The Impact of Cognitive Tasks while Exergaming in Virtual Reality

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***Abstract*—Previous studies show that exergaming has a positive impact on users motivation to exercise over traditional methods. Unfortunately, these studies also show a lack of adherence over a longer term which is closely related to the user's engagement and motivation. This project aims to study the effects of cognitive tasks on motivation while exergaming in virtual reality, and whether they provide a positive impact on the chances of continued use. The prototype exergame we created involves flying a helicopter through a series of rings for points, and is played with an exercycle, a joystick for control, and with the Oculus Rift used to provide the virtual reality simulation.**

The proposed game was evaluated with a user study which compared two different versions of the game, one with only simple point scoring mechanics, and the second with an additional cognitive task for the user to complete. This task involved memorizing an ever-increasing sequence of colours and flying through the correctly coloured rings. We found that the game with the additional cognitive task performed better in general with over half the participants preferring the cognitive to the non-cognitive version. Unfortunately, users were still extremely divided on whether either version was preferable to traditional exercise.

***Index Terms*—Virtual reality, motivation, cognitive stimulation, exercise, video game, helicopter**

I. Introduction

Exercising frequently is well known to provide many benefits to a person's general health, such as boosting their immune system, preventing heart disease, diabetes, and obesity. It has also been shown to help prevent depression and anxiety, and improve a person's mental health[1]. With the growing concern of childhood obesity, motivating people to exercise has become an extremely valuable and important task[2].

One approach to this problem that is of particular interest to us is the combination of exercise and gaming (known as exergaming). Many previous studies have shown that current exergames are good enough to meet general exercise requirements; however they do not necessarily provide the motivation to continue with the program over longer periods of time. This is, at least partially, the fault of said studies. The main focus of these studies has been to prove that exergaming contains an adequate amount of exercise to obtain the benefits listed above. As such, very few studies have focused on the motivation to play these games repeatedly, thus resulting in a lack of adherence by the users over a longer term.

Motivation is a key element towards people wanting to continue with the exercise program. In this paper, we present a study focusing on whether additional cognitive tasks while playing an exergame have an effect on the players motivation to continue playing and exercising. In particular, we wish to answer the question: How do cognitive tasks affect the motivation and long term adherence of users while exergaming?

For this project we have created an exergame in which the player uses the exercycle to power a helicopter-esque vehicle to fly through a series of rings. We utilize three devices to achieve this: An exercycle (to provide the ability to move up and down), a joystick (to control the movement of the helicopter), and the Oculus Rift (to separate the player's vision from the direction of movement).

To answer our research question, we performed a user study comparing two different scenarios in the exergame we created. The first was flying through a single series of rings with the player obtaining points for passing through each ring successfully. The second scenario involved sets of four differently coloured rings and a simple memory game in which a sequence of colours is shown to the player. The player would then have to fly through the correctly coloured rings to obtain points, which would

[1] http://www.hsph.harvard.edu/nutritionsource/staying-active-full-story/
[2] http://www.cdc.gov/healthyyouth/obesity/facts.htm

also increase the length of the sequence.

The rest of the paper is split into the following sections: section II contains a list of related papers based on exergaming studies and motivation; section III explains the design decisions for the exergame; section IV details the implementation of our game and how it functions; section V shows our results and evaluations; finally section VI is a conclusion of our findings and contributions.

II. Related Works

Caldwell et al. [1] performed a case study on the ability for video games to help provide patient empowerment via positive metaphoric visualization. While the experiment was originally inspired by a child battling cancer, the concept of empowerment could be applied to many different aspects of life such as exercising. It is stated that engagement is a significant factor in the success of their experiments. This approach relates to our work in that we are investigating methods of improving engagement and motivation for exercise through exergaming.

Reeve [2] explored the elements of competitiveness that affect intrinsic motivation. Intrinsic motivation is derived from a need for self-determination and competence. Reeve tested aspects such as competition between participants against beating personal bests, and their effect on the participant's motivation. While the results of his study showed that the elements of competitive outcome and interpersonal context do affect intrinsic motivation, past studies have been inconclusive due to the different circumstances and types of competition. It is clear that while the focus of this paper is similar to ours (researching methods of increasing motivation), the avenue that is researched is different enough from our own study to justify our contributions in this paper.

