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Development and Evaluation of an Exercycle Game Using Immersive Technologies

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Abstract

Past research into exercise video games has found that they can help to motivate people to exercise, but these exergames have been single purpose (usually fitness only) and have shown poor user adherence. In this paper, we designed an exergame suitable for customization for specific health outcomes, with the intention of inducing long term use. This exergame was designed to be played using an exercise bike, along with various immersive technologies, such as the Kinect and the Oculus Rift. We used immersive technologies based on the hypothesis that they would improve user performance and motivation to exercise due to making the game more enjoyable and distracting the user from the exercise that they are doing.

In order to evaluate this exergame, we conduced a user study comparing exercise without a game to exercise with two versions of the game: one using the Oculus Rift, and one displayed on an ordinary screen. Use of the exergame, with or without the Oculus Rift showed a small but statistically significant increase in exercise performance relative to the non-gaming condition, with the screen condition faring slightly better than the Oculus condition. The exergame showed a significant increase in user motivation and enjoyment when compared to the non gaming condition, with the Oculus condition found to be slightly more motivating than the screen condition.

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Contents

1
Introduction

Regular exercise offers significant health benefits, both for reducing the incidence of obesity and obesity-related illnesses, for maintaining a general standard of health, and for promoting longevity [15, 29]. Conversely, lack of exercise can significantly increase the risk factor for a number of health issues [6, 14]. Despite the benefits of exercising, many people do not exercise as much as they should [4]. For typical adults, The American College of Sports Medicine (ACSM) recommends 150 or more minutes of moderate intensity exercise each week, or 75 or more minutes of high intensity exercise each week [7]. One of the major problems for people who need to exercise is motivation. Pure exercise activities are generally found to not be intrinsically motivating [13], so many people do not participate in exercise for its own sake. A lack of motivation may cause an individual to not exercise as often as they should and to not exercise at a sufficient intensity or for a sufficient duration.

One of the approaches to solving the motivation problem is to combine exercise and entertainment in the form of exercise video games (exergames). A large amount of research has been put into developing exergames, and there exist several commercial exergaming products (such as the Wii Fit [20] and Dance Dance Revolution [11]). However, these exergames, both in research and commercially driven, are generally suitable only for one purpose, usually general fitness. There is a lack of exergames that are suitable for multiple potential health outcomes.

The bulk of the studies around exergames have investigated their effect on participant performance rather than motivation. In general, these studies have shown that exergames do offer a slight increase in performance, and may meet general exercise requirements, but do not solve the motivation issue to a satisfactory degree. Some games have simply lacked meaningful gameplay, whilst others have used existing games with gameplay which is not optimally suited for exercise. In particular, the immersive exergames used in past studies have a significant lack of meaningful gameplay, and as such do not give a clear answer as to how immersive exergames affect participant motivation [18, 19].

Little research has been done on the effects of immersive technologies on exergaming. The increased availability of new immersive technologies that allow for better interfacing between a user's body and a digital environment (such as the Oculus Rift and the Kinect), opens up some exciting possibilities for exergame research. Past work on exergames has lacked meaningful gameplay that fits the exercise being performed, and the use of immersive technologies offers some potential to improve participant motivation. When immersed in an exergame using these technologies, the high level of input should distract the participant from the intensity of the exercise [18], as well as help to prevent them from becoming bored. It is also possible that such technologies may be able to improve the quality of the exercise performed by the participant, as they open up the ability to have more complex exercise motions be reflected in the game.

1.1 Research Questions

From examining previous works related to exercise video games, the following research questions arise:

1. Do immersive exergames improve user exercise performance?
2. Do immersive exergames increase user enjoyment of exercise, and motivation to continue exercising?
3. How do immersive technologies such as Head Mounted Displays affect user exercise performance and motivation?
4. What are the requirements for designing an exercise game that can be adjusted to suit multiple health outcomes?

1.2 Structure of this Dissertation

Chapter 2 looks at some of the earlier research into exercise motivation factors and the benefits of exergames as performance and motivation tools. Chapter 3 details the requirements and design for an immersive exergame. Chapter 4 discusses the exact manner and technologies with which the exergame designed in Chapter 3 was implemented. Chapter 5 details the design and processes of the user study conducted to evaluate the effectiveness of the designed exergame at improving performance and motivation. Chapter 6 contains the results found by the user study. Chapter 7 reflects on the results obtained by the study, and considers possible reasons for what was found. Chapter 8 concludes the dissertation and points out future research directions.

2
Related Work

The use of exergames has been investigated previously, with many variations on exergame design and fitness requirements. Whilst several studies have looked into the motivational factors of exergames, little work has been done on producing an exergame that offers sufficient motivation to maintain long term exercise adherence. Additionally, little work has been done to investigate the effects of immersion in exergames. In particular, no studies exist examining immersive display technologies, such as Head Mounted Displays.

2.1 General Exergaming Studies

In the paper "Developing Engaging Exergames with Simple Motion Detection" by Kiili and Merilampi [12], the authors investigated the use of simple, accelerometer driven exergames as tools to motivate exercise in children. This study used a number of games in which the exercise performed did not have a connection to the activity occurring in the game; for example, users performing squats as exercise in order to pull a rope in a tug of war game. An interesting result of this study is that participants have less interest in games where the required physical activity is not challenging. The participants in this study also had a negative reaction to delays between their physical activity and the result in the game and showed a desire for motion control to be accurate. Feedback from the participants indicated that they particularly liked the fact that the games they played did not represent traditional physical activities. This contrasts with the chosen methodology of a number of other exergame studies and designs [18, 19] mentioned here, in which the exergame involved the player pedalling on an exercise bike, causing their digital representation to cycle in a virtual environment. The mundane cycling offered by these designs may be why the study by Mestre et al. showed poor long term benefits in terms of commitment and performance [18].

The paper “The Health Benefits of Interactive Video Game Exercise” by Waburton et al. [28] conducts an effective study to measure the long term motivational effects of exergames. In this study, participants were invited to participate in exercise sessions over the course of six weeks. The participants were free to attend as many exercise sessions as they saw fit, up to a maximum of five per week. The participants were divided into two groups, a control group who exercised using a stationary bike and a test group who used a GameBike® (Cat Eye Electronics Ltd., Boulder, Colorado), and the adherence level of each group to the recommended three exercise sessions per week was measured, as well as changes in the level of physical fitness of the participants. The study found that participants exercising using exergames show significantly higher rates of adherence than those exercising just on a bike. Additionally, the participants in the study who used exergames showed significantly higher levels of physical fitness after the study, which could be partially, but not entirely, attributed to higher levels of attendance. It is worth noting that the participants in this study were all previously sedentary and generally overweight according to Body Mass Index measurements. This is interesting in that it shows potential for exergames as a motivational tool for people who are not otherwise motivated to exercise, which is the group who stand to benefit from them the most.

Song et al. [25] investigated how competition factors affected participant motivation when playing exergames. The authors conducted a study using the Hula Hoop game for Nintendo Wii Fit. While playing the game, participants were shown a recording of the gameplay of another person playing the game, and told that it was another person playing. The study had a competitive and non competitive condition; these were the same except that in the competitive condition, the participant was shown a pre-recorded ranking compared with the other four people supposedly playing at the same time. This study found that while direct competition caused increased exercise performance in both competitive and non competitive players, non competitive players did not enjoy the experience and showed a significant reduction in voluntary additional play. The fact that competition increased performance but could decrease motivation is of significant interest for the design of exergames, as increased performance may offer short term benefits, but the potential long term drawbacks of decreased motivation (for example, reduced adherence to an exercise program) likely outweigh these.

The role that gaming skill plays on performance and motivation in an exergame is of interest. Sell et al. [23] conducted a study investigating different levels of participant skill on physical performance in the Dance Dance Revolution commercial exergame. Participants were divided into two categories based on the difficulty level of the game that they were able to play. The study found that participants of a higher skill level exhibited significantly higher levels of exercise on the cardiovascular metrics being measured (such as Heart Rate (HR) and Oxygen Consumption (VO_2)). However, the higher skilled participants played the game at a higher level of difficulty, which was more physically demanding. The researchers note that the increase in the intensity of the exercise performed may be attributable to the more demanding requirements of playing at that level. The study also found that the more skilled players expressed a higher level of enjoyment of the game.

2.2 Immersion Studies

Some attempts have been made to investigate the effects of immersion in exergames. The paper "Fitness Computer Game with a Bodily User Interface" by Mokka et al. [19] developed an exergame using immersive techniques to attempt to provide a more motivating experience, shown in Figure 2.1. The game involved using an exercise bike to navigate a 3D virtual environment containing a cycle track, with the goal of completing the track in a suitable time. The game provided realistic sounds suitable to the scene, and the resistance of the exercise bike changed with the gradient of the terrain; if the terrain was an uphill slope, the resistance would increase, and vice versa. A pilot study was conducted and found that whilst use of the immersive game was a pleasant experience, it still felt like exercise, rather than gaming. It should be noted that the study conducted for this paper was somewhat limited, containing only nine participants, none of whom played video games regularly.

