Development and Evaluation of an Exercycle Game Using Immersive Technologies

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Abstract

Exercise video games have become increasing popular due to their promise to increase fitness and reduce obesity levels, and due to the emergence of cheap interface devices. Previous research reported mixed results about the effectiveness of such games. Common problems are the lack of long term motivation of users, games not taking into account specific patient requirements, repetitive gameplay, and vendor lock-in. In this paper we design a novel exergame which addresses some of these shortcomings. The game employs an infinite randomly generated game environment, uses immersive technologies, and can be customized to take into account patient requirements. We present a prototype of this game design and evaluate its effectiveness using different levels of immersion. Our user study demonstrates a small but statistically significant increase in exercise performance and motivation when using the exergame. Employing the Oculus Rift resulted in a slightly higher motivation, but no noticeable change in performance. The head mounted display was most effective for sedentary users.

Keywords: exergame, exercise motivation, immersive technologies, head-mounted displays

1 Introduction

Regularly performing exercises has numerous health benefits (Owen et al. 2010, Nelson et al. 2007). For an average adult 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 (Garber et al. 2011). However, a large proportion of the population does not exercise enough (Douglas et al. 1997). A recent study in the US reported that only 8% of adolescents achieved the recommended level of physical activity (Troiano et al. 2008).

A major cause of insufficient exercises is lack of motivation. Pure exercise activities are generally perceived as not being intrinsically motivating (Kilpatrick et al. 2005). One proposed solution is to combine exercises and entertainment in the form of exercise video games (exergames). Over the past decade a large number of exergames have been developed and suitable interaction devices, such as the Wii Remote and Kinect motion sensors, the WiiFit balance pad, and the Dance Dance Revolution dance pad, have been released.

Most commercial exergames have been developed with a large target audience in mind and do not address specific health outcomes and patient requirements. Studies of exergames' effectiveness have shown mixed results and in most cases exercise motivation only increases in the short term (Altamimi & Skinner 2012, Macvean & Robertson 2013, Sun 2013). Very few researchers have used immersive technologies and little is known about their effect on exercise performance and users motivation (Mokka et al. 2003, Mestre et al. 2011, Finkelstein & Suma 2011).

In this paper we investigate requirements for designing an exergame which can take into account patient parameters and different health outcomes and which increases patient motivation. In particular we are interested in the effect of immersive technologies on motivation and performance. Based on our requirement analysis we present an exergame platform and a game prototype.

Section 2 reviews relevant research on exergames with an emphasis on exercycle-based games. Section 3 presents a requirement analysis, which is used in section 4 to motivate the design of our exergame platform and the implementation of a prototype. The resulting exergame is evaluated with a user study. Section 5 presents the study design and section 6 the results. We conclude our research in section 7 and give an outlook on future work in section 8.

2 Related Work

Research in game psychology suggests that engaging games satisfy basic psychological needs for competence, autonomy, and relatedness (Przybylski et al. 2010). We are interested in studies investigating which factors make an exergame successful, i.e., motivate users to play it sufficiently often and long enough to get the desired amount of physical activity.

Most exergames mirror physical activities in the game environment, e.g., pedaling on an exercycle is represented as cycling in the virtual environment (VE). The resulting mundane cycling task may be why Mestre et al. (2011) determined poor long term benefits in terms of commitment and performance.

Kiili & Merilampi (2010) used a different approach and let children perform a number of accelerometer-based games where the exercise performed in the real environment was mapped to a different activity in the virtual environment. For example, users had to perform squats in order to pull a rope in a virtual tug-of-war game. The authors report that participants had less interest in games where the required physical activity was not challenging, reacted negatively to delays between physical activity and action in the VE, and desired accurate motion control. The authors claim that participants particularly liked the fact that the games did not represent traditional physical activities.

Warburton et al. (2007) measured the long term motivational effects of an exercycle-based game on sedentary and overweight participants using a six week study. The authors report that participants exercising using exergames showed significantly higher rates of adherence than those exercising just on a bike. Additionally, the exergamers showed significantly higher levels of physical fitness after the study, which could be partially attributed to higher levels of attendance. This demonstrates the potential of exergames as a motivational tool for people who are not otherwise motivated to exercise, which is the group who stands to benefit from them the most.

Song et al. (2009) investigated the effect of competitive factors. The authors found that direct competition caused increased exercise performance in both competitive and non-competitive players, but decreased enjoyment and motivation in non-competitive players.

Sell et al. (2008) performed a user study using the "Dance Dance Revolution" game in order to investigate the effect of players' skill levels on performance and motivation in an exergame. The authors report that participants with a higher skill level played exergames on a higher level of difficulty and exhibited significantly higher levels of exercise on a cardiovascular metric. The higher skilled players also expressed a higher level of enjoyment of the game.

Several studies have investigated the role of immersion on exergame performance. Mokka et al. (2003) used an exercycle to enable users to traverse a VR cycle track as fast as possible. The bike's resistance changed with the track's slope. A user study (with 9 participants) found that the immersive game was a pleasant experience, but was perceived as exercise, rather than gaming. Mestre et al. (2011) found that sensory stimulation such as that provided by an exergame distracted participants from the exercise, and thus improved their performance and enjoyment. Finkelstein & Suma (2011) report for their VR exergame "Astrojumper" a significantly increased heart rate of users after gameplay. Participants' ratings of perceived workout intensity positively correlated with their level of motivation. None of the above studies used a fully immersive display, such as head-mounted display, and interaction with the virtual environment was limited.