Song et al. [3] investigated the effects of competition on intrinsic motivation in exergaming and the side-effects of presence. They tested a 2 by 2 design of experiment: Competition against Non-competition, and High individual competitiveness against Low. The results showed that there were multiple independent variables that could affect the intrinsic motivation of players, and that the variation had a strong bias from the individual player's personalities. Much like the paper by Reeve, this study has many similarities with our own study, although we have kept our focus on the differences between a game without any cognitive tasks and a game with a memorization task. Also, due to the nature of our exergame being in virtual reality, we could discover if the added immersion had any positive or negative effects.

Mokka et al. [4] developed a fitness game for a virtual fitness centre aimed at increasing the motivation and richness of the experience. Unfortunately, they had issues with the participants focusing on the exercise rather than the game itself. This has similarities to our project in that we used virtual reality to create the world for the participants. However, with the help of the Oculus Rift, we hope that users had added immersion which helped to keep the focus on the game itself, instead of the fact that they were exercising.

III. Design

In response to our research question, we chose to design an exergame that would be detached from the realities of the exercise in question (in our case, cycling). As we would like to ascertain the effects of cognitive stimulation on motivation, the exergame would incorporate cognitive tasks to help engage both the brain and body simultaneously. We created two versions of a race course, one containing simple point scoring mechanics and without any additional tasks, and a second that contained point-scoring mechanics as well as simple cognitive tasks for the users to complete.

Although studies on competitiveness, such as [2] and [3] have been performed in the past, none of them have focused on whether cognitive tasks affect people's motivation. Therefore the contribution that we wish to add is a preliminary study to find if and how cognitive tasks affect player's motivation and potential long term adherence. Due to the fact that we are limited in scope due to time constraints, this project will only be a prototype exergame followed by a survey to determine if future work would be beneficial in this area.

A. Exergame

The decision to detach the exergame from the specific exercise was made in light of studies such as [1] which describes engagement as being a large factor on the success of certain projects similar to this and [4] in which the participants had issues focusing on the game over the exercise itself. Unfortunately, this brought a separate problem of choosing a task that still intuitively made sense to the participants.

In our case, we chose a helicopter and related the exercise of cycling to the rotations of the helicopter's blades. While there were many vehicles that could perform similarly, we decided that linking the speed of the person peddling to how fast the rotor blades were spinning provided an interaction that was clear to all the people using it i.e. peddling fast results in the helicopter ascending, while not peddling will result in rapid descent.

Another decision we made was to create all versions of the exergame in virtual reality. The reason for this was to further distance the users from the belief that they were cycling the entire time. We felt that the environment created by virtual reality would help to increase the immersion that users felt while playing our exergame. This also acts as a limitation to the overall project because ideally we would like to test both VR and non-VR versions of our exergame to examine all possibilities and find the most immersive version.

B. Cognitive tasks

Choosing a way to cognitively engage the users was a difficult obstacle in our design process. Due to the wide array of tasks to choose from, there is a high possibility of many effective ways to do this. Due to the time constraints on this project, we thought that it would be best if we limited the game to only one cognitive task. We thought of ideas such as pattern recognition, moving objects, answering simple questions, and memorizing sequences. While each option was considered by our group, we ultimately settled on memorizing a sequence of colours as the final choice for this project.

Pattern recognition has a tendency to either be too simple or overly difficult and abstract. The difficulty is also dependant on the participants which makes it hard to strike a perfect balance between those two options.

We avoided choosing to move objects around despite prototyping a tractor beam for the helicopter due to our desire for the race course to have a flow to it. This meant we did not wish the players to have to stop and collect objects as we felt this would break the rhythm and forward progression.

The problem with answering simple questions was similar to our issue with pattern recognition, in that the variation on difficulty was quite large. The topics the questions would contain and how best to display the questions was another issue of concern which prevented us from using it for our prototype.

We eventually decided on a sequence of colours which the players would have to memorise. This sequence would be extended each time it was correctly completed. By limiting the number of colours (in our case this was limited to four colours), we could provide sets of rings with one per different colour of the sequence. The players would then have to fly through the correctly coloured rings in the order which they memorized.

