valued the exercise component of the games more. The majority of the participants placed the converted version of the game with power-ups in higher favor than the other converted version and the original game, for both Half-Life2 and The Elder Scrolls V: Skyrim.

We also discovered the pace and mechanics of an off-the-shelf game can affect their play experience when converted to an exergame. In particular, we found that the attention required by a fast paced game with a complex control scheme coupled with a need for accuracy and precision seemed to distract participants from pedaling. Several participants commented that they had a hard time pedaling and performing well in combat at the same time. It is unclear whether it was the pedaling action that made aiming difficult or if it was the divided concentration across multiple tasks, but the result was that players report the need to pedal slower when the game was in states of intense action.
As a follow up investigation, it might be interesting to determine whether the cause of players needing to slow their pedaling was a result of cognitive overload or if the physical movements from pedaling make it difficult to use a controller. Moving forward we think an important and interesting area would be to find ways of addressing this cause. For example if the cause is cognitive overload than would the addition of aim assistance help to increase pedaling speed?

Additional future work would be to investigate more techniques for increasing exertion in exergames. Heart Rate Power-ups are effective at increasing exertion but are not universally applicable. Designers would benefit from having an array of techniques to choose from. Possible alternative techniques could build upon Monedero’s work, which augments the movements required to play Wii sports into ones that will increase a player’s exertion [54]. This concept could potentially be effective in other games.

Overall we conclude that Heart Rate Power-ups are a valuable tool for designers of exergames and that our exploration into converting off-the-shelf games is a positive step towards exergame conversions that provide exercise level exertion. In addition, our work has helped to provide guidelines for the design and applicability of Heart Rate Power-ups. Finally, we uncover important information regarding the suitability of games targeted for conversion and the exertion levels that should be aimed for during play.
References


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ACM, 2393–2398.


http://doi.org/10.2340/16501977-0816


Appendix A
Recruitment Notice

EXERCISE AND VIDEO GAMES TOGETHER!

You are invited to participate in an experiment being carried out at the EQUIS Laboratory, School of Computing, at Queen’s University, on effectively embedding exercise into computer games. Participation requires one hour of your time on two different days. You will play a video game while doing moderate to vigorous cycling. You will be compensated $10 for the first day, and $20 more for the second day.

Participants must:

• Be between the ages of 18 and 35
• Have experience playing video games using a gamepad
• Be capable of performing exercise on a stationary bicycle
• Have no physical conditions making it inadvisable to perform moderately vigorous exercise

Please contact Mallory Ketcheson by email at ketchesn@cs.queensu.ca or by phone at (613) 533-6000 ext. 79310.

Thanks for your attention! Enrolling participants until: August 1st 2014
Appendix B
Letter of Information

LETTER OF INFORMATION

Exercise Games and Encouraging Exertion: Can in game power-ups increase the quality of exercise?

You are invited to participate in a research project directed by Mallory Ketcheson and Nicholas Graham of Queen’s University. We will read through this letter of information with you, describe our experimental procedures in detail, and answer any questions you may have.

The study explores whether aspects of a game’s design affects the physical effort put forth by players of exercise videogames.

Participants enrolled in the study will play three exercise videogames using a computer-integrated recumbent stationary bike, a display and a Logitech gamepad controller. Participants will wear a heart rate monitor strapped around their chest. This monitor provides real-time heart rate information to the game. Liberi consists of a set of mini-games, connected by a central virtual world. Participants will be asked to perform sessions on two different days, for approximately an hour each day. Before beginning gameplay, the participant’s resting heart rate will be measured using the heart rate monitor strapped around their chest. Each day, participants will be asked to play three mini-games, each for a period of seven minutes. After playing each mini-game, participants will be given a break, during which they will fill out a short questionnaire about the game they just finished. Players will continue with the next game once a minimum of five minutes has elapsed and their heart rate has dropped to the low range of a warm-up heart rate (below 55% of maximum heart rate). On the second day, after playing the three mini-games, participants will be given a final 5-10 minute questionnaire and a brief interview. The total expected investment of time for both days is approximately two hours.

To ensure that participants are well suited for physical activity, the PAR-Q (Physical Activity Readiness Questionnaire) will be administered. As with any physical activity program, it is possible that physical discomfort may result, or that minor injuries such as a strained muscle may occur. If you experience any physical issues, you should stop the use of the exercise bike immediately.

An honorarium will be given to you as a token of appreciation for your time. An initial $10 honorarium will be provided for attending the first day and $20 will be given the second day. If you decide to withdraw from the study, you will receive the honorarium for the day you have attended.