3 Requirements Analysis

The objective of our research is the development of an exergame which has an infinite non-repetitive gameplay, is motivating, and can be customized to desired health outcomes and patient requirements. The game design should also allow an investigation into what game elements are most motivating (future work), and how immersive technologies influence users motivation and performance.

3.1 Exercise Requirements

The American College of Sports Medicine (ACSM) recommends that an average adult should engage in moderate intensity exercise for 30 minutes or more on five days a week, or high intensity exercise for 20 minutes or more on three days a week (Garber et al. 2011). The ACSM defines exercises as moderate (high) intensity if the user's heart rate is between 64% and 76% (77% and 95%) of the maximum heart rate. The exercises should include a warm-up phase. Without that participants may not exercise at their full capability due to psychological reasons such as fear of injury (Genovely & Stamford 1982). The warm-up should be part of the gameplay since this is likely to make the warm-up more enjoyable, and it has been shown that an active warm-up (using the same muscles in the same manner as the subsequent exercises) offers better performance improvements than a passive warm-up (Shellock & Prentice 1985).

Since we target a wide range of users and want to test immersive technologies we need an exercise which is suitable for users of different age, does not require training, and is safe when wearing a head-mounted display while performing vigorously. After surveying exercise machines available in a gym we decided that an exercise bike is most suitable.

We hence derive the following exercise requirements:

- E1 Exercises use an exercycle
- E2 The game should be designed to encourage moderate to high intensity pedaling
- E3 The game should be scalable to users with a range of different fitness levels
- E4 The game should be ideally about 30 minutes long, but it should also be possible to do training sessions of different length
- E5 The game should have a warm-up period which is integrated into the gameplay

3.2 Gameplay Requirements

The gameplay should be intuitive and enjoyable. In order to achieve this we derive requirements based on the eight components of psychological flow proposed by Csikszentmihalyi et al. (2004). We also employ standard user interface design requirements, such as intuitive control and immediate response to user actions (Kiili & Merilampi 2010). Combining this information with the previously derived exercise requirements, results in the following gameplay requirements:

- G1 The game should be scalable to a range of different game skill levels
- G2 Since an exercycle does not have a rotating handlebar, we track users body motion to steer the virtual bike
- G3 The game should provide a transparent scoring system to enable players to compete against their personal best and/or other players
- G4 The exercise intensity and duration is captured using a performance measure, whereas the game score reflects additionally the game skills
- G5 The exerbike's resistance level should reflect the gameplay (e.g., terrain slope, obstacles)
- G6 The game should have a clear goal. At all times, it should be intuitive for players what must be done to achieve that goal

G7 Players must be able to make meaningful choices with non-trivial consequences, and must be aware of the consequences of these choices

G8 The game should NOT be just a representation of a real-world exercise,i.e., it must contain meaningful gameplay

3.3 Platform Requirements

P1 In order to allow widespread use, the platform should use consumer-level technologies only

P2 The platform should be extendable, i.e., allow easy design of new games and addition of new hardware such as different exercise machines

P3 The platform should be suitable for a wide range of users, e.g., not make any assumptions about age, size, and appearance of users

4 Design and Implementation

Based on the above requirements we designed an exergame platform and a prototype of an exergame.

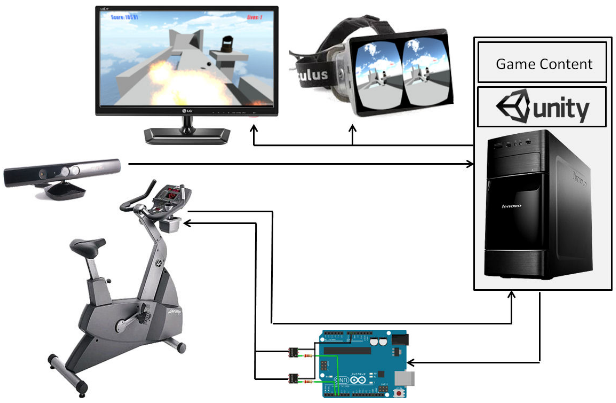

Figure 1: Our Exergame platform.

4.1 Platform Design

Our exergame platform is illustrated in figure 1. We use a Life Fitness 95Ci Upright Exercise bike, which implements the CSAFE (Communications Specification for Fitness Equipment) standard. The bike is connected to a PC using a DE9 serial cable. The exercise bike we used only allows reading of data (e.g., level, speed, calories burned, heart rate).

In order to adjust the pedaling resistance (level) from the exergame, we connected an Arduino Uno R3 via optocouplers to the circuitboard of the bike. The software on the Arduino was programmed to simulate key presses of the resistance switches to adjust the resistance to a level that could be set via serial communication by the Unity game.

Steering the bike in the virtual environment could be achieved using a game controller. However, "racing wheel" style controllers are unintuitive for a bike and potentially a safety hazard when exercising vigorously and/or using a head-mounted display. We decided to let users steer the bike using slight body movements to the left and right. This is consistent with other user actions required in the game, e.g., ducking to avoid overhead obstacles. Furthermore, mapping all user controls to body actions (pedaling, bending, ducking) results in a better workout, reduces one level of indirection in the interface, and hence results in an improved immersion.