IV. Implementation

The prototype exergame we created has been implemented in the Unity game engine. Obviously the biggest challenge for creating an entire exergame from nothing is the amount of content required (such as models, courses to race on, cognitive tasks, etc), as well as the time frame in which to create all of it. In order to make this task manageable, we have chosen to only create one course for our prototype.

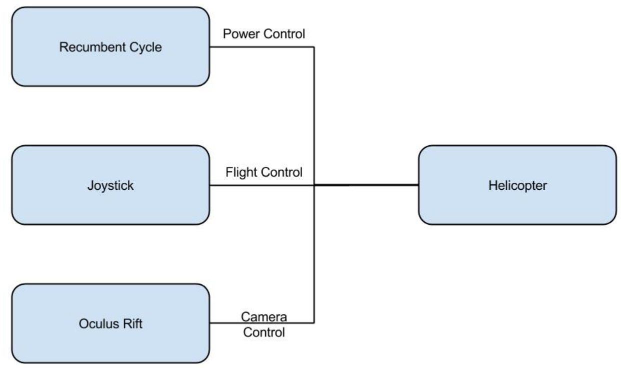

Fig. 1. Interactions of the hardware and our helicopter

To create some of the models used in our project (such as the helicopter itself) we have used Blender. The .blend files are then imported as assets which Unity automatically converts into .fbx files to be attached to game objects.

Another challenge that we had to overcome was the way in which we provide simple cognitive tasks for the users. While this went through several iterations, we ultimately chose to play a simple memory game where a sequence of coloured spheres would be shown to the players. The players would then have to fly through the correctly coloured rings in the same order as the sequence and would be scored based on how well they did.

We wanted to include a more interesting reward system where, for example, correct answers would be rewarded with a temporary speed boost as well as a lowering of the resistance on the cycle itself, while incorrect answers would increase the resistance temporarily. Unfortunately we were unable to send commands related to the resistance of the exercycle from the Unity script without a specific interface connected to the controls of the exercycle. This is a limitation of our project, not of the software and could be solved in a larger scale project with time and funding to obtain the components required.

The other hardware involved in this project include a Logitech Extreme 3d Pro Joystick, the Oculus Rift DK1, and an exercycle provided by the university. The joystick provides the users a more intuitive and natural way of controlling the helicopter's tilt, pitch, yaw, and movement. The Oculus Rift enables the user's ability to look around freely without the need to move. And finally the exercycle allows the user to control the rotors of the helicopter, and therefore the up and down movement. It is clearly also the type of exercise we have chosen for our exergame. The exercycle interfaces with Unity via a C# script provided by Lindsay Shaw, while the Oculus SDK already has integration with Unity.

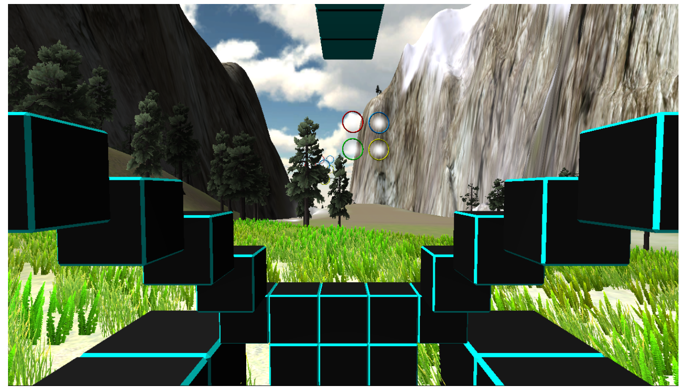

Fig. 2. Prototype of the exergame with multiple coloured rings

V. Evaluation

A. Methodology

We have investigated how an exergame utilizing simple cognitive tasks would affect the motivation of users. To achieve this we created two versions of a single main course. The first version is time-trial based, with the users receiving points for how many checkpoints they pass. The second version contains coloured rings at each checkpoint, and a simple memory game is played via floating coloured spheres inside the cockpit of the helicopter. This game involves memorizing the order of colours and then passing through the correct coloured ring at each checkpoint. Each time the sequence is completed, the length of the sequence is increased by one and the new sequence is briefly shown to the user.