The work of Mestre et al. [18] also looks at the relationship between immersion in exergames and the general experience of exercise. Using gaze tracking, the authors found that sensory stimulation such as that provided by an exergame distracted participants from the exercise, and thus improved their performance and enjoyment. This study was somewhat lacking in that the participants had no meaningful control over the virtual environment; they were only able to control the speed at which a video of a cycling perspective played, by changing the speed at which they pedalled.

2.3 Exercise Motivational Factors

While not dealing specifically with exergames, the paper "Intrinsic Motivation and Exercise Adherence" by Ryan et al. [22] offers a useful insight into the factors that motivate people to exercise. It shows an interesting difference between the reasons people tend to

Figure 2.1: Exergame test environment from the paper "Fitness Computer Game with a Bodily User Interface" [19].

begin exercising, and the reasons people continued to exercise. Specifically, while most people cited extrinsic reasons for exercising (such as body image and fitness) and that such reasons were often the cause of people initiating exercise programs, intrinsic motivation factors (fun, challenge) were more reliably related to people's adherence to an exercise program. This paper also found that extrinsic factors as a reason for exercising were more common with women than with men. This shows promise for exergames, in that their premise is to be fun, and to potentially offer challenge not directly related to the exercise itself.

The paper "College Students' Motivation for Physical Activity" by Kilpatrick et al. [13] investigated motivational factors for different kinds of physical activity. This paper found that sports and pure exercise activities have different motivational factors. Sports participation is motivated by challenge, competition, enjoyment and social factors, while pure exercise activities are motivated by appearance, health and fitness reasons. In particular, health reasons are significantly more motivating for exercise, while social and competitive factors are more motivating for sports. Similar to the findings of the paper by Ryan et al. [22], this paper found that men were more motivated by intrinsic factors, such as challenge and competition, while women were more motivated by extrinsic factors, such as weight management. The results from this paper suggest a benefit to exergames, in that they deal with pure exercise activities, which are already motivated by extrinsic factors, and they add the intrinsic factors of fun and challenge, allowing the exercise to have the best of both worlds in terms of motivation. While the authors' choice to categorise competition as an intrinsic motivation factor is questionable [26], for the purposes of this paper that categorization will be used.

Looking at the studies cited here, a strong indication of the potential for exergames to be a powerful tool for promoting exercise is shown. Participants have performed better, and shown higher rates of adherence. These studies consistently indicate the fact that the intrinsic factors of fun and challenge are major motivators in exercise and exergames, particularly in the longer term. The exergames which closely resembled mundane exercise failed to hold participants interest as they grew bored, though the exergames that offered the participants a good challenge retained more interest. These studies also suggest potential in exergames for better engaging males in aerobic exercise. They have shown that males are less motivated by body image, health and fitness factors, and more motivated by challenge and fun. Since video gaming tends to be more common among males [9, 16], a challenging exergame could be a useful tool in encouraging males to exercise more.

3 Design

The objective of this project was to design an exergame superior to existing ones; suitable for customization for different healthcare outcomes, and more motivating than previous designs. For the purposes of this project, the desired health outcome was general cardiac fitness for typical adults, but it was important that the game be customizable for other health requirements. General fitness was chosen as the health outcome, as to evaluate the game for medical outcomes would require clinical trials, something outside the scope of this project.

3.1 Requirements

3.1.1 Exercise Requirements

In terms of exercise, the ACSM recommends that for most adults they engage in moderate intensity exercise for 30 minutes or more on five days a week, for a total of 150 minutes or more each week, or high intensity exercise for 20 minutes or more on three days a week, with a total of 75 minutes or more each week [7]. The ACSM states that a combination of moderate and high intensity exercise that combines for a similar total exercise quantity is also acceptable. What constitutes moderate or high intensity exercise will change depending on the individual. The ACSM defines moderate intensity exercise as exercise that places the user's heart rate between 64% and 76% of their maximum heart rate, and high intensity exercise as exercise that places the heart rate between 77% and 95% of the maximum heart rate [7]. Based on these recommendations, the exergame should set the exercise intensity at moderate or high, but be able to calibrate the exact intensity level based on the user's individual requirements. Additionally, the exergame should at minimum be playable for periods of 30 minutes at a time. The ACSM also states that whilst the quantities of exercise described above give optimum health benefits, lesser amounts of exercise are still beneficial [7]. Even if the user does not have time to commit to a full exercise session, the game should be able to provide entertaining exercise for short sessions.

Past research has shown differing results on the benefits of warming up. Some studies have found that warming up does not show a definite benefit on exercise performance [3, 8]. Other studies have shown that warming up can provide physiological benefits, and possible psychological benefits in exercise [24]. As Genovely and Stamford [8] mention that for psychological reasons such as fear of injury, participants may not exercise at their full capability if not able to warm up, it seems sensible to include a warm-up as part of the exercise, whether or not it offers concrete benefits. As Shellock and Prentice found that an active warm-up, that is a warm-up that uses the same muscles in the same manner as the exercise which is to follow, offers better performance improvements than a passive warm-up [24], it is ideal that the game contains its own warm-up period. This section of the game should be similar to the main portion of the game, but the exercise difficulty should be scaled such that the exercise is suitable for a warm up, rather than fully-fledged exercise, and the gameplay difficulty should be sufficiently low that it does not interfere with the warm up.

From this, we derive the following game requirements related to exercise:

1. The game should suit pedalling at a moderate intensity.

2. The game should be scalable to a range of different fitness level difficulties.

3. Whilst it is ideal that the game is played for periods of 30 minutes or more, it should be adjustable for shorter duration sessions if necessary.

4. The game should be potentially infinite in length.

5. The game should have an initial warm-up up during which the gameplay is the same, in order that the same muscles be used in the same way, but where the fitness requirements are less difficult.

3.1.2 Gameplay Requirements

It is desirable that the exergame constructed for this study be enjoyable and immersive. A good measure of enjoyability for a game is how well it promotes a state of psychological flow. Csikszentmihalyi describes eight components of psychological flow, here quoted from the paper “Flow: The psychology of optimal experience” [2].

1. We confront tasks we have a chance of completing.
2. We must be able to concentrate on what we are doing.
3. The task has clear goals.
4. The task provides immediate feedback.
5. One acts with deep, but effortless involvement, that removes from awareness the worries and frustrations of everyday life.
6. One exercises a sense of control over their actions.
7. Concern for the self disappears, yet, paradoxically the sense of self emerges stronger after the flow experience is over
8. The sense of duration of time is altered.

These components translate naturally into considerations for the design of an exergame. If the game is not possible for the user, both in terms of the level of exercise required and in terms of the level of gameplay difficulty, the user will be demotivated. The controls need to be straightforward enough that the player is able to focus on playing the game rather than attempting to interact with it. The gameplay objective and in game goals must be straightforward enough that the player always understands what to do. When the player interacts with anything in game, the response of that interaction should be immediate, and the controls of the game should show immediate response, as also shown by Kiili et al [12].

Combining this and the previously discussed exercise requirements gives the following key gameplay requirements:

1. The game should be scalable to a range of different game skill levels.
2. The game should provide a transparent scoring system to allow for the player to compete against their personal best and/or indirectly against other players.
3. The higher the intensity of the exercise, the better the player’s performance and score should be.

4. The game should allow for changes in pedalling resistance that match circumstances in the game environment.

5. The game should have a clear goal. At all times, it should be intuitive for the player what they must do.

6. The participant must be able to exercise all necessary control in the game using just the bike and the motion sensor.

7. The participant must be able to make meaningful choices with non-trivial consequences, and the participant must be aware of the consequences of their choices. This is to promote a state of flow based on the requirement that ”One exercises a sense of control over their actions” [2].

8. The game should not be a simple representation of regular exercise.

3.2 Software Design

Based on the requirements detailed previously, an exergame suitable to this research can be designed. In this exergame, the player controls an object or individual moving along a semi-linear course which contains obstacles, and holds a requirement to keep moving at all times. If the player does not keep pedalling, they enter a failure state. In order to fulfil the first exercise requirement, the speed can be calibrated such that in order to proceed at a satisfactory pace, the participant must pedal at a moderate intensity.

For the second exercise requirement and first gameplay requirement, game difficulty and exercise difficulty should be kept as separate as possible. That way, the game can be calibrated such that a fit but unskilled player can receive the benefits of the exercise, without being demotivated by their inability to meaningfully play the game. Conversely, the game can also then be calibrated such that an unfit player who is highly competent at the game can have a challenging and enjoyable experience while still exercising at a manageable level. Gameplay difficulty can be calibrated by increasing the quantity and magnitude of obstacles, while exercise difficulty can be adjusted through changes to the baseline resistance (that is the resistance when the player is pedalling on a flat surface unaffected by obstacles).

For the third exercise requirement, while it is necessary that obstacles can cause a failure state, the barrier to restarting should be low, so that if the player enters a failure state, they can begin playing again in moments. To this end, the player should be given a number of lives, should they fail with lives remaining, their lives are decremented and they resume a short distance behind where they were when they failed. Should they fail with no lives remaining, they should promptly begin again from the start simply by continuing to pedal. While it should be expected that a player would run out of lives over the course of half an hour of play, if a particularly skilled player is able to avoid this, it is of no concern as we place no upper limit on exercise quantity. The initial number of lives can be calibrated for different desired durations of play.

