Conferences in Research and Practice in Information Technology

Volume 162

User Interfaces 2015

Australian Computer Science Communications, Volume 37, Number 5

User Interfaces 2015

Proceedings of the 16th
Australasian User Interface Conference (AUIC 2015),
Sydney, Australia, 27 - 30 January 2015

Stefan Marks and Rachel Blagojevic, Eds.

Volume 162 in the Conferences in Research and Practice in Information Technology Series.
Published by the Australian Computer Society Inc.

Published in association with the ACM Digital Library.

User Interfaces 2015. Proceedings of the 16th Australasian User Interface Conference (AUIC 2015), Sydney, Australia, 27 - 30 January 2015

Conferences in Research and Practice in Information Technology, Volume 162.

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Publisher: Australian Computer Society Inc.
PO Box Q534, QVB Post Office
Sydney 1230
New South Wales
Australia.

Conferences in Research and Practice in Information Technology, Volume 162.
ISSN 1445-1336.
ISBN 978-1-921770-44-9.

Document engineering, January 2015 by CRPIT
On-line proceedings, January 2015 by the University of Western Sydney
Electronic media production, January 2015 by Laurence Park, University of Western Sydney

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Challenges in Virtual Reality Exergame Design

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Abstract

Exercise video games have become increasingly popular due to their potential as tools to increase user motivation to exercise. In recent years we have seen an emergence of consumer level interface devices suitable for use in gaming. While past research has indicated that immersion is a factor in exergame effectiveness, there has been little research investigating the use of immersive interface technologies such as head mounted displays for use in exergames.

In this paper we identify and discuss five major design challenges associated with the use of immersive technologies in exergaming: motion sickness caused by sensory disconnect when using a head mounted display, reliable bodily motion tracking controls, the health and safety concerns of exercising when using immersive technologies, the selection of an appropriate player perspective, and physical feedback latency. We demonstrate a prototype exergame utilising several affordable immersive gaming devices as a case study in overcoming these challenges. The results of a user study we conducted found that our prototype game was largely successful in overcoming these challenges, although further work would lead to improvement and we were able to identify further issues associated with the use of a head mounted display during exercise.

Keywords: exergame, motion tracking, head-mounted display

1 Introduction

In recent years a number of virtual and augmented reality technologies have become commercially available. Head-mounted displays such as the Oculus Rift and motion tracking tools such as the Microsoft Kinect or Playstation Camera are widely available at a reasonable price. Many games have been developed to take advantages of these newly available technologies, and some work has been done around combining motion tracking and head-mounted displays, but no work has been done combining these technologies to create an immersive exergame based entirely on a bodily interface.

Whilst these new technologies show a lot of potential for the creation of immersive exergames, they also bring with them a number of challenges. We have identified the following five major challenges associated with the use of immersive technologies in exergaming. Firstly, careless game design when using a head-mounted display is likely to cause motion sickness (Merhi et al. 2007). This may be due to sensory disconnect, or cue conflict (Reason 1978, Duh et al. 2004). Secondly, when using motion controls in a game, these motion controls need to be accurate, otherwise they will lead to frustration for the player (Kiili & Merilampi 2010, Hernandez et al. 2012). The third challenge lies in selecting an appropriate view for the player based on the display technology being used. The fourth challenge is the collection of health and safety risks associated with the use of bodily motion controls and head-mounted displays during high intensity exercise. The fifth challenge we identified during user testing of our exergame prototype, and is the issue of feedback latency. When an exergame is giving sensory feedback to the user, it is important that this feedback occurs with minimal delay.

In this paper, we discuss these challenges and their potential solutions, and show a prototype exergame we developed as a case study in overcoming these challenges. The results with respect to the efficacy of this prototype as an exercise motivational tool following our user study are discussed in another paper (Shaw et al. 2015). Section 2 reviews relevant research on virtual reality interaction and immersive exergame designs. Section 3 presents a brief summary of the design and implementation of our case study exergame. Section 4 discusses the major challenges we identified in virtual reality exergame design, talks about the steps we took to overcome these challenges, and evaluates the effectiveness of these steps in light of how our prototype performed during our user study. We conclude our research in Section 5 and identify some areas suitable for further research.