Detection of body motions is achieved using a Microsoft Kinect motion sensor, which is placed about two meters towards the side of the bike, at a height of 1.6 meters (approximate head height of a user sitting on the bike). Using the Kinect SDK we performed upper body tracking ("seated mode") and then used the head position to detect user motions (e.g., leaning left/right, ducking, standing upright). The head provides a good proxy for the motion of the upper body, since the player's lower body on the bike is more or less fixed. We found that wearing the Oculus Rift HMD had no negative effect on tracking performance, since the Kinect SDK matches the entire body shape for tracking, rather than performing face recognition.

The height of the Kinect had to be occasionally adjusted when dealing with very small or tall users. We also tested several motion capturing techniques using a web-cam: the OpenCV optical flow implementation, FaceAPI for face tracking, and the OpenCV Viola-Jones object detection framework for face tracking. However, all of these methods proved unreliable. For example, face detection failed when users wore a head-mounted display and was prone to interference (e.g., people in the background). Optical flow performed poorly under certain lighting conditions and for certain types of clothes.

Connected to the PC were two types of displays: a traditional computer monitor placed in front of the user, and alternatively an Oculus Rift head-mounted display. The game itself was implemented using the Unity 3D game engine.

4.2 Exergame Design

Based on the requirements derived in section 3 we decided on a gameplay where the user controls by cycling and body motions a character moving along a semi-linear course containing obstacles and rewards.

4.2.1 Game Objective

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The objective of the game is to cycle along the course for a predetermined period of time (depending on player preferences and desired health outcomes), and to achieve the best score possible. The score is a function of the player's speed and distance traveled. In contrast to exercise bikes, where an increasing resistance results in higher exercise performance (e.g., calories burned), we decided that resistance has no direct effect on the score. This gives players a motivation to avoid obstacles increasing resistance.

The player has a fixed number of lives and can loose a life when hitting an obstacle, or if the pedaling speed drops below a predetermined minimum intensity depending on the player's health parameters. After loosing a life the game resumes at the position just before the life was lost. New lives can be obtained by collecting rewards (see below).

The game finishes if the preset exercise duration has been reached. If the player looses all lives beforehand, the game restarts with a score of zero.

4.2.2 Player Representation

The player representation depends on the display device. If the player wears the Oculus Rift head-mounted display we employ a first-person view, i.e., the player character is not visible on the display. Two different views, slightly offset from each other, are rendered using the Unity 3D bindings for the Oculus Rift (see figure 2).

When using a monitor in front of the exerbike we employ a third-person view and represent the player

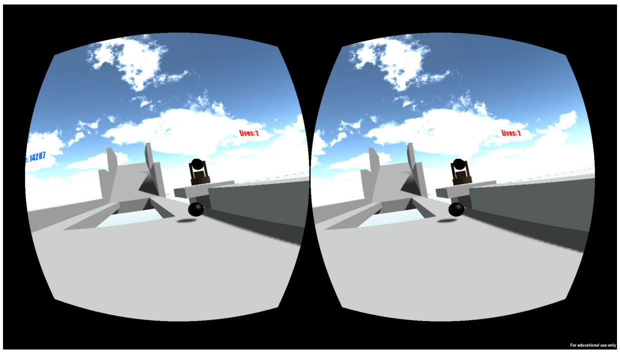

Figure 2: For the Oculus Rift head-mounted display two different views, slightly offset from each other, are rendered.

character by a green blobby figure as shown in figure 3. The figure clearly indicates the player's position in the game, and reflects players' body motions (leaning left/right, ducking) by tilting. Without this abstract representation players would not know when to steer the bike to avoid an obstacle or why they lost a life (e.g., hitting a bridge).

4.2.3 Terrain

We use a semi-linear course, i.e., the course occasionally branches, but always eventually merges back together (see figure 3). A linear course, such as a race track, would restrict player movements too much (i.e., limit choices), whereas an arbitrary branching of the course might reduce motivation (e.g., if the player feels getting lost), and would make it more difficult to create an effective multi-player implementation (competitive or collaborative gameplay). If the course branches the resulting branches always have different levels of difficulty. The "easy" branch is wider and has less obstacles, whereas the "difficult" branch is narrower and has more obstacles and rewards, i.e., it is riskier, but enables the player to obtain a higher score.

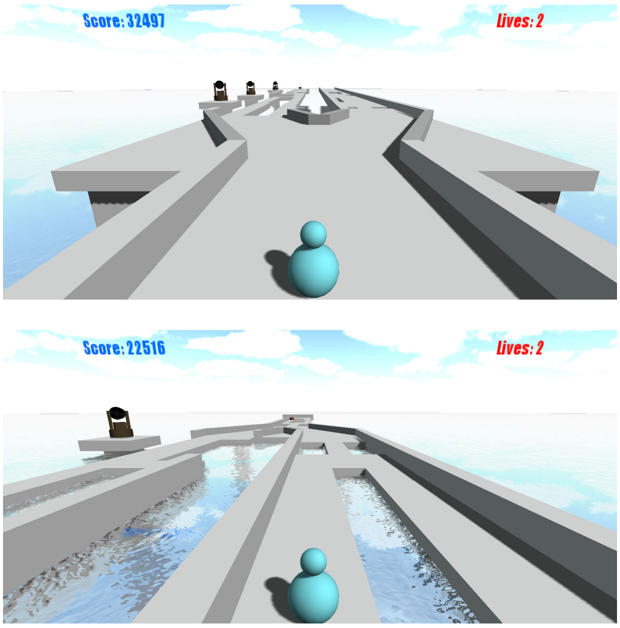

Figure 3: The course can branch (top), but branches eventually always merge back together (bottom).