For the fourth exercise requirement, the game environment should be procedurally generated. As long as the player continues to play, more content should be generated.

For exercise requirement five, the first part of the game should have gentle exercise requirements, and simple gameplay. This section can serve to introduce the player to the different types of obstacle that they can encounter, as well as serving as a warm up.

For the second gameplay requirement, the player's score should be based on distance travelled; the further they go (and thus the longer that they exercise), the higher their final score. Similarly, for the third gameplay requirement, if the player pedals faster (thus exercising at a higher intensity), they will travel farther, faster, and thus receive a higher score than someone who worked at a lower intensity for the same period of time.

For the fourth gameplay requirement, some obstacles in the game should not be failure conditions, but rather adjust the difficulty of pedalling. For example, the course may run uphill or downhill, or through difficult ground. Increases to the difficulty of pedalling should represent the increased or decreased difficulty of moving through that area.

For the fifth gameplay requirement, the goal is very straightforward. The player must keep moving forward while trying to avoid obstacles. Furthermore, the game is divided into separate levels.

For gameplay requirement six, the player's ability to interact with the game is straightforward. Their rate of pedalling controls their speed, and as they lean to the left and right, they move sideways in corresponding directions in order to avoid obstacles or acquire bonuses (such as additional points or lives). Early testing found that steering by leaning was counter-intuitive when playing the game with the Oculus Rift, so for simplicity's sake the game should not require turning, and should instead simply require motion from side to side. The player can also duck to avoid overhead obstacles. As shown in past studies [12, 10], it is important that these motion controls are responsive.

For the seventh gameplay requirement, whilst the track that the player moves along should generally be linear, periodically the player should encounter branches in the track where one branch is significantly safer but offers no rewards, whilst the other branch is significantly more dangerous (containing many more obstacles), but also offers more rewards in the forms of various bonuses. In order for the player to be aware of the consequences of their choices, it should be clear which branch is which as the player approaches. These branches will not have a significant effect on the exercise, but improve the enjoyability of the game by adding some strategy. Additionally, there should be obstacles for which the player is able to strategically react in order to reduce their effect.

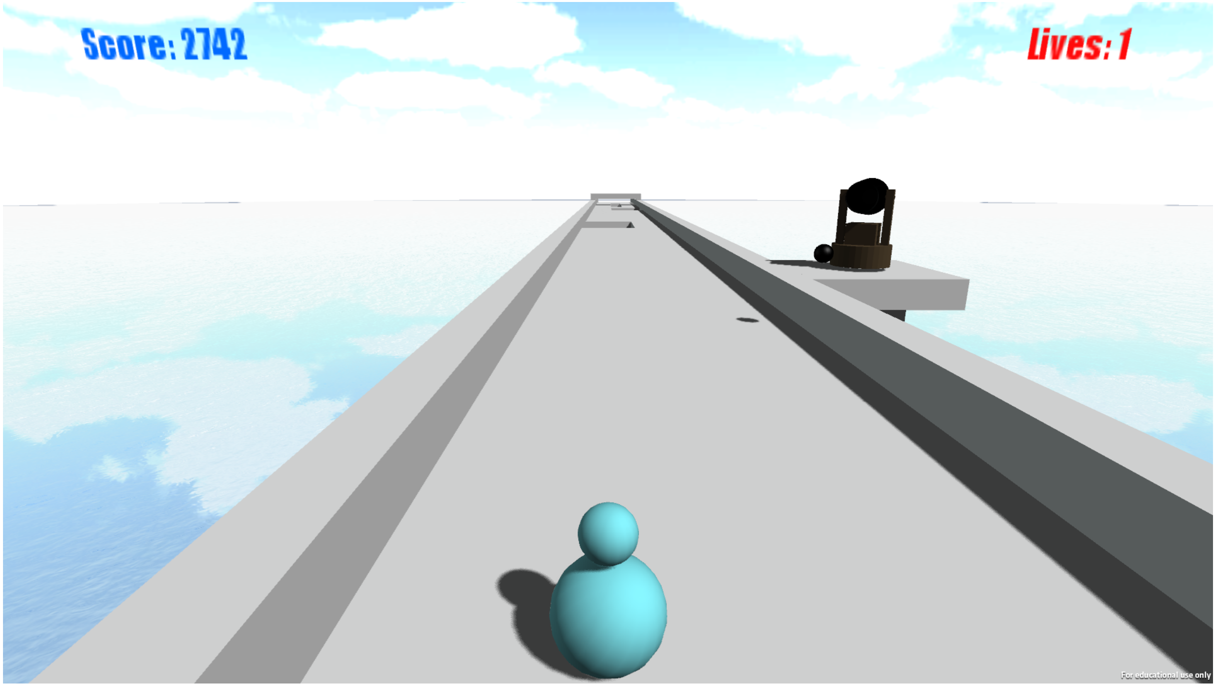

Figure 3.1: Screenshot of the exergame.

In non-abstract terms, the game involves a simple representation of the player moving along a track containing pits, ramps, and overhead beams as obstacles. This can be seen in Figure 3.1. Additionally, placed beside the track are cannons which shoot balls at the player that temporarily magnify the resistance if they hit, and potentially knock the player into the pit. The player is able to see these obstacles coming and react accordingly. Additionally, the track periodically contains power-ups, which have varying levels of difficulty in obtaining them; for example, the power-up could be in the middle of a flat area, placed right beside a pit, or floating over a pit requiring that the player jump to get it. These power-ups offer either a fixed amount of extra points, a bonus life, ten seconds of pedalling at minimum resistance, or a random one of the previous three options.

Because competition has been shown to be a powerful motivational factor, but also potentially harmful to enjoyment [25], this exergame only employs competition indirectly and optionally. The game maintains a list of high scores, thus a participant is able to compare their score to the scores on the high score list. They can attempt to beat the high scores, but their success in any given session in the exergame is independent of other users.

This style of game is also well suited for modifications for future work, in particular in the areas of competition and collaboration, as the track system lends itself well to playing with another player present. In terms of competition, the system would suit having an opponent present, introducing competition for bonuses, and potentially the risk that a player who falls too far behind may lose. Similarly, if playing against a replay of an opponent, the player will see the opponent speeding off into the distance, or falling behind. In terms of collaboration, a slipstream system could be supported, where a player that follows close behind another player receives less pedalling resistance due to having less wind resistance. A following player might also be protected from some obstacles.

3.3 Hardware Design

The exergame has some requirements in terms of hardware functionality. The exercise bike needs to be able to adjust the pedalling resistance (we use an Arduino for this purpose), and provide speed and heart rate information to the computer at a high frequency. The exergame also requires a method of controlling the player's horizontal movement, as mentioned in the previous section. For this purpose, using a camera based system rather than a game controller or steering wheel is ideal, in order to maximise immersion by having all controls for the game mapped to the user's body movement. This has the added advantages of requiring less specialized hardware, and allowing the user to keep their hands on the exercise bike's handlebars.

Figure 3.2 shows how the exercise bike formed the centre of the equipment. Two metres to the right of the exercise bike, at approximately 1.6 metres high (roughly head height for a typical person sitting on the bike) was placed the Kinect. In front of the exercise bike was placed the screen (when testing with the Oculus Rift, this screen was not used). Connected to the bike was the Arduino. All devices were connected to the same controlling computer.