2 Related Work

Reviewing related literature led to the identification of several potential challenges in VR exergaming. One challenge associated with VR is simulator sickness, discussed in several papers. Kolasinski (1995) offers a thorough evaluation of the potential causes and factors associated with motion sickness in virtual reality environments. The paper identifies factors that may be associated with motion sickness and divides them into three categories. The first category is subject factors, which are characteristics of the individual using the simulator such as age and simulation experience which may predispose them to motion sickness. The second category is simulator factors, characteristics of the simulation mechanism such as poor calibration or framerate which make it more likely to cause motion sickness. The third category is task factors, characteristics of the specific virtual environment and task such as duration and the user's degree of control which may make it more likely to cause motion sickness. The design of an immersive virtual reality exergame should take into consideration these factors, in particular the simulation and task factors.

Moss & Muth (2011) also examine simulator sickness. Their work is particularly relevant due to its focus on head-mounted displays. In our work we are using a head mounted display to provide an immersive experience to the user. The paper examines how various conditions including update delay, image scale factor, and peripheral vision affect the incidence of motion sickness among individuals using head-mounted displays. While many of the findings are mainly applicable for the design of head-mounted display hardware, it shows consistent results with previous research both in theories of cue conflicts leading to motion sickness (Reason 1978, Duh et al. 2004), and in postural instability leading to motion sickness (Riccio & Stoffregen 1991, Stoffregen & Smart Jr 1998).

The paper "Design of an Exergaming Station for Children with Cerebral Palsy", by Hernandez et al. (2012) is one of the few past works that examines human-computer-interaction considerations in exergaming. This paper is similar to our paper, in that it discusses challenges in the design of an exergaming system. However, the particular challenges this paper examines are those associated with the limitations caused by cerebral palsy, for example the necessity of providing proper support for a user who may not be able to support themselves. In this paper, the authors design and evaluate an exercycle gaming device to be used by children who suffer from cerebral palsy, as well as some simple exergames using this device. Whilst the findings of this paper are mostly applicable to designing for users suffering from cerebral palsy, its examination of pedalling input methods is interesting. It found that any disconnect or latency between changes to the player's pedalling speed and the reflection of that speed in game was quickly noticed and disliked by the players, even when the disconnect appeared to make the game easier.

Sinclair et al. (2007) also discuss interaction considerations for exergame design. Unlike our work, this paper evaluates several existing commercial exergaming products and motion control systems, and discusses the psychological, exercise, and interface factors that affect an exergame. Of interest is the examination of interface factors. The authors state that the player should be able to focus on a narrow field of attention, either the game being played or the input device being used. As an example, they identify the frequency of exercise bikes being used as the primary input device, where the user is stable and thus able to focus on the game instead of the device. They also point out a two similar devices with different success levels, Dance Dance Revolution and the Nintendo Power Pad. In Dance Dance Revolution, the game provides simple visual information, allowing the players to focus on their input. The Nintendo Power Pad is a similar device, but with more elaborate games requiring a split in the player's attention, which the authors suggest may have led to it being less successful.

Some attempts have been made to investigate the effects of immersion in exergames. Mokka et al. (2003) developed an exergame using immersive techniques to attempt to provide a more motivating experience. For this paper, the authors produced an exergame similar in many design aspects to our prototype. 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 this study was somewhat limited, containing only nine participants, none of whom played video games regularly.

The work of Mestre et al. (2011) 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.

Kiili & Merilampi (2010) investigate the use of simple, accelerometer driven exergames as tools to motivate exercise in children. Similarly to our work, their goal is to determine optimal design factors for exergames. However, some of the games in this study involve activity that may have reduced the immersion experienced by the participants. These games use exercise that did not have a relation to the activity occurring in the game; for example, users perform squats as exercise in order to pull a rope in a tug of war game. The participants in the study reportedly showed less interest these games than in the ones with a better mapping between bodily motion and game activity. 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. This suggests that a close mapping between user's motion and game actions in a virtual reality environment is highly important.

