Towards a Human Machine Interface Concept for Performance Improvement of Cycling

Menah El Bastawisy[1(✉)], Dirk Reichardt[2], and Slim Abdennadher[1]

[1] German University in Cairo, Cairo, Egypt
{menah.elbastawisy,slim.abdennadher}@guc.edu.eg
[2] Duale Hochschule Baden-Württemberg, Stuttgart, Germany
dirk.reichardt@dhbw-stuttgart.de
http://www.guc.edu.eg/

Abstract. Exercising tends to be tedious and boring. Users search for means of entertainment during their workout. Motivation is an essential factor that inspires a person to maintain physical activity levels. A number of exercise bicycle manufacturers have enabled their equipment to port data signals to computers for the purpose of training logs. However, they all lack the motivational and the fun factors in their system. Many people face obstacles to improve their physical activity due to lack of accessibility to physical activity facilities and physical trainers. Technology can provide immediate personal assistance anywhere and anytime. In this paper, we present a persuasive game environment integrated to cycle training. The system measures the performance of a rider and visualizes a scenario through which the virtual bike trip leads. The players maintain their excitement while riding the bicycle to improve their performance on how to enhance cycling skills.

Keywords: Test environment · Android · Persuasive technology · Exergaming

1 Introduction

It is commonly known that users who exercise on bicycles and other fitness devices, watch television or listen to music so as not to become bored during their workout. In addition, motivation is an essential factor that can help maintain and increase physical activity levels. With the introduction of computer systems, home and gym fitness enthusiasts began seeking solutions for electronic motivational workouts. A number of exercise bicycle manufacturers have enabled their equipments to port data signals to computers for the purpose of interactive training logs. None, however, provides gaming environment, which allows the virtual cycling simulation to be experienced with excitement. There have been many types of exercising devices developed that replicate the leg and body movement of riding a bicycle and are grouped into so called stationary or exercise bicycles. Many people face obstacles to improve their physical activity due to various reasons; such as lack of accessibility to physical activity facilities and

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physical trainers. Technology can aid in facilitating physical activity by providing immediate personal assistance anywhere and anytime. The Duale Hochschule Baden-Wrttemberg (DHBW) Intelligent Interaction Lab in Stuttgart, Germany provides a Cycle Trainer system, which measures the performance of a rider and visualizes a scenario through which the virtual bike trip leads. Power and cadence measurements are taken from both pedals and the heart rate will be monitored as well. The aim is to develop a persuasive HMI system for the riders, which influences their behavior in order to improve their performance, through using persuasive computing [3]; by embedding the training into a game environment. The game should be intriguing and interesting to the extent of keeping the motivation of the bike rider up and their performance gains should be improved. However not so overwhelming not to distract the user from the main purpose of the exercise. The game should be captivating and absorbing to keep the user going for a long period of time without getting bored. Nonetheless, it should be as challenging as well to trigger the sense of adventure of the user and the need to go on with the exercise. The Human Machine Interface HMI was tested with a reasonable number of candidates at the end. The interface was be carried out on an appropriate percentage of different mindset of users to verify the quality and the success of the research done. This paper is organized as follows, in Sect. 2, a discussion of the related work done in cycling applications and exergaming is introduced. In Sect. 3, an overview of the system, explanation of the project approach and the game description is given. Section 4, introduces the user study and the results of this work. Finally, Sect. 5 concludes and provides insight into future work.

2 Related Work

Cycling Application. Bolton, Lambert, Lirette and Unsworth [1] presented PaperDude, a Virtual Reality cycling based exergame. Users bike down a virtual street using the Oculus Rift, pedaling on a physical bicycle attached to a power trainer and throwing virtual papers using a gesture through a Microsoft Kinect camera. Another related study with similar setup to our project was done by Hirose and Kitamura [2]. In their work, they used an indoor cycling system but instead of displaying virtual reality routes; they used Google Street view to display Street view images with a route map. They did not provide the users with pedaling speed information. The participants were asked to ride the bike twice, once without anything displayed on the screen and a second time with different assigned tasks. The average speed of both rides where compared to evaluate their system. Their findings concluded that the group who did the exercise with Street view had higher significance in their average over those who did the exercise with no display [2].