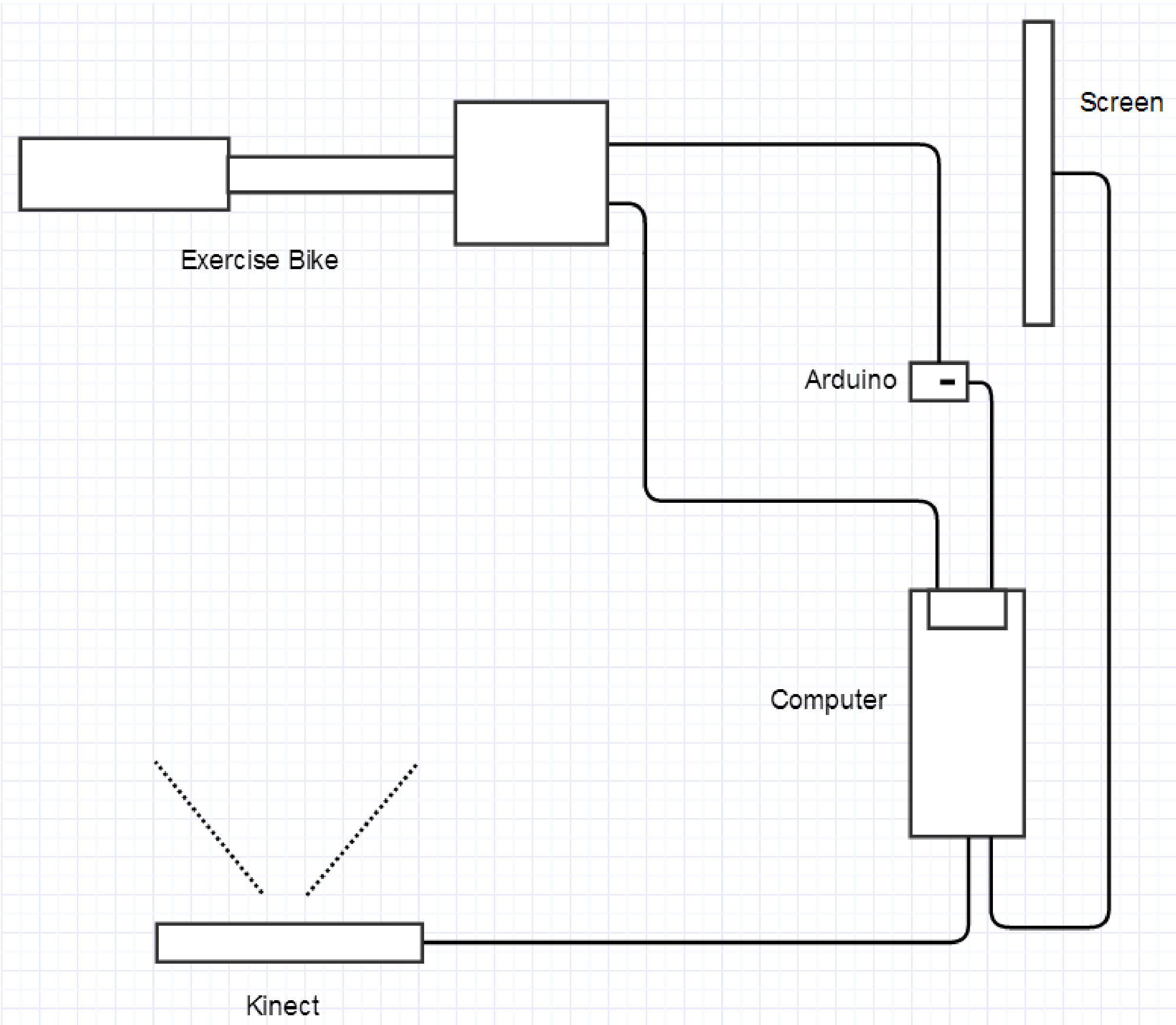

Figure 3.2: Arrangement of devices.

4 Implementation

4.1 Game Engine

The exergame was written using the Unity game engine, version 3.5.7. The Unity game engine was selected based on several requirements. Firstly, the engine had to be able to produce procedural content, based on the design requirement that the game be able to be played for as long as the user wanted to play, and that it should be providing an experience not identical every time. Secondly, the engine had to support communication with a range of hardware devices. It had to be able to communicate with the exercise bike and Arduino micro-controller, read data from a web camera, Kinect, or similar device, and interface with the Oculus Rift. Due to the time constraints of this research, it was also ideal that the engine be well-documented, so that the available time could be spent producing the exergame, rather than attempting to understand the game engine. For similar reasons, it was ideal that the engine provide a development tool-kit, rather than it simply being a source code base.

4.2 Motion Tracking

Several potential methods exist for tracking the bodily motion of an individual on the exercise bike. The level of tracking required is not extremely high. It is necessary to know to which side (left, right, forwards, or backwards) a user is leaning, and by how much.

	Procedural Content	Custom Hardware	Documentation	Tool-kit
CryEngine	Yes	Yes, not natively	Reasonable	Yes
Source	Yes, not natively	Yes	Poor	Yes
UDK	Yes, not natively	Yes	Reasonable	Yes
Unity	Yes	Pro Only	Very Good	Yes

Table 4.1: Game Engine evaluation results

Beyond that, further detail is unnecessary (although potentially very useful for future work that uses bodily motion for more than simple obstacle avoidance). I evaluated four methods of tracking the user's position: Optical Flow, FaceAPI, Haar Cascades, and the Microsoft Kinect. These tracking methods were evaluated on five criteria items:

1. What portion of the time is the tracking method able to track the user's movements?
2. In how many dimensions can the user's movements be tracked?
3. How prone is the tracking method to interference?
4. How easily can the tracking method be integrated with the game in Unity?
5. Will use of the Oculus Rift cause problems with the tracking method?

The first method, Optical Flow, was tested using the OpenCV implementation of the Block Matching and Lucas-Kanaade algorithms. The video stream on which these algorithms was applied was sourced from a standard web camera placed in front of the user on the exercise bike. The vector map generated by the optical flow process was examined to determine the centre of the movement. Based on where in the image the centre of movement fell, the user's current position (and therefore movement) was determined.

Evaluating optical flow against the criteria given above, optical flow picked up all movement. However, because it produced regions of movement, it was difficult to reliably identify movement other than from side to side, meaning that the tracking was essentially one dimensional. Optical flow was extremely prone to interference. Every time the camera settings changed (for example, adjusting to handle a changed light level in the room as someone out of view passes in front of a window), the entire image would show movement for a few frames, any motion in the background would cause interference, and certain materials showed motion at all times (a user wearing a red woollen jersey showed constant movement in the torso area). Optical flow is not natively supported by unity, but the creation of a plugin or data streaming tool to allow it to work with Unity is not a complicated process. Because optical flow works just by detecting areas of movement, rather than attempting to identify specific features, a user wearing an Oculus Rift (or other headgear) is not a problem.

The second method, FaceAPI provided by SeeingMachines proved to be quite effective. Again, the image source for this method was a standard web camera placed in front of the user. With the web camera placed at the necessary range for use with the exercise bike, it did have some difficulty initially detecting the face, though once a face had been identified, it could track it reliably and with high accuracy. However, if a user's head was turned too far (roughly 60 degrees) to either side, it would often stop recognising the face. FaceAPI was effective at tracking the face in three dimensions, and was able to provide both position and orientation data. Generally speaking, it was not prone to interference; whilst it might sometimes switch to tracking another face that entered the camera's field of view at an appropriate range, other faces entering the field of view is something that is easy to control in test conditions. FaceAPI had no unity integration, and while tools exist for that purpose, they do not work with the currently available version. Again, the creation of a plugin or data streaming tool would be necessary to make it work with Unity or other game engines. Unfortunately, because FaceAPI is based on detecting facial features, wearing something that obscures a significant portion of the face, such as the Oculus Rift, causes it to stop tracking the user.

The third method, face detection with Haar Cascades, used the OpenCV implementation of the Viola-Jones object detection framework [27]. Again, the image source for this method was a standard web camera placed in front of the user. At close range , this method provided fairly good facial detection, picking up the user's face in the majority of frames (90%). At the range the camera was set up with the bike, however, it proved less effective, being only able to detect the user's face approximately 50% of the time. Additionally, as the face's orientation skewed, face detection became less reliable. Because tracking was based on the position of the user's face in the camera image, this method was able to effectively track in two dimensions. Some three dimensional information was also available. Based on the size of the face detected a rough approximation of depth was possible, but it was insufficiently accurate to be useful. This method was prone to some interference, as a number of faces would be incorrectly detected in the background. However, filtering out these false positives is generally straightforward based on the assumptions that initially a prominent face will be detected near to the centre of the image. From that point forward, there will be a prominent face not far from the location of the primary face of the previous frame. Like the previous two methods, this method is not natively supported by Unity, but the creation of a plugin or data streamer to provide the information is not difficult.

Like FaceAPI, because this method is based on recognising a face, wearing the Oculus Rift interferes with detection. However, this method is able to use alternative data sets as a basis for the feature detection. Using a mouth detection data set (the mouth not being covered by the Oculus Rift) this method was still able to track the user's face with about 75% accuracy even when wearing the Oculus Rift.

The fourth method, skeleton detection using the Microsoft Kinect, used a standard Xbox model Kinect placed to the side of the user on the bike. This method suffers from the limitation that the Kinect must be placed at a distance of approximately two metres from the user, as nearer than that the Kinect's ability to identify a person becomes unreliable. The Kinect proved extremely reliable in tracking the user's position, although it did require initial calibration to map its skeletal model to the user. However, after this initial calibration, it was able to track the user's head almost 100% of the time. The Kinect was able to provide accurate tracking information in three dimensions, regardless of the orientation of the user's head. The Kinect was largely not prone to interference, although if someone stood in the middle of its field of view in such a way that their image in the depth map was more clearly a person, it would occasionally switch to tracking them. Integration with Unity for the Kinect is straightforward, as Kinect plugins and documentation for Unity already exist. As the Kinect does not require facial recognition, but rather detects human shapes, headgear such as the Oculus Rift does not interfere with its ability to track users (although some things such as long thick hair or a headscarf, that make the neck less distinct from the head, do make it slightly less reliable at the initial detection of the head). The Kinect did initially have some issues with the Oculus Rift in that the Kinect operates at exactly thirty frames per second, but that low framerate can cause motion sickness when using the Oculus Rift. However, this problem was solved by moving the Kinect operations into a side thread that did not affect the overall framerate of the game.

It should be mentioned that whilst during the initial testing, the Kinect proved highly accurate with its tracking, during user testing, where the game was exposed to a greater range of body types, the Kinect's position did need to be adjusted in order to track the tallest of participants. However, if there had been space to position the Kinect further from the bike, the greater field of view may have meant that this would not have been a problem.