Previous research has touched on HCI design challenges in exergames and the challenges of using immersive virtual reality technologies. However there has been no detailed evaluation of these design challenges or guidelines on how to overcome them.

3 Case Study of an Exercycle Game

3.1 Design

We constructed an exergame as a case study for designing around the challenges associated with virtual reality exergaming. The primary requirement for the design of our exergame was that it be suitable for moderate to high intensity exercise for extended periods of time.

In our game, the user cycles on an exercise bike in order to move their virtual representation along a track. The track contains obstacles such as pits which the user attempts to avoid by moving their body in order to control their position in game. The speed at which the user moves in game depends on the speed at which they are cycling.

The objective of the game is to achieve the maximum score within a predetermined time (depending on player preferences or intended health objectives). The rate at which the player's score increases depends on the speed at which they are pedalling, and upon their ability to secure often difficult to obtain bonuses. The player starts the game with a certain number of lives, which may be depleted by failing to avoid pits in the track, or by being knocked off the track by shots from cannons positioned to the sides of the track. The number of lives may be increased by collecting bonus lives available in the game environment. When the player loses a life, the game places them back at a point just before the location where the life was lost.

The game environment is a semi-linear track suspended above water. The entire game environment is procedurally generated, allowing it to be potentially infinite in length, and guaranteeing that no two play sessions will be identical. The game environment contains obstacles that may be avoided using simple motion controls: pits and barriers on the track itself, and cannons beside the track that fire at the player. It also contains various bonuses, such as additional lives, extra points, and boosts that temporarily set the resistance of the exercise bike to the minimum level.

3.2 Implementation

The exergame was written using the Unity game engine, version 3.5.7. The Unity game engine was chosen based on its ability to interface with a broad range of devices, the quality of its documentation, and its ability to handle procedural content generation. Game objects were developed using the Blender modelling tools and Unity's built in primitives. Some of Unity's standard asset packages (e.g. water, particle effects) were also used.

Our exergame interfaces with a LifeFitness 95CI Upright Exercise Bike, shown in Figure 1. We had two requirements for interfacing with the bike, firstly that we were able to retrieve from the bike information about the speed at which the user was pedalling. The second requirement was that we were able to control the resistance of the bike in order to create immersion by having the difficulty of pedalling reflect circumstances within the game (e.g. pedalling difficulty increasing as the user attempts to travel up a slope).

For the first requirement, we were able to read exercise data using the bike's Communications Specification for Fitness Equipment (CSAFE) port. This provides serial communication between the bike and a computer, and specifies a set of commands to which the bike will respond. Through this we were able to retrieve a number of useful pieces of information, including the user's speed and heart rate.

Whilst CSAFE offers commands for adjusting the resistance and/or incline of exercise equipment, the 95CI exercise bike does not support those commands. In order to get around this problem, we used an Arduino micro-controller to electronically trigger presses of the bike's manual resistance buttons. The exergame maintains a serial connection with the Arduino, and whenever it determines that the resistance should change, it sends the updated resistance level to the Arduino. The Arduino then determines the required number of button presses to reach that desired resistance and begins pressing the buttons. Whilst this does fulfil our requirement, it suffers from a lack of speed. The minimum interval at which the bike can recognise subsequent button presses is approximately 160 milliseconds. This means that it can take several seconds for the bike to go from one extreme of resistance to the other.

Due to the required delay when adjusting the resistance level of the exercise bike, it is possible for the computer to send adjustments to the desired resistance level at a higher rate than can be processed. In order to keep the actual resistance level synchronised with the desired resistance level as much as possible, the Arduino discards all input except for the most recent in each cycle. This means that it will always be adjusting the resistance to the current desired level, rather than to a previously queued one.