The course usually contains boundary walls preventing the player form falling off. More challenging sections have missing boundary walls, a reduced width, and/or holes (pits) inside of it as illustrated in figure 4.

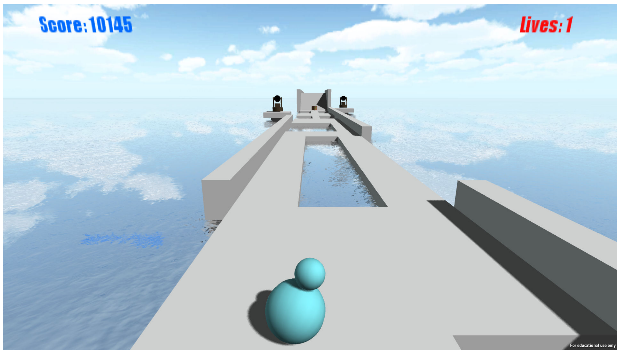

Figure 4: Challenging sections of the course have missing boundary walls, a reduced width, and/or holes (pits), which the player has to navigate around.

The entire course (width, boundaries, holes, obstacles, slopes, branches, rewards) is procedurally generated on the fly, i.e., while playing the game. This guarantees that the game is non-repetitive and infinite. One drawback is that sometimes far away sections are invisible (see figure 5).

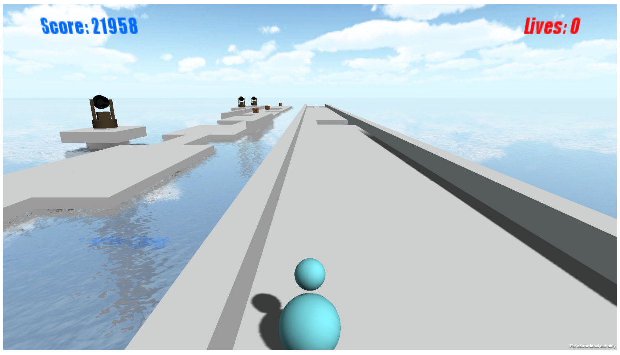

Figure 5: The course is procedurally generated on the fly and occasionally far away sections are invisible (since not generated yet).

In order to give the player clearly visible intermediate goals the course has stages. The end of each stage is indicated by a sharp upward slope, which is twice as high as the maximum height change within a stage, followed by a steep drop and flat section (see figure 6). With each stage the game gets slightly harder (e.g., more pits, slopes and obstacles), but also more rewards are generated.

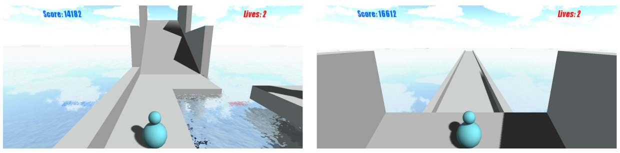

Figure 6: The end of a stage is indicated by a sharp upward slope (left) followed by a steep drop and flat section (right).

4.3 Obstacles and Rewards

In order to fulfill the gameplay requirements listed in the previous section, the following game elements were added to the gameplay:

The gameplay difficulty can be adjusted to fit the player's skills by changing parameters of the course (width, slope, holes), the number and severity of obstacles, and having less or more difficult to reach rewards.

There are two types of obstacles: Cannonballs are shot at the user. If a cannonball hits the player it slows down the player by dramatically increasing the exerbike's resistance. Players can loose a life if a cannonball pushes the player over the edge of the course. Cannonballs will explode after a preset time and "free" the player (see figure 7). Players can escape a cannonball by cycling faster and/or changing direction. The second type of obstacle are bridges. The player must duck on the exerbike to avoid a collision, which would result in loosing a life.

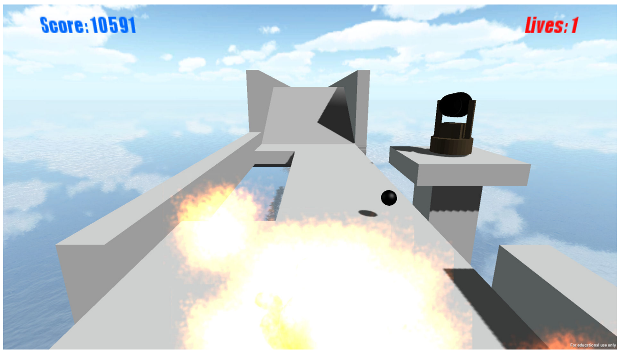

Figure 7: A cannonball has hit the player and explodes after a preset time.

In addition there are obstacles designed purely to increase the exercise level, but without reducing the score or number of lives. This includes sloping terrain and different ground materials, which both can reduce or increase the pedaling resistance

Rewards are indicated by boxes (see figure 8) and if collected (by touching the box) can result in an increase of the score by a fixed amount, a bonus life, ten seconds of pedaling at minimum resistance, or a random choice of the previous three options.

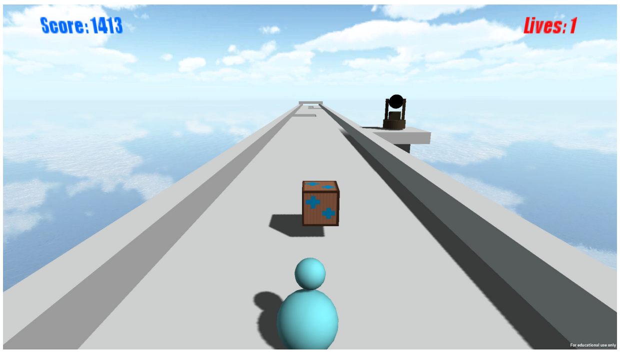

Figure 8: Rewards are indicated by boxes, in this case bonus points which are added to the player's score.