With your consent, we will use quotations of you discussing your experience with the exercise game in publications, talks and promotions. All quotations will be anonymized – for example, your name will not be used. You may choose to withhold consent for such public use of your quotations. All information will be kept confidential, and data will be stored in a secured manner, in locked file cabinets or stored on password-protected computers inside the EQUIS Laboratory at Queen’s University. All data will be kept for five years following publication of the results. At that time, all written information and electronic data will be shredded and deleted. All results
produced will be from group data, and no individuals will be identified. Interviews will be recorded and transcribed; however, all names and identifying characteristics will be withdrawn from the transcripts. The transcripts will be coded and analyzed for common themes.

Participants may withdraw without any explanation or consequence at any time during the study.

This study has been granted clearance according to the recommended principles of Canadian ethics guidelines, and Queen's policies. However, the final decision about participation is yours. Any questions about study participation may be directed to Nicholas Graham (nicholas.graham@queensu.ca, 613-533-6526). Any ethical concerns about the study may be directed to the Chair of the General Research Ethics Board at chair.GREB@queensu.ca or 613-533-6081.

Please retain a copy of the letter of information and consent form.

__________________________________________

Name of participant
Appendix C
Consent Form

CONSENT FORM:

Exercise Games and Encouraging Exertion: Can in-game power-ups increase the quality of exercise?

I have read the letter of information describing this study being conducted by Mallory Ketcheson and Nicholas Graham of Queen’s University. I understand that I will be participating in a research project whose structure and procedures are described in the attached letter of information. I have had the opportunity to ask questions related to this study, and have received satisfactory answers to any questions.

I am aware that my participation is voluntary and that I may withdraw my study participation at any time without penalty by advising the researcher.

I understand that I may address any questions about study participation to Mallory Ketcheson (ketchesm@cs.queensu.ca, 613-770-6062), and that any ethical concerns about the study may be directed to the Chair of the General Research Ethics Board at chair.GREB@queensu.ca or 613-533-6081.

Please circle one Please initial your choice

I consent to the use of non-identifying quotations in publications, talks and promotions

YES NO ________

__________________________   __________________     __________
Participant Name          Signature         Date

Please retain a copy of the letter of information and consent form.
Appendix D

The Physical Activity Readiness Questionnaire for Everyone

CSEP approved Sept 12 2011 version

PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

Regular physical activity is fun and healthy, and more people should become more physically active every day of the week. Being more physically active is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor or a qualified exercise professional before becoming more physically active.

SECTION 1 - GENERAL HEALTH

Please read the 7 questions below carefully and answer each one honestly: check YES or NO.

<table>
<thead>
<tr>
<th>Question</th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Has your doctor ever said that you have a heart condition OR high blood pressure?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>2. Do you feel pain in your chest at rest, during your daily activities of living, OR when you do physical activity?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>3. Do you lose balance because of dizziness OR have you lost consciousness in the last 12 months? Please answer NO if your dizziness was associated with over-breathing (including during vigorous exercise).</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>4. Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>5. Are you currently taking prescribed medications for a chronic medical condition?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>6. Do you have a bone or joint problem that could be made worse by becoming more physically active? Please answer NO if you had a joint problem in the past, but it does not limit your current ability to be physically active. For example, knee, ankle, shoulder or other.</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>7. Has your doctor ever said that you should only do medically supervised physical activity?</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

If you answered NO to all of the questions above, you are cleared for physical activity.

Go to Section 3 to sign the form. You do not need to complete Section 2.

- Start becoming much more physically active – start slowly and build up gradually.
- Follow the Canadian Physical Activity Guidelines for your age (www.csep.ca/guidelines).
- You may take part in a health and fitness appraisal.
- If you have any further questions, contact a qualified exercise professional such as a CSEP Certified Exercise Physiologist® (CSEP-CEP) or CSEP Certified Personal Trainer® (CSEP-CPT).
- If you are over the age of 45 yrs. and NOT accustomed to regular vigorous physical activity, please consult a qualified exercise professional (CSEP-CEP) before engaging in maximal effort exercise.

If you answered YES to one or more of the questions above, please GO TO SECTION 2.

Delay becoming more active if:

- You are not feeling well because of a temporary illness such as a cold or fever – wait until you feel better.
- You are pregnant – talk to your health care practitioner; your physician, a qualified exercise professional, and/or complete the PARmed-X for Pregnancy before becoming more physically active OR
- Your health changes – please answer the questions on Section 2 of this document and/or talk to your doctor or qualified exercise professional (CSEP-CEP or CSEP-CPT) before continuing with any physical activity programme.
### SECTION 2 - CHRONIC MEDICAL CONDITIONS

Please read the questions below carefully and answer each one honestly: check YES or NO.