	Accuracy	**Dimensions**	**Interference**	**Unity**	**Oculus**
Optical Flow	Moderate	One	High	No	Yes
FaceAPI	High	Three	Low	No	No
Haar Cascades	Moderate-High	Two	Moderate	No	Partial
Microsoft Kinect	High	Three	Low	Yes	Yes

Table 4.2: Motion tracking evaluation results

Based on the aforementioned criteria, the Kinect proved to be the best choice of the four. Bodily movement of the user is accessed as a simple three dimensional vector by initially calibrating the game with a default head position, and then from that point

Figure 4.1: LifeFitness 95CI Upright Exercise Bike. Image taken from the manufacturer's website [1].

forward measuring the difference between the current head position reported by the Kinect and the default head position. As past studies [5, 21] have indicated that motion sickness may be caused by a sensory mismatch such that the user's visual indications of motion do not match their physical ones, when testing the game with the Oculus Rift the camera's position is updated based on the changing head position; if the user leans to the right, the camera moves to the right as well in order to keep visual and physical sensory input consistent.

4.3 Equipment

The exergame interfaces with a LifeFitness 95CI Upright Exercise Bike, shown in Figure 4.1. The exergame reads data from the exercise bike via the bike's Communications Specification for Fitness Equipment (CSAFE) port, and controls the bike's resistance via an Arduino micro-controller which triggers button presses on the bike's resistance buttons. The user's body motion is tracked using a Microsoft Kinect, and the game is presented to them either on a standard computer monitor, or on an Oculus Rift.

The 95CI exercise bike was chosen based on the fact that it supports the CSAFE standard. The CSAFE standard allows a connected computer to read exercise information from the bike; including heart rate and speed. Whilst the CSAFE standard does include functionality for a connected computer to control the bike's resistance and/or incline, this particular model of exercise bike does not support that feature. In order to get around this problem, an Arduino micro-controller was attached to the bike's manual resistance buttons, allowing the game to control the resistance through serial communication with the Arduino.

5
User Study Design

5.1 Test Conditions

In order to evaluate the exergame and determine its effect on user performance and motivation during exercise, a user study was conducted. Participants for this user study were drawn from University of Auckland students, recent graduates, and staff. Each participant participated in a single test session of approximately one hour in duration. During this hour, they completed a pre-test questionnaire, and then performed three exercise sessions of ten minutes each, separated by five minute breaks, and then completed a post-test questionnaire. Three conditions were evaluated:

1. Exercising without a game.

2. Exercising with the game displayed on a screen in front of the participant.

3. Exercising with the game displayed on the Oculus Rift worn by the participant.

The three exercise sessions each participant did each represented one of the conditions. Each participant did each condition in a pseudo-random order (determined by the method of Latin Square), such that the overall distribution of orderings was approximately equal. This was to mitigate the effects of fatigue in the later conditions and the learning effect for improvement at the game in later conditions. Prior to starting any of the exercise sessions, the participants were given instructions detailing the game they were to play during the gaming conditions. During the non-gaming condition, the resistance on the exercise bike was set to the default game resistance level (that is, the resistance level provided by the game when the player is travelling horizontally). Participants were told to use the exercise bike in this condition as if they were using it for exercise of their own accord, such as at a gym or in the home, and thus they were allowed to adjust the resistance if they so chose.

All participants performed the tests using the same equipment in the same location, with the screen condition being shown on a typical computer monitor placed in front of the bike, running at 1920*1080 resolution. At the end of each exercise session, the measurements for distance travelled and calories burned were recorded from the bike (measurements were taken from the bike rather than the game in order to measure the overall quantity of exercise as opposed to in game progress). Additionally, during the two gaming conditions, participants' heart rate and speed were measured and recorded with information about the current game state (i.e. the nature of the track at that point) every 0.5 seconds. The study took place over two weeks at the University of Auckland campus.

5.2 Participant Feedback

The pre-test questionnaire sought to gain general demographic information about potentially relevant factors. Questions 2, 4, and 6 were answered by selecting the appropriate option from a selection of ranges. The questions in the pre-test questionnaire were as follows:

1. What is your gender?
2. What is your age category?
3. What is your Body Mass Index (BMI)?
4. Approximately how many hours a week do you spend on moderate or high intensity exercise?
5. Do you regularly use a bicycle or exercycle when exercising?
6. Approximately how many hours a week do you play video games of any sort?
7. Have you previously played exergames, such as Wii Fit or Dance Dance Revolution?
8. Have you used a Head Mounted Display such as the Oculus Rift before?
9. If you have used a Head Mounted Display before, did you suffer from any form of motion sickness or discomfort?

The post-test questionnaire sought to establish how the different conditions motivated the participant. Questions 1-8 were answered on a seven point Likert scale containing the following values: "Strongly Disagree", "Disagree", "Slightly Disagree", "Neutral", "Slightly Agree", "Agree", "Strongly Agree". The questions/statements in the post test questionnaire were as follows:

1. I enjoyed the non-gaming exercise session.
2. I enjoyed the session with the game on a screen.
3. I enjoyed the session with the game on the Oculus Rift.
4. I found the non-gaming exercise session motivating.
5. I found the exercise session with the game on a screen motivating.
6. I found the exercise session with the game on the Oculus Rift motivating.
7. Using the exergame with the Oculus Rift would cause me to use the exercise bike more often.
8. Using the exergame with the Oculus Rift would cause me to use the exercise bike for longer.
9. Please rank the three experimental conditions from most enjoyable to least enjoyable.
10. Would you prefer to plan an exergame like the one presented in the study for regular exercise?
11. Did you suffer from any form of motion sickness during the Oculus Rift condition?
12. Do you have any other feedback?

During and between the exercise sessions, the participants were also free to give verbal feedback. They were also asked about their levels of tiredness and general well-being if they showed signs of unexpectedly high fatigue, and informed that they should stop if at any point they were concerned about their health during the exercise.

6
Results

The user study comprised 27 participants, drawn from students, recent graduates, and staff, of the University of Auckland. Of these 27, 26 of them were able to complete the three conditions and are included in the results detailed in this chapter. One participant stopped half way through the second condition (in that case, the non-gaming condition), and was unable to continue due to concern for their health. Their results have been omitted.

6.1 Performance

Participant performance was measured by taking the distance travelled and calories burned readouts directly from the bike at the ten minute mark of each condition. The measurement of this value should be accurate to within 3-5 seconds, or 0.5-0.9%.

As shown by Figure 6.1, participants generally travelled the most distance in the condition with the game shown on the screen in front of them (Mean: 3.66 km, Median: 3.75 km). The condition with the game shown on the Oculus Rift followed this by a small margin (Mean: 3.56 km, Median: 3.61 km), followed by the non-gaming condition at a larger margin (Mean: 3.18 km, Median 3.29 km). Similarly, as shown in Figure 6.2 the quantity of calories burned was greatest in the screen condition (Mean: 68.36, Median: 68), followed by the Oculus Rift condition (Mean: 66.15, Median: 66), and then the non-gaming condition (Mean: 63.04, Median: 61.5). The results were fairly normally