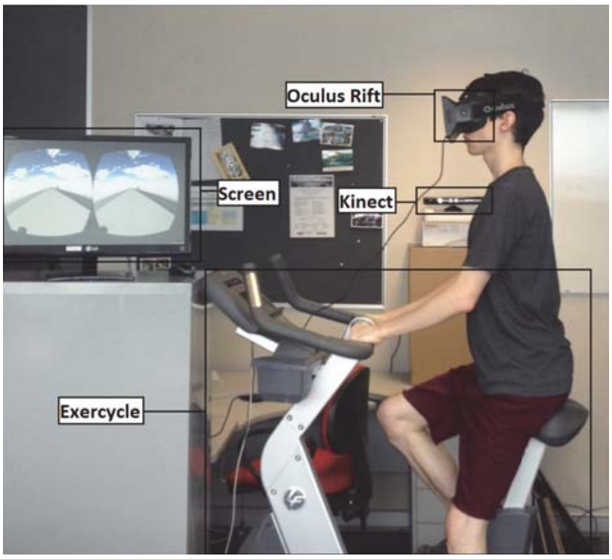

Figure 1: Exercycle game hardware setup.

We placed the Kinect 2 metres to the right of the user, and 1.6 metres above the ground (the approximate height of the user's head when seated on the bike). Figure 2 shows the approximate arrangement of devices. We found it advantageous to place the Kinect to the side of the user rather than in front of the user, as it was able to track them equally well from the side whilst our equipment setup would interfere with its ability to detect the user when placed in front of them.

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 related discomfort when using a head-mounted display (Kolasinski 1995). However, this problem was solved by moving the Kinect operations into a separate thread that did not affect the overall framerate of the game.

4 HCI Challenges

4.1 Motion Sickness due to Sensory Disconnect

Past work has indicated that video games presented on a head-mounted display can induce motion sickness (Merhi et al. 2007, Moss & Muth 2011). One of the theories which may explain this is cue conflict, where different senses give conflicting reports about

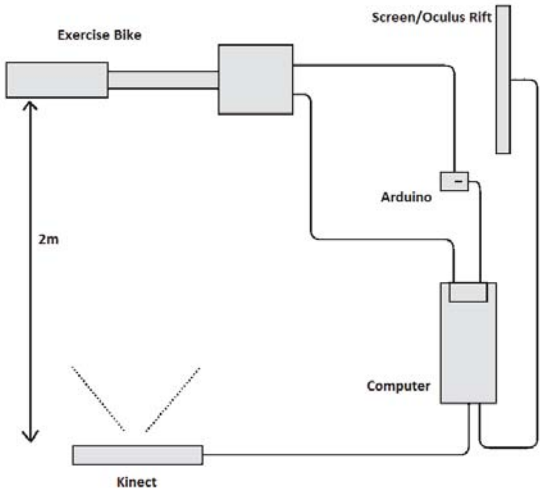

Figure 2: Arrangement of Devices

the body's motion, inducing sickness (Reason 1978, Duh et al. 2004). Motion sickness is highly undesirable in an exercise game, thus we endeavoured to design the game to minimise the likelihood of it occurring.

In our early testing, we detected the user leaning left and right on the exercise bike, and mapped this leaning to turning left and right in the game. Whilst this was reasonably straightforward when the game was presented on a screen, we found that when the game was presented on a head-mounted display this was counter-intuitive and caused motion sickness related discomfort. We found better results with the user's bodily motion mapped to sideways travel. Because of this, we designed the game environment in such as way as to not require turning, but only linear motion on any axis. The track proceeds in a specific direction, and the user's bodily motion causes their representation to move to either side of the track.

In order to minimise cue conflicts, we closely map the position of the user's head as detected by the Kinect to the position of the game camera. As the user moves their head to the left, the camera also moves to the left, and vice versa.

Our exergame prototype was reasonably effective in preventing motion sickness through sensory disconnect. The incidence of motion sickness in our study was relatively low, likely in part to our use of the Kinect to track the user's head position and update the camera position accordingly, thus reducing potential sensory mismatch. However, there were some circumstances where motion sickness related discomfort did arise. When cycling down ramps or falling down pits while wearing the Oculus Rift, several participants commented on an uncomfortable feeling of the bike pitching forwards. We believe that this was a case of sensory mismatch similar to that identified in past works (Reason 1978, Duh et al. 2004), where conflicting information was being received: the visual system indicates that the body is travelling downhill, whilst the vestibular system indicates that the body is on a level surface. Of interest is the fact that this was only mentioned when moving down, not up. This may be because the user feels in control when moving upwards; when moving upwards their motion decelerates, in contrast to the acceleration experienced when moving downwards as the game included no capacity for braking one's motion. Our results on motion sickness related discomfort suggest that future designs of fully immersive exergames should work to minimise cue conflicts that may arise, either by avoiding such triggering scenarios in the game itself (for example: using artificial boosts rather than slopes), or by utilising technology that allows for vestibular feedback.