<table>
<thead>
<tr>
<th>Question</th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Do you have Arthritis, Osteoporosis, or Back Problems?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylothesis/pars defect (a crack in the bony ring on the back of the spinal column)?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. Have you had steroid injections or taken steroid tablets regularly for more than 3 months?</td>
<td></td>
<td></td>
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<tr>
<td>2. Do you have Cancer of any kind?</td>
<td></td>
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</tr>
<tr>
<td>a. Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma, cancer of plasma cells, head, and neck?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. Are you currently receiving cancer therapy (such as chemotherapy or radiotherapy)?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Do you have Heart Disease or Cardiovascular Disease? This includes Coronary Artery Disease, High Blood Pressure, Heart Failure, Diagnosed Abnormality of Heart Rhythm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. Do you have an irregular heart beat that requires medical management? (e.g., atrial brillation, premature ventricular contraction)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. Do you have chronic heart failure?</td>
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<td></td>
</tr>
<tr>
<td>d. Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer YES if you do not know your resting blood pressure)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>e. Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?</td>
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<td></td>
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<tr>
<td>4. Do you have any Metabolic Conditions? This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Is your blood sugar often above 13.0 mmol/L? (Answer YES if you are not sure)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, and the sensation in your toes and feet?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. Do you have other metabolic conditions (such as thyroid disorders, pregnancy-related diabetes, chronic kidney disease, liver problems)?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Do you have any Mental Health Problems or Learning Difficulties? This includes Alzheimer’s, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)</td>
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<td></td>
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<tr>
<td>b. Do you also have back problems affecting nerves or muscles?</td>
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<tr>
<td>Question</td>
<td>YES</td>
<td>NO</td>
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<td>-------------------------------------------------------------------------</td>
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</tr>
<tr>
<td><strong>6. Do you have a Respiratory Disease?</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary</td>
<td></td>
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</tr>
<tr>
<td>High Blood Pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6a. Do you have difficulty controlling your condition with medications</td>
<td></td>
<td></td>
</tr>
<tr>
<td>or other physician-prescribed therapies? (Answer NO if you are not</td>
<td></td>
<td></td>
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<tr>
<td>currently taking medications or other treatments)</td>
<td></td>
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<tr>
<td>6b. Has your doctor ever said your blood oxygen level is low at rest</td>
<td></td>
<td></td>
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<tr>
<td>or during exercise and/or that you require supplemental oxygen therapy?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6c. If asthmatic, do you currently have symptoms of chest tightness,</td>
<td></td>
<td></td>
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<tr>
<td>wheezing, laboured breathing, consistent cough (more than 2 days/week),</td>
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<tr>
<td>or have you used your rescue medication more than twice in the last</td>
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<tr>
<td>week?</td>
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<tr>
<td>6d. Has your doctor ever said you have high blood pressure in the</td>
<td></td>
<td></td>
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<tr>
<td>blood vessels of your lungs?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>**7. Do you have a Spinal Cord Injury? This includes Tetraplegia and</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paraplegia</td>
<td></td>
<td></td>
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<tr>
<td>7a. Do you have difficulty controlling your condition with medications</td>
<td></td>
<td></td>
</tr>
<tr>
<td>or other physician-prescribed therapies? (Answer NO if you are not</td>
<td></td>
<td></td>
</tr>
<tr>
<td>currently taking medications or other treatments)</td>
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<tr>
<td>7b. Do you commonly exhibit low resting blood pressure significant</td>
<td></td>
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<tr>
<td>enough to cause dizziness, light-headedness, and/or fainting?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7c. Has your physician indicated that you exhibit sudden bouts of high</td>
<td></td>
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<tr>
<td>blood pressure (known as Autonomic Dysreflexia)?</td>
<td></td>
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</tr>
<tr>
<td>**8. Have you had a Stroke? This includes Transient Ischemic Attack</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(TIA) or Cerebrovascular Event</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8a. Do you have difficulty controlling your condition with medications</td>
<td></td>
<td></td>
</tr>
<tr>
<td>or other physician-prescribed therapies? (Answer NO if you are not</td>
<td></td>
<td></td>
</tr>
<tr>
<td>currently taking medications or other treatments)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8b. Do you have any impairment in walking or mobility?</td>
<td></td>
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</tr>
<tr>
<td>8c. Have you experienced a stroke or impairment in nerves or muscles in</td>
<td></td>
<td></td>
</tr>
<tr>
<td>the past 6 months?</td>
<td></td>
<td></td>
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<tr>
<td>**9. Do you have any other medical condition not listed above or do you</td>
<td></td>
<td></td>
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<tr>
<td>live with two chronic conditions?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9a. Have you experienced a blackout, fainted, or lost consciousness as</td>
<td></td>
<td></td>
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<tr>
<td>a result of a head injury within the last 12 months OR have you had a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>diagnosed concussion within the last 12 months?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9b. Do you have a medical condition that is not listed (such as</td>
<td></td>
<td></td>
</tr>
<tr>
<td>epilepsy, neurological conditions, kidney problems)?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9c. Do you currently live with two chronic conditions?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Please proceed to Page 4 for recommendations for your current medical condition and sign this document.
PAR-Q+