4.4 Interaction Design

Players' motions are directly mapped onto motions of the bike in the virtual environment, i.e., no physical interaction devices, such as joysticks, and no GUIs are employed. This is to enable the player to fully concentrate on the exercises and game objectives, and to increase immersion. The player's rate of pedaling controls the speed, leaning to the left / right steers the bike (e.g., to avoid obstacles), and ducking makes the player character duck to avoid hitting bridges.

Early testing found that implementing steering motions by rotating the virtual bike (and hence rotating the camera view) resulted in discomfort. The reason for this is probably due to sensory disconnect since the player's inertia system does not register a rotating motion on the exercise bike. We hence implement direction changes by keeping the player's view straight, but shifting the bike sideways depending on the duration of detected body motions. In our subsequent user study (see section 5) nobody considered this motion unrealistic or unpleasant.

Care was taken that the game character responded immediately to user's motions.

4.5 Gameplay versus Exercise Objectives

In order to achieve customized health objectives the gameplay difficulty and exercise difficulty have been separated as much as possible (exercise requirement E2). That way an unskilled player can receive the benefits of the exercise, without being demotivated by an inability to meaningfully play the game. Conversely, for competent but unfit players the gameplay difficulty can be increased (to make the game more interesting) and the exercise difficulty can be decreased to prevent players overextending themselves.

The gameplay difficulty depends on a player's experience and previous achievements, i.e., players usually start at the lowest level of difficulty and then progress with increasing experience. As mentioned previously, the gameplay difficulty can be adjusted by changing the course, obstacles and rewards. The exercise difficulty can be adjusted through changes to the baseline resistance (that is the resistance when the player is pedaling on a flat course without obstacles), and by increasing the frequency resistance-effecting obstacles, e.g., ramps, are generated.

The exercise objective of performing a steady moderate intensity workout (exercise requirement E3) is achieved by requiring users to pedal at a minimum speed (otherwise a life is lost) and by designing the course such that there are no overly long straight sections (to prevent the user from speeding up too much and reaching an unhealthy high heart rate). The heart rate is monitored at all times. It is possible to adjust the course on the fly if the heart rate gets too high, but right now we only give a warning message.

The exercise requirement E4 is achieved by using a procedurally (potentially infinite) terrain and the game objectives described in subsection 4.2.1.

The exercise requirement E5 is achieved by having a "warm-up section" at the start of a course as illustrated in figure 9. In this section both sides of the track have barriers present at all times, and the bulk of the track is obstacle free. This means, it is unlikely that a player looses a life within this section. Obstacles are introduced at a slow rate and with a low level of difficulty (e.g., narrow holes) in order to enable the player to recognize and learn to master the obstacles.

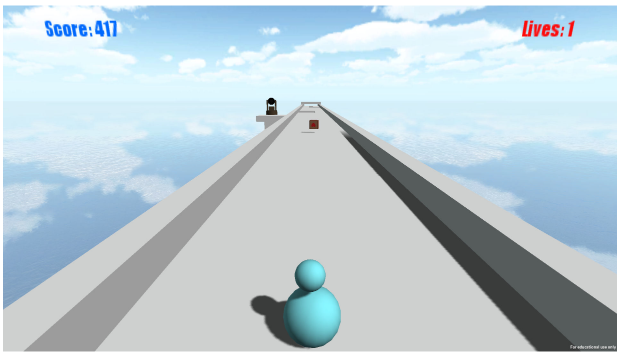

Figure 9: The "warm-up section" at the start of a course.

A limited amount of competition is provided in terms of a highscore list at the end of the game (see figure 10). The list contains the top five scores over all instances of the game. Player names are currently not included because of privacy concerns and conditions of our ethics approval.

Figure 10: High Score list.

4.6 Exergame Implementation

The exergame was developed using the `MonoDevelop` development environment from Unity3D version 3.5.7. 3D content was obtained by modeling it using `Blender` and by using Unity's 3D primitives and some existing assets packaged into Unity (e.g., water, particle effects). Some code from the Oculus Rift forums was used to overcome an incompatibility between the built-in Unity skybox system and the Oculus Rift.

5 User Study Design

In order to evaluate the exergame and determine its effect on user performance and motivation during exercise, a user study was conducted.

5.1 Methodology

Participants for this user study were drawn from the authors' institution's students, recent graduates, and staff. Each participant took part in a single test session of approximately one hour in duration.

At the beginning of a session participants completed a pre-test questionnaire collecting demographic information (see subsection 5.2). Participants were then given an explanation of the game and told to exercise as if they were in a gym. This was followed by three exercise periods of ten minutes each, separated by five minute breaks. And the end of the session participants had to complete a post-test questionnaire (see subsection 5.3).

The three exercise periods used three different conditions:

C1 Exercising without a game.

C2 Exercising with the game displayed on a standard PC monitor (1920 × 1080 resolution) in front of the participant.

C3 Exercising with the game displayed on the Oculus Rift worn by the participant.

In order to mitigate learning and fatigue effects, the order of the three conditions was determined with the Latin Square method, such that the overall distribution of orderings was approximately equal.