The participants were given approximately 2-5 minutes each to familiarize themselves with the controls, and then they were given 6 minutes to get as far as they could with each version of the main course. To reduce learning bias as much as possible, half of the participants started on the first version and half on the second. Users were also asked to fill out several questionnaires during the experiment. Table I shows us the questions they filled out before the experiment, table II was filled out after each of the two tasks (once per task), and table III was filled out at the end of the experiment.

The experiments were carried out over two days, taking approximately 30 minutes per participant. Since each of these days were managed by different members of our team, a script was created and used to keep testing conditions as standard as possible, and reduce the amount of bias between sessions. Important aspects of the experiments such as how much help should be given to participants and what order tasks should be performed were described in this script.

We also wanted to measure the user's heart rates using a simple heart rate monitor on a watch to find out if the exergame provides sufficient exercise to benefit potential future clients. This also would allow us to discover if the two differing versions of the game provide different amounts of physical stress for users. Unfortunately, this did not eventuate and the consequences will be discussed later.

B. Results

We performed this experiment with 10 participants, and recorded the non-short answer questions in tables IV, V, VI, and VII.

When asked whether the memorization task had any effect on their performance versus not having to memorize anything, participants were divided. While there were a range of answers, such as the extra task improving performance since they were more focused on memorizing the sequence or that it took their mind off the actual pedalling, the majority were closely split between two main answers. Three participants thought that the extra task made little to no difference to their performance, and four participants believed that it made the experiment slightly more difficult.

The next question asked which mode would be preferred to be used as a form of entertainment, to which participants had a clear favourite: six people stated that they would prefer the version with the cognitive task as a form of entertainment. The remainder of the participants were evenly divided between the non-cognitive version, both versions being equal, and neither version being preferable.

Similar to the second question, participants were then asked which mode would be preferred to be used as a form of exercise. Once again, six people chose the cognitive version, but unlike the previous question, all of the remaining people chose the non-cognitive version as their preferred option.

The final question asking for comments and suggestions received a large range of answers. Some comments asked for improvements to the current build such as improving the control scheme, changing the visuals of the helicopter to look more like helicopters in real life, adding methods for colour-blind people to tell the rings apart, and the ability to change the difficulty to help get used to the controls. Others contained suggestions to include guns and/or multiplayer, or just commented that it was an enjoyable experience.

C. Discussion

A total of 10 people volunteered for this experiment (8 men and 2 women), all between the ages of 18-24. 9 out of ten identified themselves as students, with the 10th having marketing as an occupation. The students came from several different faculties in the university. While this could be a potential threat to validity due to self-selection bias, it can also be useful since 20.6% of adults aged 15-24 in New Zealand are considered obese. This statistic continues to rise as we look at older demographics and therefore targeting this age group is an important step in prevention of obesity in older age groups.

One major threat to validity was the lack of a heartbeat monitor during the experiments. By not measuring the exertion of our participants, we have no way of determining if our exergame provides sufficient exercise. This also renders our question about perceived exertion relatively useless as we cannot compare the answers with empirical evidence. Despite this, an interesting statistic to note is that on average, the participants believed that the non-cognitive mode required more exertion that the cognitive mode. This could, in part, be due to focusing more on the memorization task, thus taking their minds off the exercise itself.

Another interesting statistic is while 6 people found the cognitive exergame more motivating, the answer to whether they prefer the exergame to traditional exercise was much more divided with 3 disagreeing, 4 people agreeing, and the remainder staying neutral. This could be due to a variety of reasons, but unfortunately we did not have a follow-up question to find out.

Other common threats to the validity of the study were minimized as follows: Order bias was reduced by alternating the version that the participants started on. Potential training effects from the course that the user started on was solved by giving each user a short period to train with the control scheme and the Oculus Rift. During the training period, if the users required direction or help with the controls we would help to explain it to them. However, during the experiment itself, we kept advice and help to a minimum to allow the participants room to try solve any potential problems themselves. Participants were also given a short break between each version to reduce any fatigue that might have occured. Finally, we were aware that social desirability bias could be an issue and as such, we asked for honest feedback from the users. While there isn't any way to prove that we prevented social desirability bias, we hope to have diminished it.

VI. Conclusion

The goal of this project was to investigate the effects of cognitive tasks on the motivation and long term adherence of users while exergaming. We created two versions of a virtual reality exergame aiming to answer this question. While the length of our project has limited the scope, the results of our preliminary study show that the version of our exergame with the additional cognitive task was preferred by the majority of our participants. They also show that our participants were particularly divided on whether they preferred traditional exercise over our exergame.