If you answered NO to all of the follow-up questions about your medical condition, you are ready to become more physically active:

- It is advised that you consult a qualified exercise professional (e.g., a CSEP-CEP or CSEP-CPT) to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually – 20-60 min. of low- to moderate-intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate-intensity physical activity per week.
- If you are over the age of 45 yrs. and NOT accustomed to regular vigorous physical activity, please consult a qualified exercise professional (CSEP-CEP) before engaging in maximal effort exercise.

If you answered YES to one or more of the follow-up questions about your medical condition:

- You should seek further information from a licensed health care professional before becoming more physically active or engaging in a fitness appraisal and/or visit a qualified exercise professional (CSEP-CEP) for further information.

Delay becoming more active if:

- You are not feeling well because of a temporary illness such as a cold or fever – wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the PARmed-X for Pregnancy before becoming more physically active OR
- Your health changes – please talk to your doctor or qualified exercise professional (CSEP-CEP) before continuing with any physical activity programme.

SECTION 3 - DECLARATION

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The Canadian Society for Exercise Physiology, the PAR-Q+ Collaboration, and their agents assume no liability for persons who undertake activity. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.
- Please read and sign the declaration below:

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that a Trustee (such as my employer, community/fitness centre, health care provider, or other designated) may retain a copy of this form for their records. In these instances, the Trustee will be required to adhere to local, national, and international guidelines regarding the storage of personal health information ensuring that they maintain the privacy of the information and do not misuse or wrongfully disclose such information.

NAME ___________________________ DATE ___________________________

SIGNATURE ______________________ WITNESS _______________________

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER ______________________

For more information, please contact: Canadian Society for Exercise Physiology www.csep.ca

KEY REFERENCES

The PAR-Q+ was created using the evidence-based AGREE process (1) by the PAR-Q+Collaboration chaired by Dr. Darren E. R. Warburton with Dr. Norman Gladish, Dr. Veronica Jermik, and Dr. Donald C. McKenna (2). Production of this document has been made possible through financial contributions from the Public Health Agency of Canada and the BC Ministry of Health Services. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada or BC Ministry of Health Services.

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CSEP approved Sept 12 2011 version

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Appendix E
Initial Questionnaire

Questionnaires

Gaming History

Do you currently play video games?  
   Yes  No
   If yes, how many hours do you play each day? ______

Do you currently play computer games?  
   Yes  No
   If yes, how many hours do you play each day? ______

Physical Activity Levels

This part of the questionnaire addresses your own leisure time physical activity habits. How many times on average per week do you do physical activity and what is the duration of these activities?

When answering these questions please:
⇒ Note that the main difference between the three categories is the intensity of the physical activity.
⇒ Please write the average frequency on the first line and the average duration on the second line.

<table>
<thead>
<tr>
<th></th>
<th>Times Per Week</th>
<th>Average Duration Per Session (min)</th>
</tr>
</thead>
</table>
| STRENuous PHYSICAL ACTIVITY  
(Heart beats rapidly, sweating) 
  e.g. sports, running, jogging, hockey, squash, basketball, judo, vigorous swimming |                 |                                   |
| MODERate PHYSICAL ACTIVITY  
(Not exhausting, light perspiration)  
  e.g. baseball, tennis, bicycling, volleyball, badminton, easy swimming, alpine skiing, dancing, brisk walk |                 |                                   |
| MILD PHYSICAL ACTIVITY  
(Minimal effort, no perspiration)  
  e.g. tai chi, fishing, bowling, casual walk |                 |                                   |
## Appendix F
### Gameplay Questionnaires

After each of the three games that included power-ups.
Please rate how much you agree or disagree with each statement.