During the non-gaming condition (C1), the resistance on the exercise bike was set to the default game resistance level (horizontal terrain, no obstacles). 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 in a gym or at home, and thus they were allowed to adjust the resistance. All participants performed the tests using the same equipment in the same location.

At the end of each exercise session, the measurements for "distance traveled" 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 exercises rather than the game score. Additionally, during the two gaming conditions (C2 and C3), 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 authors' research laboratory.

5.2 Participant Demographics

The study had 27 participants of which 26 completed the study. One participant had to abort the study because of exhaustion. Of the 26 participants completing the study 24 were male and 2 female.

18 out of these 26 participants did two or more hours of exercise per week. 14 played two or more hours of computer games per week; and of those eight did two or more hours of exercise per week. 15 participants had previously played exergames. Nine participants had previously used a head mounted display and three of those nine has suffered from motion sickness or discomfort.

The Mean and Median Body Mass Index (BMI) was 23.3 and 22.9, respectively. The mean and median age was 24.3 and 22 years, respectively.

5.3 Questionnaire

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". Question 9 asked users to rank the conditions C1, C2 and C3. Questions 10-12 were open-ended questions.

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 use 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 comments and feedback of participants were recorded. Participants were informed before the test that they should stop if at any point they were concerned about their health during the exercise. Participants were observed during each session and asked about their condition if displaying excessive tiredness or signs of unease or illness.

6 Results

6.1 Performance

Participant performance was measured by taking the "distance traveled" and "calories burned" readouts from the bike at the end of each 10 minute exercise period.

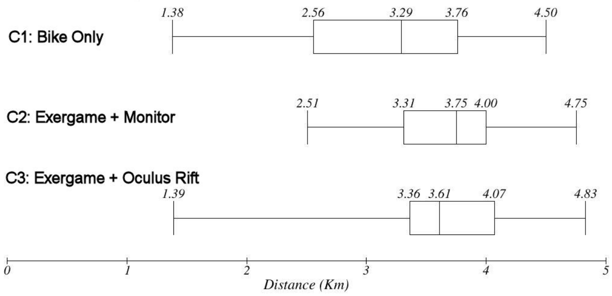

Figure 11: Distance traveled for the test conditions C1 (bike only), C2 (exergame with monitor), and C3 (exergame with Oculus Rift HMD). The chart shows the median, minimum, maximum, lower quartile, and upper quartile values for the 26 user study participants.

Figure 12: Calories burned for the test conditions C1 (bike only), C2 (exergame with monitor), and C3 (exergame with Oculus Rift HMD). The chart shows the median, minimum, maximum, lower quartile, and upper quartile values for the 26 user study participants.

Figure 11 shows that on average participants covered a larger distance when playing the exergame. The game with monitor produced slightly better results (Mean: 3.66 km, Median: 3.75 km) than the game with the Oculus Rift HMD (Mean: 3.56 km, Median: 3.61 km). The results for using the exerbike without exergame were: Mean: 3.18 km, Median 3.29 km. Similar outcomes were obtained for the "calories burned" parameter: Exergame with monitor: Mean: 68.4 cal, Median: 68.0 cal. Exergame with Oculus Rift HMD: Mean: 66.2 cal, Median: 66.0 cal. Exerbike without exergame: Mean: 63.0 cal, Median: 61.5 cal. In both cases the distribution of participants' results was close to normal.

The results were compared using the Wilcoxon Signed Rank test, with a two tailed hypothesis and a p-value significance threshold of 0.05. When comparing the results for "distance traveled" the difference between condition C1 (bike only) and C2 (exergame with monitor) was significant (Z-value -4.03, p-value < 0.001). Likewise for the difference between condition C1 (bike only) and C3 (exergame with Oculus Rift): Z-value -2.83, p-value < 0.001. The difference between condition C2 and C3 was not significant: Z-value -0.53, p-value 0.60.

When comparing the results for "calories burned" the difference between condition C1 (bike only) and C2 (exergame with monitor) was significant: Z-value -2.22, p-value 0.03. However, the differences between condition C1 and C3 (Z-value -1.32, p-value 0.19) and between C2 and C3 (Z-value -1.10, p-value 0.27) were both not significant.

It is interesting to note that the maximum values were similar in all cases, and the maximum value for "calories burned" was largest for condition C1 (bike only). This indicates that the exergame makes little difference for a user wanting a serious workout, and the "bike only" condition might be most suitable for such a scenario since the user can increase the resistance freely and that way achieve a higher "calories burned" result.

Another interesting observation is that the minimum values for "calories burned" were obtained for condition C3 (exergame with Oculus Rift). An explanation might be that some users were distracted by the head-mounted display and concentrated on the immersive environment rather than the cycling. We also found that some users had more difficulty controlling the bike using the Oculus Rift. For example, when passing a bridge in condition C2, the user can see the avatar and can duck lower if the avatar is not leaning enough forward to fit under the bridge. The Oculus Rift view did not provide visual feedback and some users did not duck enough and got killed by bridges, whereas other users ducked so much that their head and HMD touched the front of the exerbike.

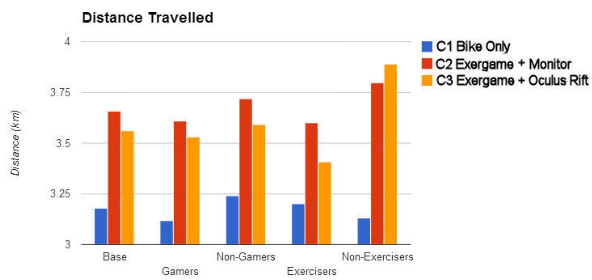

Figure 13: "Distance traveled" results for the entire cohort (base) and the following subgroups: gamers, non-gamers, users performing regular exercises, and users not performing regular exercises.