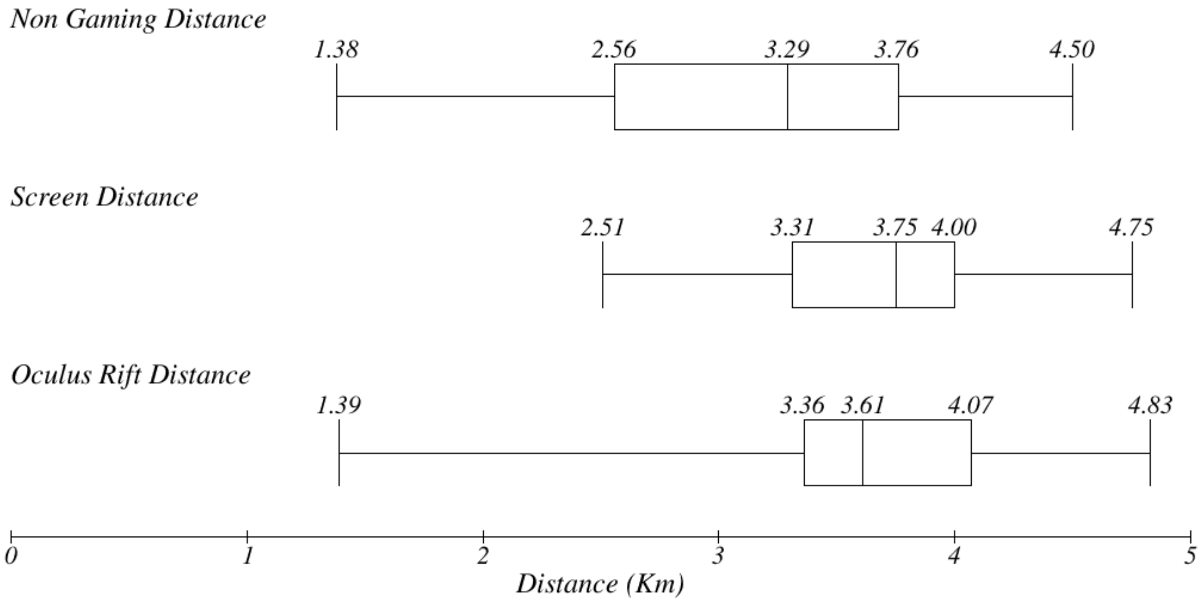

Figure 6.1: Distance travelled in the three conditions

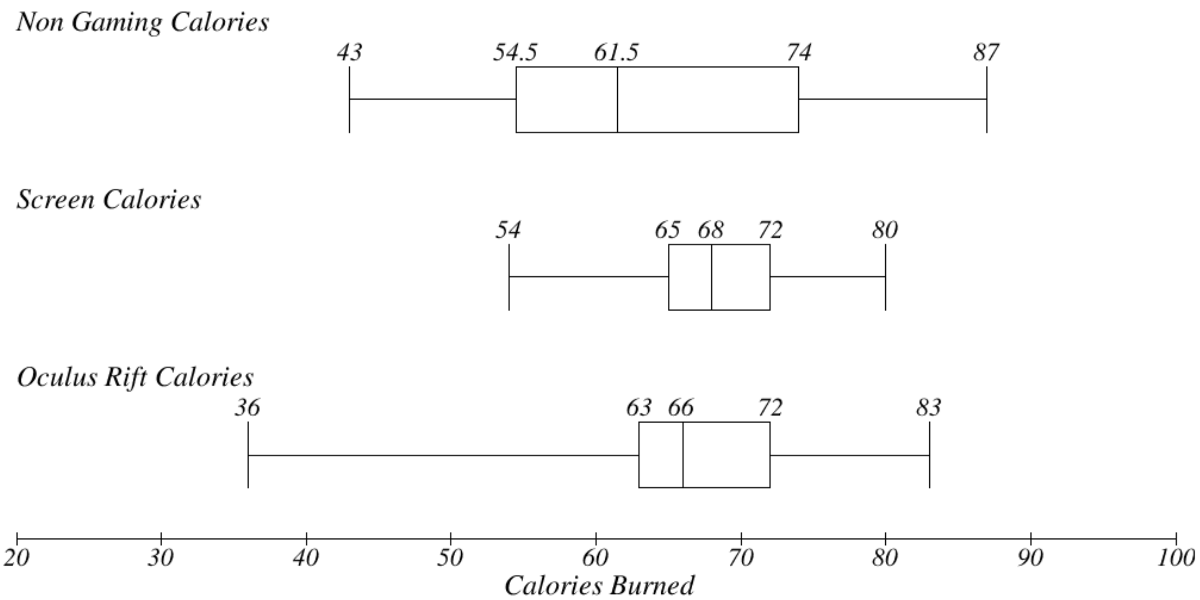

Figure 6.2: Calories burned in the three conditions

distributed, with the mean and median values being close.

Comparing user distance results using the Wilcoxon Signed Rank test, with a two tailed hypothesis and a p-value significance threshold of 0.05 shows that the difference in distances between the screen condition and the non-gaming condition is significant (Z-value -4.03, p-value 0.00). Likewise, the difference in distances between the Oculus Rift condition and the non-gaming condition is also significant (Z-value -2.83, p-value 0.00). Between the screen condition and the Oculus Rift condition however, the differences are not significant (Z-value -0.53, p-value 0.60). For calories spent, the results differ. Signifi-

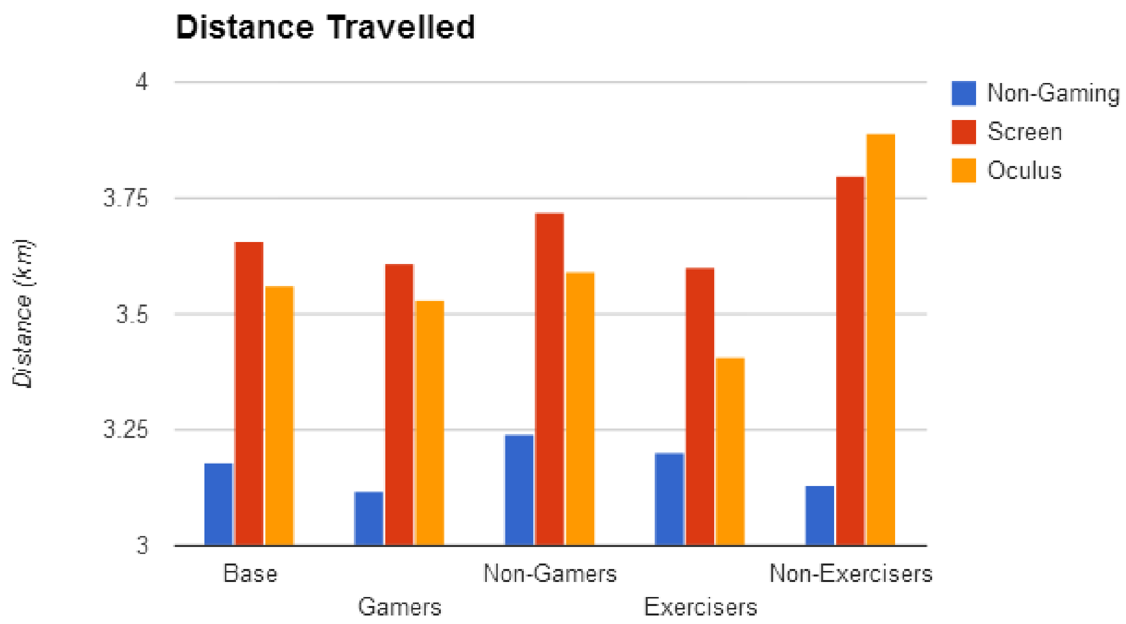

Figure 6.3: Mean distance travelled in the three conditions by demographic

cantly more calories were burned in the screen condition than in the non-gaming condition (Z-value -2.22, p-value 0.03), but the difference between the Oculus Rift condition and the non-gaming condition are not significant (Z-value -1.32, p-value 0.19). The differences between the two gaming conditions were again not significant, with a Z-value of -1.10 and a p-value of 0.27.

Figure 6.3 shows the distance travelled by participants in the three conditions, broken down into various demographics. The gamers (fourteen of the twenty-six participants) are defined as individuals who regularly spent two or more hours each week playing video games. Similarly, the exercisers (eighteen of the participants) are defined as individuals who regularly spent two or more hours each week doing exercise.

6.2 Motivation

Participant motivation was measured via the participants' responses to the post-test questionnaire. For questions 1 through 8, a value was assigned to each point on the Likert scale, with Strongly Disagree being 1, Neutral being 4, and Strongly Agree being 7. As shown by Figure 6.4 and Table 6.1, participants rated the two gaming conditions as significantly more enjoyable than the non gaming condition, and rated the Oculus Rift condition as slightly more enjoyable than the screen condition. Similarly, participants rated the two gaming conditions as significantly more motivating than the non-gaming condition, and

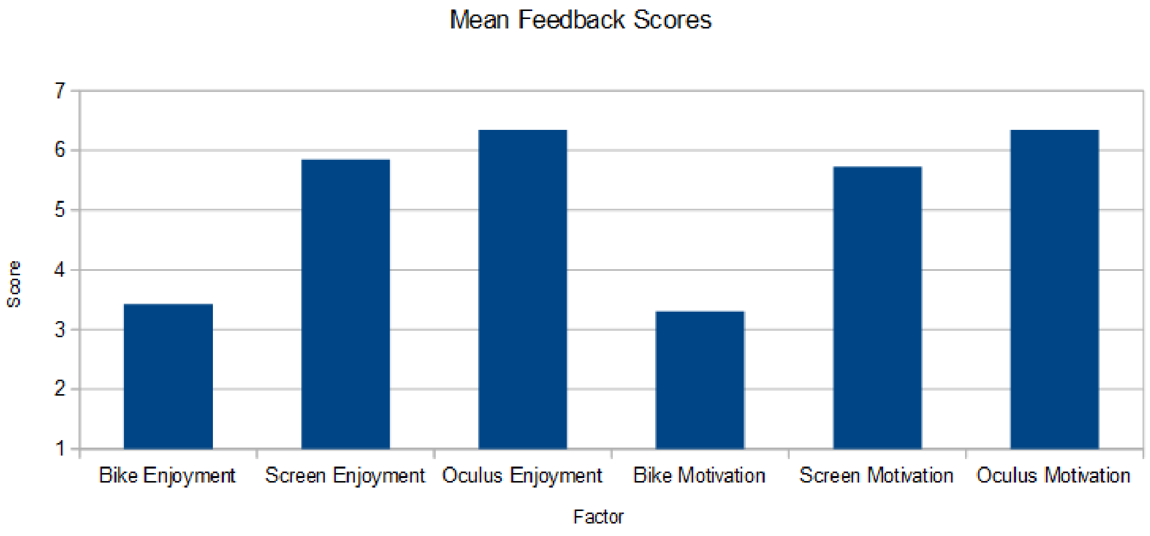

Figure 6.4: Mean feedback scores for enjoyment and motivation in the three conditions