We conducted a minor secondary study using our exergame to look specifically at motion sickness while wearing a head-mounted display. In this secondary study, participants were instructed to use the game for 20 minutes or until they felt sick. During this study, several participants felt some initial discomfort, but as their session progressed they were able to overcome it and only one participant was unable to complete the full 20 minutes, stopping after 2 minutes due to severe nausea. Our findings of participants who suffered only minor discomfort becoming familiar with the virtual environment and no longer suffering discomfort are consistent with past research (Kolasinski 1995).

4.2 Motion Tracking

When using bodily motion controls, past research has indicated that it is important that these motion controls are accurate (Kiili & Merilampi 2010, Hernandez et al. 2012). Because of this, we found it necessary to evaluate several methods of motion tracking for their accuracy and suitability for use in our exergame. We required that the tracking method be able to identify to which side and approximately how far the user was leaning. Ideally, the tracking method should also be able to identify motion in a second dimension. We allowed for small amounts of interference on the grounds that our game should be able to filter it out. We evaluated four different methods of tracking the user's head position: Optical Flow, Haar Cascades, FaceAPI, and the Microsoft Kinect. These four 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 a head-mounted display, in particular the Oculus Rift, interfere with the method's ability to track the user?

4.2.1 Optical Flow

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.

4.2.2 FaceAPI

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.

4.2.3 Haar Cascades

The third method, face detection with Haar Cascades, used the OpenCV implementation of the Viola-Jones object detection framework (Viola & Jones 2001). 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.

4.2.4 Kinect

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, some types of headgear, including the Oculus Rift, do 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).

Based on the relative accuracy and reliability of the four methods we evaluated, we chose to use the Kinect. While performing the initial testing and evaluation of tracking methods, the Kinect proved highly accurate with its tracking. However, when conducting a user study on the full game, 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.

Overall, our prototype was good for providing responsive motion controls. The controls were accurate and consistent, with the Kinect effectively picking up all of the user's motion. Nonetheless, the responsiveness of the motion controls was still the subject of some feedback similar to that found by Kiili & Merilampi (2010), particularly when using the Oculus Rift. When a user leans to the side, their motion first removes any momentum in the opposite direction, before adding momentum to their desired direction. Thus if users are travelling in one direction, a change of direction may take a second to occur. This was not a major problem when testing the game using a traditional monitor as display, since the third person view of the avatar indicated how the body motion effected the characters pose and cycle direction. However, some participants who played the exergame using the Oculus Rift prior to playing it on a monitor gave negative feedback about the controls. The exergame might be improved by using instantaneous movement responses, rather than a momentum based approach. Unlike side to side motion, ducking was immediately responsive, but the margin of error on ducking under overhead beams was very narrow, and some participants took some time to learn to duck low enough. We believe that this indicates that full body motion controls should be both responsive and forgiving.

4.3 Exercise Health and Safety Considerations

When designing an exergame it is important to include the capacity for a warm-up. Past research has shown conflicting results on the benefits of warming up, with some studies failing to find a definite benefit (De Bruyn-Prevost 1980, Genovely & Stamford 1982), and others showing potential physiological and psychological benefits (Shellock & Prentice 1985). As Genovely & Stamford (1982) 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.

There are two reasons to include a warm-up as part of the exergame, rather than encouraging users to do one beforehand. The first is to ensure that the users do actually complete a warm-up. The second is to ensure that the warm-up uses the same muscles as the actual exercise. Shellock and Prentice found that a warm-up that uses the same muscles in the same manner as the exercise to follow offers better performance improvements than a passive warm-up (Shellock & Prentice 1985). Our exergame includes a warm-up in the form of a tutorial area. In this tutorial area, the gameplay is the same as the main portion of the game, but the exercise requirements are undemanding in order to provide a suitable warm-up, and the game elements are introduced slowly one by one in order to allow the user to familiarise themselves with them at low risk.