<table>
<thead>
<tr>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>This game was physically tiring</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trying to get the power-up motivated me to pedal harder</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I was good at achieving the game’s objectives</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>I paid attention to the heart rate indicator during the game</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I tried to reach and maintain my target heart rate during gameplay</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Using the power-up made it easier to complete the game’s objectives</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Playing this game was a vigorous workout</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>I consider this game to be fast paced</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

After each of the three games that do not include in game power-ups.
Please rate how much you agree or disagree with each statement.

<table>
<thead>
<tr>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>This game was physically tiring</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>I was good at achieving the game’s objectives</td>
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<tr>
<td>I was focused on the heart rate indicator during the game</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>I tried to reach and maintain my target heart rate during gameplay</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Playing this game was a vigorous workout</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I consider this game to be fast paced</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix G
Rate of Perceived Exertion Scale
Appendix H
Final Questionnaire

**Final Questionnaire**
Please rate how much you agree or disagree with each statement:

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>I was encouraged to pedal harder during the games when power-ups were available.</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>I did better at the games when the power-ups were available.</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>I did not have to pedal as hard to do well in the games when the power-up was available.</td>
<td></td>
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<tr>
<td>The games were more fun when the power-ups were available.</td>
<td></td>
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<tr>
<td>Pedaling hard is more rewarding when the power-ups are available.</td>
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</tr>
</tbody>
</table>
Appendix I

Interview Questions

Interview Questions:

1. Did you notice a difference in how physically tiring the games were with power-ups versus without them?
   If yes:
   Was it more or less tiring with power-ups? Why do you think that?

2. Do you think that in some games the power-ups had more of an effect on how quickly you pedaled?
   If yes:
   Which ones and why do you think that is?

3. Were there any power-ups you felt were not helpful at encouraging you to reach and maintain your target heart rate?
   If yes:
   Which one(s) and Why?

4. Were there any games you thought were ineffective at encouraging you to reach and maintain your target heart rate?
   If yes:
   Which one(s) and why?

5. Did you find the power-ups made any of the games more fun?

6. Did the addition of power-ups to the game affect your strategies in any way?

7. Did the power-ups remind you of the need to pedal quickly?

8. Were there ever cases where the availability of the power-ups were demotivating or made you feel like giving up?

9. Were there ever cases where the power-ups seemed very difficult to achieve?

10. Do you have any other observations or thoughts we didn’t ask you about?
Appendix J
Debriefing Letter

Debriefing Letter
Exercise Games and Encouraging Exertion: Can in game power-ups increase the quality of exercise?

Thank you very much for participating in this study. Now that you have completed the study, the experimenter will answer any questions you have about it.

During the past two sessions, you played three mini-games using a game bike and heart rate monitor. Each of the games you played varied in pace. As you experienced, on one of the days you played, power-ups were awarded based on your heart rate and on the other day they were not. Ontario’s ministry of health and long-term care describes a person’s target heart rate as “The optimum heart rate at which you should train in order to get an effective workout”. The power-ups were awarded for reaching and maintaining your target heart rate.

One of the questions we were exploring with this study is whether awarding power-ups based on a player’s exertion, as measured by heart rate, will affect the effort levels of players during exercise games. We hypothesize that the power-ups will encourage people to be more conscious of their exertion level and strive to reach their target heart rate and that this effect will be more noticeable in slower paced games. These results will allow us to develop effective and novel interventions for exercise games that we hope will help Canadians meet and adhere to the national physical activity guidelines. Physical exercise has proven to significantly reduce the risk of developing cancer.

We expect to publish the results of our study in journals and conferences in the future.

We thank you once again for participating in this study. If you have any further questions, please contact Mallory Ketcheson (ketchesm@cs.queensu.ca) or Nicholas Graham (nicholas.graham@queensu.ca, 613-533-6526). If you have ethical concerns about the study please contact the Chair of the General Research Ethics Board at chair.GREB@queensu.ca or 613-533-6081.
Appendix K

General Research Ethics Board Approval

June 10, 2014

Ms. Mallory Ketcheson
Master's Student
School of Computing
Queen's University
Kingston, ON, K7L 3N6

GREB Ref #: GCISC-075-14; Romeo #: 6012957
Title: "GCISC-075-14 Exercise Games and Encouraging Exertion: Can in game power-ups increase the quality of exercise?"

Dear Ms. Ketcheson:

The General Research Ethics Board (GREB), by means of a delegated board review, has cleared your proposal entitled "GCISC-075-14 Exercise Games and Encouraging Exertion: Can in game power-ups increase the quality of exercise?" for ethical compliance with the Tri-Council Guidelines (TCPS) and Queen's ethics policies. In accordance with the Tri-Council Guidelines (article D.1.6) and Senate Terms of Reference (article G), your project has been cleared for one year. At the end of each year, the GREB will ask if your project has been completed and if not, what changes have occurred or will occur in the next year.