Figure 13 shows two surprising results. In the figure "base" refers to the entire study cohort. The gamers (14 of the 26 participants) are individuals who regularly spent two or more hours each week playing video games. Exercisers (18 of the 26 participants) are individuals who regularly spent two or more hours each week doing exercise.

The distance covered in the exergame was greater for non-gamers than for gamers. One possible explanation is that gamers were disappointed with the visual quality and gameplay and hence were less motivated. However, we can see that gamers also performed lower for the “bike only” condition, and hence a more likely explanation is that the gamers were less fit or less inclined to perform physical exercises. The results also indicate that the gameplay was intuitive and easy to control and no previous gaming experience was necessary in order to perform well.

The second surprising result is that users exercising regularly performed better than average in the “bike only” condition, but performed poorly in the two exergaming conditions. In contrast, users who did not exercise regularly achieved the best results of all subgroups. This indicates that the game was particularly motivating for non-physically active users, but had the lowest motivating effect on participants who were already physically active.

6.2 Motivation and Enjoyment

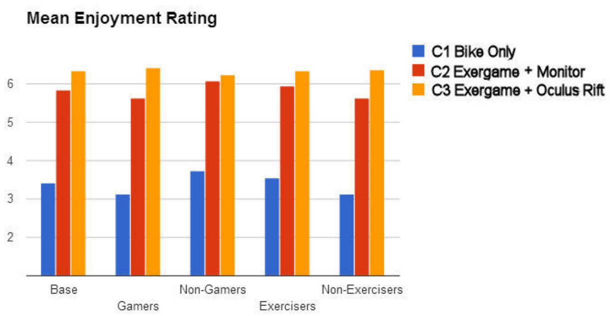

Figure 14: Mean enjoyment scores (on a scale from 1 to 7) for the entire cohort (base) and the following subgroups: gamers, non-gamers, users performing regular exercises, and users not performing regular exercises.

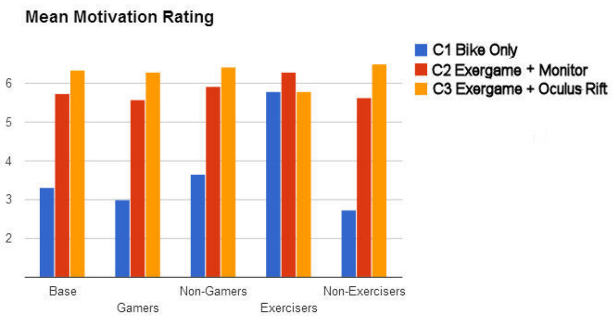

Figure 15: Mean motivation scores (on a scale from 1 to 7) for the entire cohort (base) and the following subgroups: gamers, non-gamers, users performing regular exercises, and users not performing regular exercises.

	Bike Only	Exergame with Monitor	Exergame with 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

Figure 16: Mean enjoyment and motivation scores (on a scale from 1 to 7) for the test conditions C1 (bike only), C2 (exergame with monitor), and C3 (exergame with Oculus Rift HMD).

Participant motivation and enjoyment was measured using the answers to the questions 1-8 in the post-test questionnaire (see subsection 5.3). The answers are on a seven point Likert scale ranging from 1 (Strongly Disagree) to 7 (Strongly Agree), where 4 indicates neutral.

Figures 14-16 show that participants rated the two gaming conditions as significantly more enjoyable and motivating than “bike only” condition. Using the exergame with the Oculus Rift HMD was slightly more enjoyable and motivating than using the game with a monitor.

The statement “Using the exergame with the Oculus Rift would cause me to use the exercise bike more often” had a mean response 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 (”Agree”).

An interesting observation from figure 14 and 15 is that for users performing regular exercises the exergame does significantly improve enjoyment, but has little effect on motivation when compared with the “bike only” condition.

Performing an ANOVA (Analysis of Variance) test on the participants’ feedback with a p-value significance threshold of 0.05 shows that the “exergame with monitor” was significantly more enjoyable and motivating than the “bike only” and using the Oculus Rift HMD resulted in a significantly increased enjoyment and motivation over both the “bike only” condition and the “exergame with monitor” condition.

All of the 26 participants ranked the “bike only” condition as the least enjoyable. Seven of them ranked the “exergame with monitor” condition as the most enjoyable, while the rest ranked the “exergame with Oculus Rift” condition as the most enjoyable. Only three participants stated that they would not like to use an exergame for regular exercise.

6.3 Discussion

The results indicate that the exergame significantly increases participants’ performance. In the study presented in this paper each participant attended only one session, and it is hence unknown whether these increases are due to the novelty, or would also apply in long-term use.

The “exergame with monitor” condition gave slightly better results than the “exergame with Oculus Rift” condition. Possible reasons are that users felt more comfortable using the traditional display (no simulator sickness), that they found it easier to control the bike (since the display shows the user’s position in the virtual environment using an avatar), and that they were less distracted (since for most users this was the first time they wore a HMD).

Despite of this participants rated the ‘exergame with Oculus Rift” significantly higher than the other conditions both in terms of enjoyment and motivation.