A secondary health and safety concern with an exergame utilising immersive virtual reality technologies is the presence of the cables attached to the various devices, in particular the cable attached to the head-mounted display. Should the user catch themselves in a cable while exercising it would be possible for them to be injured. In order to minimise the risk of such injuries we maintain a metre clearance around the sides of the exercise bike, and run all cables out over the front of it. This keeps the cables away from the moving areas of the user's body. Ideally, we would also be using a wireless head-mounted display.

Another concern associated with the use of a head-mounted display is the increased risk of the user falling off the exercycle while wearing the display. In addition to the fact that the user is blind to their surroundings, some research has indicated that visual conflicts (such as the cue conflicts that may arise when using a head-mounted display) may lead to balance related issues such as postural instability and disequilibrium (Redfern et al. 2001). This means that while exergaming with a head-mounted display, the user should be positioned such that there is little risk of them losing their balance. Past work has also indicated that having something to hold may assist in reducing the incidence of motion sickness (Moss & Muth 2011). From a practical perspective, when using an upright bike the user should always have both hands on the handlebars, and care should be taken before utilising a hand held controller. We chose to use bodily motion and exercise intensity for all controls in our game, allowing the user to keep hold of the exercise bike's handlebars at all times.

Based on events during our user study, the design of our exergame proved to be moderately effective from a health and safety perspective. Our design was effective at handling the concerns we identified earlier in the paper; none of the participants lost their balance and fell off the bike, and nobody caught themselves on a wire. However, our design created one risk which we believe requires mitigation. The game environment contains overhead obstacles which the user must duck to pass underneath. This was not an issue when the game was displayed on a screen in front of the user, but when wearing the Oculus Rift the users were no longer able to see the exercise bike, and several came close to banging their faces on the bike's display when lowering their heads. This issue should be mitigated simply by making obstacles of that nature forgiving, allowing the player to pass with only a mild ducking motion.

4.4 Appropriate Player View

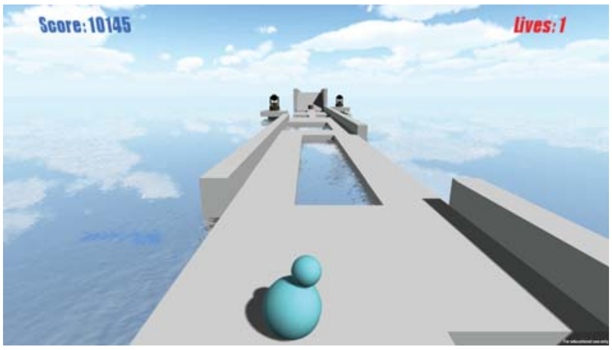

Figure 3: View of the game on a standard monitor.

The manner in which the player sees the game depends on how the game is displayed. When playing the game on a monitor, the game is displayed using a third-person perspective, with the player represented as two spheres as shown in figure 3. The lower sphere is the body position, showing where the user sits in the game environment for the purposes of interaction with parts of the environment. The upper sphere reflects the user's head position, as they lean from side to side the upper sphere moves relative to the lower sphere to reflect this. Figure 3 shows that the player is leaning slightly to the right. When playing the game using the Oculus Rift, the game is displayed using a first-person perspective, as shown in figure 4.

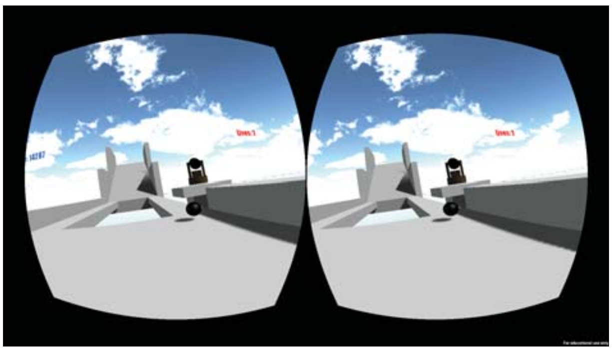

Figure 4: View of the game as shown in the Oculus Rift.