You are reminded of your obligation to advise the GREB, with a copy to your unit REB, of any adverse event(s) that occur during this one year period (access this form at https://eservices.queensu.ca/romeo_researcher/ and click Events - GREB Adverse Event Report). An adverse event includes, but is not limited to, a complaint, a change or unexpected event that alters the level of risk for the researcher or participants or situation that requires a substantial change in approach to a participant(s). You are also advised that all adverse events must be reported to the GREB within 48 hours.

You are also reminded that all changes that might affect human participants must be cleared by the GREB. For example you must report changes to the level of risk, applicant characteristics, and implementation of new procedures. To make an amendment, access the application at https://eservices.queensu.ca/romeo_researcher/ and click Events - GREB Amendment to Approved Study Form. These changes will automatically be sent to the Ethics Coordinator, Gail Irving, at the Office of Research Services or sriagg@queensu.ca for further review and clearance by the GREB or GREB Chair.

On behalf of the General Research Ethics Board, I wish you continued success in your research.

Yours sincerely,

Joan Stevenson, Ph.D.
Chair
General Research Ethics Board

c: Dr. Nikolaus Graham, Faculty Supervisor
Appendix L
Recruitment Notice II

Assessing a technique for converting commercial games into exergames

Seeking participants for a study on exercise video games. You will play modified versions of Half-Life 2 and The Elder Scrolls V: Skyrim. During your gameplay sessions we will record your screen and heart rate. There will be questionnaires and a short interview regarding your thoughts on the modified versions of the games. Participation requires one hour of your time on two separate days. You will be compensated $10 for the first day, and $20 for the second day.

To be eligible, you must:

- Be between the ages of 18 to 35
- Have 100+ hours of experience playing first-person video games with an Xbox-style controller
- Be able to perform exercise on a stationary bicycle
- Not suffer from any medical conditions preventing you from performing moderate to vigorous exercise

Please contact Mallory Ketcheson by email at ketcheson@cs.queensu.ca or by phone at (613) 533-6000 ext. 79331 for more information.
Appendix M

Letter of Information II

LETTER OF INFORMATION
Assessing a technique for converting commercial games into exergames

You are invited to participate in a research project directed by Mallory Ketcheson, Luke Walker and Nicholas Graham of Queen’s University. We will read through this letter of information with you, describe our experimental procedures in detail, and answer any questions you may have.

The study explores whether commercial video games can be converted into exercise video games (exergames).

Participants enrolled in the study will play two video games using a computer-integrated recumbent stationary bike, a display and a Logitech gamepad controller. Participants will wear a heart rate monitor. This monitor provides real-time heart rate information to the games. Participants will be asked to perform sessions on two different days, for approximately an hour each day. Before beginning gameplay, the participant’s resting heart rate will be measured using the heart rate monitor. Each day, participants will be asked to play either three gameplay sessions from the video game Half-Life 2 or three sessions from the video game Skyrim, each for a period of seven minutes. Participants screen will be recorded during each of the seven minute play sessions. After playing each game session, participants will be given a break, during which they will fill out a short questionnaire about their experience with the game session they just finished. Participants will continue with the next game session once a minimum of five minutes has elapsed and their heart rate has dropped to the range of a warm-up heart rate. On the second day, after playing the game sessions, participants will be given a final 5-10 minute questionnaire and a brief interview. The total expected investment of time for both days is approximately two hours.

To ensure that participants are well suited for physical activity, the PAR-Q (Physical Activity Readiness Questionnaire) will be administered. As with any physical activity program, it is possible that physical discomfort may result, or that minor injuries such as a strained muscle may occur. If you experience any physical issues, you should stop the use of the exercise bike immediately.

An honorarium will be given to you as a token of appreciation for your time. An initial $10 honorarium will be provided for attending the first day and $20 will be given the second day. If you decide to withdraw from the study, you will receive the honorarium for the day you have attended.

With your consent, we will use quotations of you discussing your experience with the exercise games in publications, talks and promotions. All quotations will be anonymized – that is, your name will not be used. You may choose to withhold consent for such public use of your quotations. All information will be kept confidential, and data will be stored in a secured manner, in locked file cabinets or stored on password-protected computers inside the EQUIS Laboratory at Queen’s University. After 5 years, all written information will be shredded and all electronic data will be deleted. All results produced will be from group data, and no individuals will be
identified. Interviews will be recorded and transcribed; however, all names and identifying characteristics will be withdrawn from the transcripts. The transcripts will be coded and analyzed for common themes.