Interesting results were obtained for different subgroups. The exergame resulted in the lowest increase in performance for users regularly exercising, and it resulted in the highest increase in performance for users not regularly exercising. These results are explained by the observation that for users regularly exercising the exergame increased enjoyment, but not motivation. In contrast, for users not exercising regularly, the exergame resulted in the highest increase in motivation when compared with the “bike only” condition.

Slightly different results were obtained for the performance measures “distance traveled” and “calories burned”. A detailed analysis of the reasons for this is not possible since it is unknown how the “calories burned” value is computed by the exerbike.

6.4 Simulator Sickness

Simulator Sickness is a common occurrence when using virtual environments, and in particular when using VR displays (Merhi et al. 2007, Kennedy et al. 2010, Moss & Muth 2011). Common symptoms are eyestrain, headaches, dizziness, sweating, disorientation, vertigo, and nausea. Simulator Sickness symptoms are similar to motion sickness, but are not caused by physical motion of the user, but by motion within the virtual environment.

In our user study four of the 26 participants complained about discomfort when using the exergame with the Oculus Rift head-mounted display. In all cases only weak symptoms were experienced and nobody had to abort the study. From the three participants who reported previous experience of simulation sickness in the pre-test questionnaire only one experienced discomfort in our study. Nobody experienced discomfort in the "bike only" and "bike with monitor" condition.

Discussion with users revealed that the discomfort occurred only during slopes, with downward slopes causing a stronger reaction than upward slopes. The most likely cause is a sensory disconnect between the horizontal position of the bike in the real world and the tilted view in the virtual environment. Speed also seems to be a factor since downward slopes caused more discomfort and were associated with a higher speed than upward slopes.

6.5 Limitations

When interpreting the results some limitations of the user study must be taken into account. The demographic of the participants was 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 young males may be an ideal target audience for exergames due to their tendency to enjoy video games and the fact that their exercise motivation factors are largely intrinsic (Kilpatrick et al. 2005, Ryan et al. 1997), this might imply that the results of this study do not apply to the general population.

Our 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 a longitudinal study, such as the one conducted by Waburton et al. (Warburton et al. 2007), must be performed.

In section 3 we suggested that based on recommendations by the American College of Sports Medicine a 30 minute exercise duration is ideal. In the user study participants had to cycle three times for 10 minutes (i.e., 30 minutes in total). However, one participant was unable to complete and several participants stated that the game was hard and that they were exhausted afterwards. Our default resistance level might have been too high, or we might have underestimated the motivating effect of the game. However, none of the participants reached a dangerously high heart rate. We believe some more fine-tuning is necessary to achieve a more constant and slower pedaling speed for unfit users.

Simulator sickness is an important issue to consider when developing VR exergames. Our results so far indicate that discomfort dependent on the level of sensory disconnect. We are currently working on replacing the slopes with game elements which have a similar effect (i.e., slowing down and speeding up the user), but do not change the bike's inclination in the virtual environment.

Another problem was latency of the bike's resistance. Since the bike provided only read-out of bike parameters, changes in the resistance 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 reached. This latency was noticed by a few participants.

Finally some participants complained about the Oculus Rift: its display resolution was lower than the monitor's one, which made it difficult to see far away obstacles. When sweating the lenses of the HMD would fog up. This made using it less appealing and some participants requested a pause functionality in order to wipe the lenses without effecting their score. There were also some concerns about hygiene since the padding of the Oculus Rift soaked up sweat.

7 Conclusion

We presented a novel exergame with procedurally generated game elements taking into account user parameters and offering an infinite (non-repetitive) gameplay. We tested the exergame using different VR display technologies and compared it to "bike only" exercises.

Our results indicate that the exergame significantly increases participants' performance, motivation and enjoyment. Combining the exergame with an immersive HMD resulted in increased motivation and enjoyment compared to using a traditional display, but not in increased performance. Effectiveness of the game varied for different user groups and the largest positive effect was observed for users not regularly exercising.

Our exergame platform does not display the mode of motion (e.g., pedaling or walking). Hence the game can be used with other exercise machines such as treadmills (walking/running) and cross trainers (cross country skiing). Note, however, that with these machines excessive sideway body movements can result in loss of balance and injury. Using a treadmill while wearing a HMD is strongly discouraged. A more suitable device are omni-direction treadmills (e.g., Virtuix Omni and Cyberith Virtualizer), which have a safety harness or enclosing safety bar, and allow motions in all directions.

8 Future Work

The research we presented in this paper represents a starting point for our understanding of the utility of VR exergames as an effective intervention tool. Our findings suggest several avenues for future research.

In order to determine the effectiveness of our game in practice, we want to conduct a longitudinal study testing long-term effects. We also want to modify the game play such that it achieves translational effects, i.e., users get motivated to perform more physical activities in the real-world. This might require the development of a whole suit of games targeting different user demographics and and interests.

More research is needed on individual differences in the motivational appeal of games that differ in styles of play. We want to evaluate the motivational properties of VR exergames games and whether, and if yes why, some motivational concepts are more effective in an immersive environment. We are also interested in competitive versus collaborative game play and the use of ghosting, to enable users to compare their performance with previous attempts.

So far we only looked at improvements in physical activity. We want to investigate whether engaging exergames might have cognitive or neuroprotective benefits over the long term. In particular game design could combine cognitive training with cardiovascular exercise - both of which have been implicated in delaying or preventing the onset of age-related dementias. In this sense, exergaming may be an especially beneficial form of both exercise and cognitive training.

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