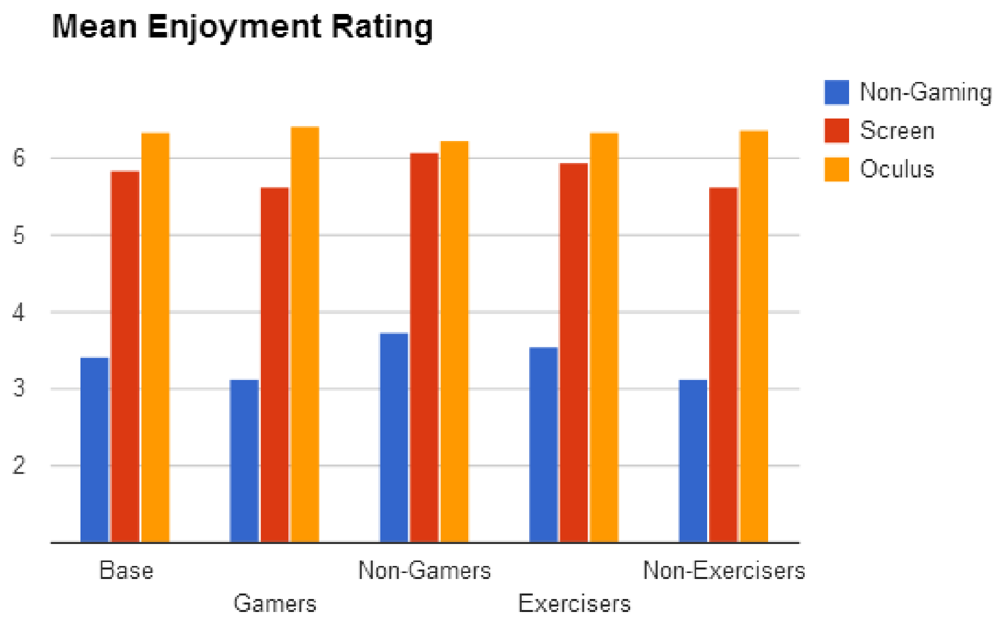

Figure 6.5: Mean enjoyment rating for the three conditions by demographic

the Oculus Rift condition as slightly more motivating than the screen condition. The statement "Using the exergame with the Oculus Rift would cause me to use the exercise bike more often." had a mean reponse of 5.7, and a median response of 6 ("Agree"). The statement "Using the exergame with the Oculus Rift would cause me to use the exercise bike for longer." had a mean response of 6, and a median response of 6. Again, the results had similar mean and median values.

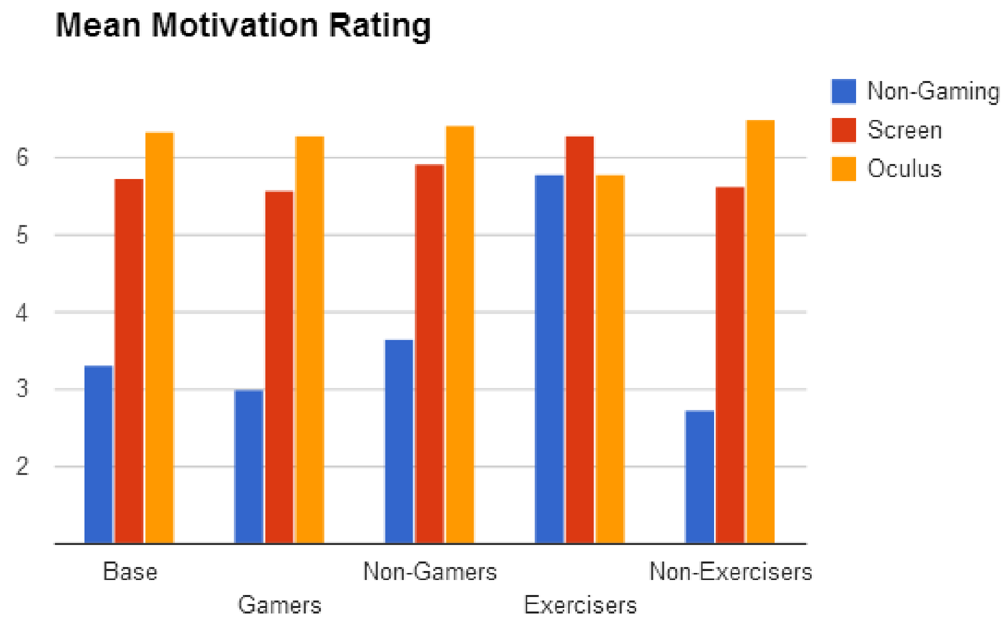

Figure 6.6: Mean motivation rating for the three conditions by demographic

	Non Gaming	Screen	Oculus Rift
Mean Enjoyment	3.42	5.85	6.35
Median Enjoyment	4	6	6.5
Mean Motivation	3.31	5.73	6.35
Median Motivation	3	6	6

Table 6.1: Enjoyment and motivation responses for the three conditions.

Performing an ANOVA (Analysis of Variance) test on the participant's feedback with a p-value significance threshold of 0.05 shows that the difference in enjoyment ratings between the non-gaming condition and the screen condition is significant (F-value 87.27, p-value 0). Similarly, the increase in enjoyment of the Oculus Rift condition was significant over both the non-gaming condition (F-value 115.15, p-value 0.00) and the screen condition (F-value 5.96, p-value 0.02). For motivation, the difference was again significant between all three categories, with the non-gaming to gaming comparisons having a p-value of 0.00 in both cases, and the Oculus Rift condition being rated as more motivating than the screen condition with a p-value of 0.00.

Of the twenty six participants, all of them ranked the non gaming condition as the least enjoyable. Seven of them ranked the screen condition as the most enjoyable, while the rest ranked the Oculus Rift condition as the most enjoyable. Only three of them stated that they would not like to use an exergame such as this one for regular exercise.

6.3 Motion Sickness

Of the 9 participants who stated on the pre-test questionnaire that they had used a Head Mounted Display such as the Oculus Rift, 3 (33.3%) stated that they had suffered from motion sickness while doing so. Of the 26 participants included here, 4 (15.4%) stated on the post-test questionnaire that they had suffered from motion sickness during the Oculus Rift condition. Of the 3 participants who stated that they had previously suffered from motion sickness when using a Head Mounted Display, 1 (33.3%) stated that they suffered from motion sickness during the Oculus Rift condition in this experiment. None of the participants who had used a Head Mounted Display and had not previously suffered from motion sickness suffered from it in this experiment.

7 Discussion

7.1 Analysis of Results

It is difficult to clearly account for the discrepancy between distance travelled and calories burned between the three conditions, although the measurements for distance travelled on the bike are more accurate than the measurements for calories burned. The distance travelled can be directly derived from information available to the bike (based on speed and time), but the calories spent are calculated mechanically (based on resistance and speed), not taking into account participant-specific factors. The two measurements also were available at different levels of precision. Distance was measurable in increments of ten metres, whilst calories were only measurable in integral values. To change the measurement for calories burned takes a significantly longer period of pedalling than to change the measurement of distance. Furthermore, for one participant, a measurement of calories was unable to be taken, and thus their calorific expenditure values are excluded from this analysis. Despite this discrepancy, the results show that this immersive exergame improved participant exercise performance to a statistically significant degree.

The motivation and enjoyment results are consistent with previous works, showing that exergames offer increased enjoyment and motivation when compared with traditional exercise [12], and that immersive exergames will improve exercise enjoyment by distracting the user from the exercise intensity [18]. Whilst the user study only had two female participants, it is worth mentioning that their feedback indicates results consistent with findings in previous works [22][13], that the exergame might be slightly less motivating for them due to its intrinsic motivational factors. However, their mean rating for how motivating and enjoyable the gaming conditions was only slightly lower than that of the male participants.

Only 9 of the 26 participants (35%) in this study had used a Head Mounted Display such as the Oculus Rift before. However, due to recent media attention, all of the participants were aware of what an Oculus Rift was, and many of them expressed particular interest in trying the Oculus Rift. A few stated outright that they had volunteered for the study in order to get a chance to try the Oculus Rift. It is possible that the participants who had not previously used the Oculus Rift rated the conditions using it as higher than the conditions that did not, simply due to the novelty factor. The participants who had not used the Oculus Rift before did give it a slightly higher mean rating in every question, but there were not enough participants to draw definite conclusions about the significance of this fact.

The reduced incidence of motion sickness amongst the participants in this study is of interest. In particular, the fact that some previous participants who had suffered from motion sickness did not suffer from it in this situation is important. Due to the small number of participants who had previously suffered from motion sickness, no definite conclusion about the efficacy of the technologies and methods used in this study to prevent motion sickness can be drawn, but it is still an indication that there is something worth further investigation. It is also interesting to note how most of the participants described a falling sensation when going downhill during the Oculus Rift condition. Several described it as the sensation of the bike tipping forward while they were on the slope. This suggests that the combination of the bike's feedback and the Oculus Rift is a potent immersion tool. However, a few participants did describe this sensation as unpleasant.