Participants may withdraw without any explanation and with no consequence at any time during the study.

This study has been granted clearance according to the recommended principles of Canadian ethics guidelines, and Queen's policies. However, the final decision about participation is yours. Any questions about study participation may be directed to Mallory Ketcheson (ketcheson@cs.queensu.ca, 613-770-6062). Any ethical concerns about the study may be directed to the Chair of the General Research Ethics Board at chair.GREB@queensu.ca or 613-533-6061.

Please retain a copy of the letter of information and consent form.

___________

Name of participant
Appendix N

Consent Form II

CONSENT FORM:
Assessing a technique for converting commercial games into exergames

I have read the letter of information describing this study being conducted by Mallory Ketcheson, Luke Walker and Nicholas Graham of Queen’s University. I understand that I will be participating in a research project whose structure and procedures are described in the attached letter of information. I have had the opportunity to ask questions related to this study, and have received satisfactory answers to any questions.

I am aware that my participation is voluntary and that I may withdraw my study participation at any time without penalty by advising the researcher.

I understand that I may address any questions about study participation to Mallory Ketcheson (ketchesn@cs.queensu.ca), and that any ethical concerns about the study may be directed to the Chair of the General Research Ethics Board at chair.GREB@queensu.ca or 613-533-6081.

Please circle one  Please initial your choice

I consent to the use of non-identifying quotations in publications, talks and promotions

YES       NO

_________________________   ___________________   ________________
Participant Name   Signature   Date

Please retain a copy of the letter of information and consent form.
Appendix O

Initial Questionnaire II

Questionnaires

**Gaming History**

Do you currently play video games? ___________ Yes  No

If yes, how many hours do you play each day? _______
During the period in which you played video games most frequently, how many hours did you play a day? ______

Have you played the Half Life Series before? If so approximately how many hours have you played in total? _______
Have you played Half Life 2 before? If so approximately how many hours have you played in total? _______

Have you played any of the Elder Scrolls series before? If so approximately how many hours have you played in total? _______
Have you played Skyrim before? If so approximately how many hours have you played in total? _______

**Physical Activity Levels**

This part of the questionnaire addresses your own leisure time physical activity habits. How many times on average per week do you do physical activity and what is the duration of these activities?

When answering these questions please:

⇒ Note that the main difference between the three categories is the intensity of the physical activity.
⇒ Please write the average frequency on the first line and the average duration on the second line.

<table>
<thead>
<tr>
<th></th>
<th>Times Per Week</th>
<th>Average Duration Per Session (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>STRENuous PHYSICAL ACTIVITY</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Heart beats rapidly, sweating)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>e.g. sports, running, jogging, hockey, squash, basketball, judo, vigorous swimming</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MODerate PHYSICAL ACTIVITY</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Not exhausting, light perspiration)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>e.g. baseball, tennis, bicycling, volleyball, badminton, easy swimming, alpine skiing, dancing, brisk walk</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MILD PHYSICAL ACTIVITY</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Minimal effort, no perspiration)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>e.g. tai chi, fishing, bowling, casual walk</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Appendix P**

**Intrinsic Motivation Inventory**

Please rate how much you agree to the following items based on your experience with the activity you just completed.

<table>
<thead>
<tr>
<th></th>
<th>Not at all true</th>
<th>Some what true</th>
<th>Very true</th>
</tr>
</thead>
<tbody>
<tr>
<td>I enjoyed doing this activity very much</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>This activity was fun to do.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I thought this was a boring activity. (R)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>This activity did not hold my attention at all. (R)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I would describe this activity as very interesting.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I thought this activity was quite enjoyable.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>While I was doing this activity, I was thinking about how much I enjoyed it.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I think I am pretty good at this activity.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I think I did pretty well at this activity, compared to other students.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>After working at this activity for a while, I felt pretty competent.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I am satisfied with my performance at this task.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I was pretty skilled at this activity.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>This was an activity that I couldn’t do very well. (R)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I didn’t try very hard to do well at this activity. (R)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I tried very hard on this activity.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>It was important to me to do well at this task.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I didn’t put much energy into this. (R)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I did not feel nervous at all while doing this. (R)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I felt very tense while doing this activity.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I was very relaxed in doing these. (R)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I was anxious while working on this task.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I felt pressured while doing these.</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