The first person perspective is ideal from an immersion standpoint, and is appropriate for use with the Oculus Rift as the camera orientation is mapped to the orientation of the user's head as sensed by the Oculus Rift. When not using the Oculus Rift however, the game better suits a third person perspective, as the user lacks the ability to control the camera. Early testing found it difficult to avoid obstacles in the first person perspective due to the limited field of view.

During our user study, participants were easily able to understand the representation of the game in first and third person perspectives on the screen and Oculus Rift respectively, even after playing one version and then switching to the other. We believe that choosing an easily understood view system is very helpful in reducing the number of things a player must focus on, which has been identified as an important consideration for exergaming design (Sinclair et al. 2007).

4.5 Feedback Latency

Similar to how it is important that motion controls be responsive, we found that it is important that sensory feedback from the game is immediate. When an event occurs in the exergame, the associated feedback response should occur right away. We discovered this in user testing due to the implementation of our resistance feedback.

Due to the fact that we were unable to directly control the resistance of the bike via the bike's CSAFE port, we adjust the resistance on the bike by electronically triggering presses of its resistance buttons with the Arduino. The minimum interval at which the bike can recognise and process subsequent button presses is approximately 160 milliseconds. Because the exercise bike offers 25 resistance levels, this means that it can take several of seconds for the bike to go from one extreme of resistance to the other. During user testing quite a few of our participants noticed this fact, with several exhibiting confusion or frustration at the delay. When the resistance began to change, they might not notice the first few levels of change, and thus by the time they did notice the altered resistance, there was a disassociation between the game event and the response. While we were able to mitigate some of the delays in resistance changes by making sure we were always adjusting to the most recent desired resistance level, given the limitations of our hardware it might be advisable to adjust the game design such that it does not require sudden significant resistance changes.

4.6 Exercise Related Issues

During our user study, we found some additional issues with the use of a head-mounted display for an exergame. The level of exercise encouraged by the game was of moderate to high intensity, and the increased body temperature and sweating of the participants caused some issues. The lenses on the Oculus Rift fogged up on several occasions, causing the game to become difficult to see, particularly when combined with the relatively low resolution of the Oculus Rift model we were using. This issue will likely be partially mitigated by future models having a higher resolution, but the fogging issue is harder to solve, potentially requiring customization of the hardware for the purposes of exercise. Furthermore, due to the Oculus Rift having padding pressed against the user's face, there is the potential hygiene concern of this padding absorbing sweat from the user.

5 Conclusion

We have identified five important challenges to be considered when using immersive virtual reality technologies in exergaming, and presented methods for overcoming these challenges. We have evaluated four common approaches to tracking the motion of an individual's head and found that for exergaming purposes, this is best accomplished with the use of gaming hardware such as the Kinect, as this technique proved to be both the most accurate and the most powerful.

As a case study, we have presented a novel exergame utilising several interesting technologies. The methods of interaction with the game: exercise input and bodily motion control, proved intuitive and immersive as well as motivating and enjoyable. Our work has demonstrated the potential of easily available hardware for use in virtual reality exergames and we believe our lessons learned provide useful guidelines for other developers of exergames using similar technologies.

5.1 Future Work

There are a number of areas of potential interest for further investigation into the ideal design of immersive virtual reality exergames. In particular, the prevention of motion sickness while using a head-mounted display in exercise is worth further research. Our work has identified a number of ways by which the incidence of motion sickness may be reduced, in particular by eliminating cue conflicts, but we have not addressed other theories as to the cause of motion sickness, such as postural instability (Riccio & Stoffregen 1991, Stoffregen & Smart Jr 1998), other than by designing our case study exergame to allow the users to hold on to the bike.

The motion tracking used by our game was relatively simple, merely the detection of the user's head position. However, the tracking method we chose offers significantly more potential: the Kinect's skeletal tracking system can track the user's entire body. We found that the presence of the exercise bike or other exercise equipment interfered with the Kinect's ability to track the user's body by introducing non-bodily related data at similar depth values to the user's body, but we believe that this issue can be overcome to allow for the creation of exergames utilising motion controls based on the user's entire body.

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