7.2 Population Comparisons

Interestingly, as seen in Figure 6.3, the participants classified as non-gamers (less than two hours of video games played per week), travelled a longer distance than the participants classified as gamers. Participants showed a significant improvement at the game the longer they played it. Unrelated to their level of fitness, their ability to avoid obstacles on the track increased the longer they played. The fact that players are able to gain skill at the exergame is beneficial, indicating the possibility of greater enjoyment and performance as they continue to play [23]. As Figure 6.5 shows, there was little difference in how the different demographics rated the three conditions in terms of enjoyment, and none of the demographics deviated from the overall population in terms of their relative ratings of the three conditions. In terms of motivation, both participants classified as gamers and participants classified as non-gamers were again consistent with the overall population.

Comparing the results of participants who exercise regularly (two or more hours per week) with the results of participants who do not exercise regularly (less than two hours per week) yields surprising results. As shown by Figure 6.3, while the participants who exercised had a further mean distance travelled on the non-gaming condition, the participants who did not exercise as much had further mean distances on both of the gaming conditions. In terms of mean enjoyment rating, both participants who exercised and participants who did not were consistent with the overall population. However, in terms of motivation, the participants who exercised for two or more hours per week deviated from the norm in that they rated the screen condition higher on average than they did the Oculus Rift condition. Additionally, the participants who exercised regularly rated the non-gaming condition much more motivating than the participants who did not regularly exercise. This could be because the participants who regularly exercise are more self-motivated to exercise anyway.

7.3 Limitations

Whilst the user study was generally effective, and provided useful data, it did suffer from some flaws and limitations. The demographics of the participants were fairly narrow. Almost all of the participants were male (92%), and between the ages of 20 and 24 (77%). Furthermore, most of the participants were drawn from either Computer Science or Software Engineering backgrounds. While earlier it was mentioned that young males may be an ideal target for exergames due to their tendency to enjoy video games and the fact that their exercise motivation factors are largely intrinsic [13][22], it does mean that the results of this study may not apply to the general population.

This user study evaluated motivation through a questionnaire, asking participants direct questions about how motivated they felt after completing the exercise sessions. While this can give a reasonable indication about short term motivation (that is, the participants indicated after exercising that they felt motivated, and would like to continue), it is not necessarily a good indication of long term motivation. In order to evaluate whether an immersive exergame is an effective motivational tool in the long term, an extended study that measures long term exercise adherence in the presence of exergames such as the one conducted by Waburton et al. [28] would be useful.

Generally, the design fulfilled the requirements well. Participant feedback was generally positive, and all participants rated the exergame as preferable to exercising without a game. For the user study, as participants were using the game in ten minute intervals, the difficulty was calibrated for ten minutes, rather than the suggested thirty minutes. However, the game may have still been calibrated to a higher than optimum level of difficulty, as several participants stated that the game was very hard. That said, other participants found the game relatively easy. The exergame had room for improvement in the area of promoting pedalling at a reasonably constant rate. Some sections were sufficiently difficult that the player had to either significantly slow down to safely navigate tight turns, or to significantly speed up to go fast enough to jump gaps.

The responsiveness of the motion controls was the subject of some feedback similar to that found by Killi et al. [12], particularly in the Oculus Rift condition. When a user leans to the side, their motion first removes momentum in the opposite direction, before adding momentum to their desired direction. Thus if they are travelling in one direction, a change of direction may take a second to occur. This was not such a problem in the screen based condition, where the fact that this was happening was more obvious, but some participants who first played the Oculus Rift condition gave negative feedback about the controls. The exergame might be improved by using instantaneous movement responses, rather than a momentum based approach. Additionally, while ducking was responsive, the margin of error on ducking under overhead beams was very narrow, and some participants took some time to learn to duck low enough.

The exergame implementation had some limitations. Some were hardware related, and some were software related. The hardware issues were associated with the exercise bike's ability to change the resistance, and with the Oculus Rift. Because the model of bike used did not support the CSAFE commands to adjust the resistance, changes in the resistance of the bike had to occur through the connected Arduino micro-controller triggering button presses on the bike's resistance buttons. These buttons had a maximum frequency at which they could register presses. When the game called for a sudden, sharp change in resistance (such as when the player is hit directly by a cannon ball), it could take a noticeable amount of time for the desired resistance to be achieved (going from the default resistance level of 7 to the maximum resistance level of 25 would take slightly more than a second and a half). This fact was occasionally noticed by a few participants who mentioned that it felt like there was a slight delay in feeling the effects of resistance changing factors.

Several participants also expressed dissatisfaction with the Oculus Rift, in that its resolution was rather low making it difficult to make out obstacles in the distance. Also, as participants worked up a sweat, the lenses on the Oculus Rift would sometimes become foggy, making details even more difficult to distinguish at a distance. Whilst higher resolution Head Mounted Displays are expected to be produced in the near future, the issue of lenses fogging could still make exergames using Head Mounted Displays less appealing. At the very least, this suggests that such exergames should be able to be paused so that the user may take a moment to wipe away condensation on the lenses.

The software had some problems that may have prevented it from being as motivating as it could have been. The exergame used a very basic visual style, the track being constructed out of plain blocks, and the player's representation being extremely simple. A professionally produced game with a visual quality on par with other mainstream games may be more appealing. Moreover, the game did not take full advantage of the Oculus Rift. With the Oculus Rift, the player is able to look around and draw information from all directions, but that was not really necessary in this exergame. However, this is not necessarily a flaw, as the same exergame was used for both the Oculus Rift condition and the screen condition. As the player did not have the capacity to look around in the screen condition, if the game required the participant to act on peripheral information the participants would have very much struggled in the screen condition. The game also suffered from some minor bugs which could cause a player to lose a life when they should not have done so.

8
Conclusion

This paper has presented an effective exergame for improving participant performance and motivation during exercise. Despite some limitations, the exergame showed higher performance from participants when compared with non-gaming exercise under the same conditions. Contrary to expected results, the use of a Head Mounted Display (the Oculus Rift) did not show a significant difference in performance when compared with the exergame presented on a screen. However, as the screen presented exergame was found significantly more motivating and enjoyable than the non-gaming condition, so too was the Oculus Rift condition significantly more enjoyable and motivating than the screen condition. These results are likely due to the fact that both gaming conditions forced the participant to exercise at a similar level, but the Oculus condition offered a more immersive and fun experience.

From this study, it can be concluded that the use of immersive technologies can offer significant benefits as motivational tools to promote general fitness. The exergame design given in this paper was shown to be effective as a tool to promote the desired health outcome of general fitness and should be easily customized for other health outcomes. Because the exercise difficulty can be calibrated separately from the game difficulty, and the game environment is procedurally generated according to a set of easily modified rules (thus allowing for control over both the type and frequency of the obstacles), this exergame should be suitable for many kinds of exercise based healthcare.

Based on the results of this study, future work investigating exergames should take advantage of immersive technologies such as the Kinect and should consider the gameplay design factors given here, such as the procedural generation of the game environment. For research purposes, Head Mounted Displays such as the Oculus should definitely be further investigated, as they have shown great potential to improve user motivation. However, for commercial applications, they may not be desirable for use yet, due to practical considerations such as motion sickness, and limitations of the current available hardware. Given that the game condition presented on the screen was also highly enjoyable and motivating for the participants in this study, use of the Oculus Rift for practical applications of this research should be delayed until further work can be done to mitigate the associated issues.

8.1 Future Directions

This research has opened the possibility of some interesting future work. In particular, there are several main areas worth investigating. The first of these is the medical applications of this work. Due to the scope and timeframe of this project, the exergame was calibrated for the health outcome of general fitness. However, the exergame was designed to be able to be calibrated for multiple purposes. With obesity as a growing problem, modifying the game to allow for the selection of multiple specific types of exercise (such as strength training or fat burning) offers a potential improvement. Additionally, specific forms of training on an exercise bike are something that can be recommended for rehabilitation of knee injuries [17]. It would be interesting to see how effective this exergame design is for requirements such as these, and to test it for such health outcomes with clinical trials.

The second area of interest is the effects of competition and collaboration in exergames. Verbal feedback from participants during testing indicated an interest in several of them regarding the scores, wanting to know how close they were to a high score, and expressing annoyance if they fell short of beating a high score. Similar to the findings of Song et al. [25], competition appears to be effective motivation for this exergame. The exergame as it stands is well suited to modification for the purposes of competition and collaboration. The high score system used in this game as a method of allowing for indirect competition could be adjusted and expanded into a motivational tool for specific objectives. For personal motivation, it could show only the current user's high scores, whilst for competitive motivation, it could show non-anonymous high scores for all users. Furthermore, the game could display the current highest score or nearest high score while the user is playing, so that they can see how close they are to beating it.

The third area of interest is in the prevention of motion sickness when using a Head Mounted Display. While efforts were taken in the design of this exergame to minimise motion sickness, and this test did have a reduced incidence of motion sickness, there were too few cases to prove significance. It may be that pedalling on the bike gives the user the physical feeling that they are moving, thus reducing the cue conflicts discussed by Reason [21] and Duh et al. [5]. In particular, the effect of bodily motions being reflected in the camera position may be worth investigating.

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