It is clear that there is potential in this research area. Should future work be performed by us, we would like to create a larger study encompassing a more diverse age group as well as including an empirical measurement of the participant's physical exertion to ensure that it meets general exercise requirements. We would also like to monitor participants over a longer period of time to properly research the effects on long term adherence.

References

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Age:	12-17	18-24	25-34	35-44	45+
Gender:		Male		Female	
Occupation:					

	Daily	Two-Three times a week	Weekly	Monthly	Never
Have you used an Oculus Rift/VR headset before?	1	2	3	4	5
Have you used a joystick before?	1	2	3	4	5
Have you used an exercycle/bicycle before?	1	2	3	4	5
How often do you exercise?	1	2	3	4	5
How often do you play video games?	1	2	3	4	5

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I consider myself physically fit	1	2	3	4	5
I feel physically fit today.	1	2	3	4	5
I enjoy exercising.	1	2	3	4	5
I enjoy playing video games.	1	2	3	4	5

TABLE I
PRE-QUESTIONNAIRE

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I found the experience physically challenging.	1	2	3	4	5
I felt comfortable while using the system.	1	2	3	4	5
I experienced motion sickness while playing the game.	1	2	3	4	5
I felt physically challenged while using the system.	1	2	3	4	5
I felt cognitively challenged while using the system.	1	2	3	4	5
Playing the exergame was enjoyable overall.	1	2	3	4	5
The exergame was immersive.	1	2	3	4	5
On a scale of 6-20, what number best describes your level of exertion?					

TABLE II
POST-TASK QUESTIONNAIRE

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I enjoyed playing the exergame.	1	2	3	4	5
I would prefer to exercise using this exergame rather than through traditional means.	1	2	3	4	5
I found the game with the cognitive exercises more motivating.	1	2	3	4	5
How do you think the additional task affected your performance?					
Which of the modes of play would you prefer to use as a form of entertainment?					
Which of the modes of play would you prefer to use as a form of exercise?					
Comments and Suggestions?					

TABLE III
POST-QUESTIONNAIRE

Age:	18-24	
Gender:	Male: 8	Female: 2
Occupation:	Student: 9	Marketing: 1

	Daily	Two-Three times a week	Weekly	Monthly	Never
Have you used an Oculus Rift/VR headset before?				1	9
Have you used a joystick before?				1	9
Have you used an exercycle/bicycle before?	1	1		3	5
How often do you exercise?	3	2	4		1
How often do you play video games?	3	3	1	3	

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I consider myself physically fit		1	2	4	3
I feel physically fit today.	1		4	4	1
I enjoy exercising.	1		2	6	1
I enjoy playing video games.				4	6

TABLE IV
PRE-QUESTIONNAIRE RESULTS

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I found the experience physically challenging.		3	1	6	
I felt comfortable while using the system.		4	1	4	1
I experienced motion sickness while playing the game.	3	4	2	1	
I felt physically challenged while using the system.		3	3	4	
I felt cognitively challenged while using the system.	1	2	2	3	2
Playing the exergame was enjoyable overall.			2	6	2
The exergame was immersive.			2	8	
On a scale of 6-20, what number best describes your level of exertion?		Mean: 12.2		Median: 12	

TABLE V
NON-COGNITIVE QUESTIONNAIRE RESULTS

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I found the experience physically challenging.		2	3	5	
I felt comfortable while using the system.		2	2	4	2
I experienced motion sickness while playing the game.	2	5	2	1	
I felt physically challenged while using the system.		2	5	3	
I felt cognitively challenged while using the system.		1	3	5	1
Playing the exergame was enjoyable overall.				8	2
The exergame was immersive.			3	6	1
On a scale of 6-20, what number best describes your level of exertion?		Mean: 11.8		Median: 12	

TABLE VI
COGNITIVE QUESTIONNAIRE RESULTS

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I enjoyed playing the exergame.			2	6	1
I would prefer to exercise using this exergame rather than through traditional means.		3	2	3	1
I found the game with the cognitive exercises more motivating.		1	2	4	2

TABLE VII
POST-QUESTIONNAIRE RESULTS