**Interest/Enjoyment**

**Perceived Competence**

**Effort/Importance**

**Pressure/Tension**
Appendix Q
Interview Questions II

Interview Questions:

1. Which version of Skyrim did you enjoy the most and which the least? Why?
2. Which version of Half-Life 2 did you enjoy the most and which the least? Why?
3. For each game, which did you prefer – one of the exercise versions of the game, or the original game? Why?
4. Did you find the power-ups motivated you to pedal faster in Skyrim? How about in Half-Life 2?
5. Did you find that the power-ups motivated you more in Half-Life 2 or in Skyrim, or were they equally motivating? Why?
6. Was the in-game effect of the power-up clear and easy to understand in Skyrim? In Half-Life 2?
7. Would you be interested in playing the exercise version of either (or both) of these games at home if they were made available? Would you be more interested in Skyrim, Half-Life 2 or both equally? Why?
8. In Half-Life 2, did the addition of exercise affect your strategy in any way? How about for Skyrim?
9. Were there ever cases in either game where the exercise was demotivating or made you feel like giving up?
10. Do you have any other observations or thoughts that we didn’t ask you about?
Appendix R
Debriefing Letter II

Debriefing Letter
Assessing a technique for converting commercial games into exergames

Thank you very much for participating in this study. Now that you have completed the study, the experimenter will answer any questions you have about it.

During the past two sessions, you played three conditions from Half Life 2 and three conditions from Skyrim using a game bike and heart rate monitor. The three conditions were as follows: (1) the game un-modified, (2) the game with the modification that pedaling controlled avatar movement, and (3) the game with heart rate based power-ups.

The main question we are exploring with this study is whether it is possible to convert existing video games into exergames. We hypothesize that the power-ups will be the most effective condition at encouraging high exertion levels. These results will allow us to make progress on our goal of broadening the number of available exergames by leveraging existing successful video games. We hope to help Canadians meet and adhere to the national physical activity guidelines.

We expect to publish the results of our study in journals and conferences in the future.

We thank you once again for participating in this study. If you have any further questions, please contact Mallory Ketcheson (ketchesm@cs.queensu.ca) or Nicholas Graham (nicholas.graham@queensu.ca). If you have ethical concerns about the study please contact the Chair of the General Research Ethics Board at chair.GREB@queensu.ca or 613-533-6081.
Appendix S

General Research Ethics Board Approval II

June 02, 2015

Ms. Mallory Ketcheson
Master’s Student
School of Computing
Queen’s University
Kingston, ON, K7L 1N6

GREB Ref #: GCISC-081-15; Romes #: 6015544
Title: "GCISC-081-15 Assessing a technique for converting commercial games into exergames"

Dear Ms. Ketcheson,

The General Research Ethics Board (GREB), by means of a delegated board review, has cleared your proposal entitled “GCISC-081-15 Assessing a technique for converting commercial games into exergames” for ethical compliance with the Tri-Council Guidelines (TCPS) and Queen’s ethics policies. In accordance with the Tri-Council Guidelines (article D.11.G) and Senate Terms of Reference (article G), your project has been cleared for one year. At the end of each year, the GREB will ask if your project has been completed and if not, what changes have occurred or will occur in the next year.

You are reminded of your obligation to advise the GREB, with a copy to your unit REB, of any adverse event(s) that occur during this one year period (access this form at https://services.queensea.ca/romeo_researcher/ and click Events - GREB Adverse Event Report). An adverse event includes, but is not limited to, a complaint, a change or unexpected event that alters the level of risk for the researcher or participants or situation that requires a substantial change in approach to a participant(s). You are also advised that all adverse events must be reported to the GREB within 48 hours.

You are also reminded that all changes that might affect human participants must be cleared by the GREB. For example you must report changes to the level of risk, applicant characteristics, and implementation of new procedures. To make an amendment, access the application at https://services.queensea.ca/romeo_researcher/ and click Events - GREB Amendment to Approved Study Form. These changes will automatically be sent to the Ethics Coordinator, Gail Irving, at the Office of Research Services or irvingg@queens.ca for further review and clearance by the GREB or GREB Chair.

On behalf of the General Research Ethics Board, I wish you continued success in your research.

Yours sincerely,

[Signature]

Joan Stevenson, Ph.D.
Chair
General Research Ethics Board

c: Dr. Nicholas Graham, Faculty Supervisor
   Mr. Luke Walker, Co-investigator
Appendix T

CORE Certification

Certificate of Completion

This document certifies that

Mallory Ketcheson

has completed the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans Course on Research Ethics (TCPS 2: CORE)

Date of Issue: 14 January, 2014