Exergaming. There is a large body of work done in utilizing games in general exercises to make it more interactive. In the work of Gardiner [5], the viability of physical interfaces to impose exercise using computer interaction was explored. Exercising in general enforces tediousness and tends to be unexciting; thus integrating the exercises with game interface may change the conceptual idea behind exercises. Many physical game interfaces are in existence using several means like dancing, punching bags, virtual drums and guitars and many more. Following to the several means of exercising, is the exercise bike, Atari Puffer in 1982 was the first to prototype a game controller using the grips of the exercise bike to connect the exercise bike and the game console. Another example is using the snake mobile game in a location-based application that encourages walking. Chatter and Sioni [6] show how using the methodology exergaming, which is video games that combine exercise and play, could encourage physical activity by adding the enjoyment factor to it. Additionally, Lin et al. [7] wrote a paper about an application called FishnSteps, which combines the use of the pedometers, small electronic devices that monitor individuals step counts, with the engagement of social computing games. The application would match the count of steps the user did with the growth and emotional state of a virtual pet that was given to each user.

3 System Design and Implementation

3.1 Technology

In this section, a system overview of the tools and the gears used in this project is presented. The entire project revolves around indoor cycling and bike system. The system setup was built inside the Intelligent Interaction Lab at DHBW Stuttgart. The LCD screen is mounted on the wall plugged to a PC. The PC is connected to the Tacx cycling trainer system using the Genius Smart tool via Bluetooth Smart. In the meantime, the Android tablet is mounted at the front of the bike. The rider's movement while cycling were tracked via Garmin Vector sensor which measures the power output at the pedals. It can independently measure power from each leg and report total power as well as the balance between the right and left leg. Vector 2 records cadence and a variety of power metrics. Mio VELO is a heart rate sensor that tracks the heart rate with peak accuracy from the wrist. With built-in Bluetooth Smart and ANT+ connectivity, Mio VELO easily connects and shares fitness data in real-time with smart fitness apps, GPS watches, and bike computers. Android acted as the host platform for the monitoring and feedback system, which was deployed on an android tablet. All the sensors along with the game graphics were aligned together and integrated on to the android device. Android is starting to add ANT+ support in their newer devices to cover the wide range of sensors using ANT as a communication protocol (Fig. 1).

3.2 Gamification

The Android application and libGDX are communicating together and the user is going back and forth between both entities smoothly; thus having the entire application responsive to all changes applied by the user. Cycling Trainer Game is an Android application that embeds persuasive technology by adding a simple interactive game to the basic android sensor application.

Fig. 1. The entire project setup

Game Design. For the game to deploy the persuasive technology techniques; the users need to have a sense of accomplishment. Accordingly, the user was awarded with a score whenever the game goal is achieved.

Cycling Trainer Game aims at improving the cyclist riding experience by monitoring and providing feedback on the cyclists balance on the pedals as well as the cyclists pedaling frequency. Each unit needed to be gamified differently. Hence the application includes two distinctive games. The first game objectifies improvement in the cyclist's balance on the pedals while the latter objectifies maintaining constant frequency (cadence). In the meantime the user's heart rate was monitored for health assurance. According to Tanaka et al. [10] findings, the adequate equation for estimating the maximum heart rate is $208 - 0.7 * \text{age}$ in healthy adult humans. The equation calculation was done on the age of 30 giving a maximum heart rate of 187. Due to the physical nature of the game, the maximum heart rate was reduced to 160 since the medical background of the participants was unknown. If the user reaches the maximum heart rate while cycling a counter feedback system would initiate. The findings of Mok et al. prove that music improves significantly the patients anxiety levels, heart rates, and blood pressure over patients who did not listen to music [9]; thus a slow soothing rhythm music would initiate playing once the user reaches the maximum heart rate threshold. In addition, the display of nature scenery which was provided by Tacx's virtual reality system. The first game, the balance game as shown in Fig. 2, is a seesaw game where the cyclist targets the state where the board is perfectly horizontal. The seesaw methodology was used for its familiarity thus not putting on the cyclist extra overhead of getting accustomed with the game. The cyclist attains the horizontal state once the feet's pressure on the bikes pedals are equally distributed between the left and the right pedals. As for the second game, the cadence game as shown in Fig. 3, the cyclist is required to maintain constant frequency through the entire exercise, the cyclist needed to receive a motivational scheme to preserve consistency in frequency while completing the exercise. Subsequently, the game mechanism was

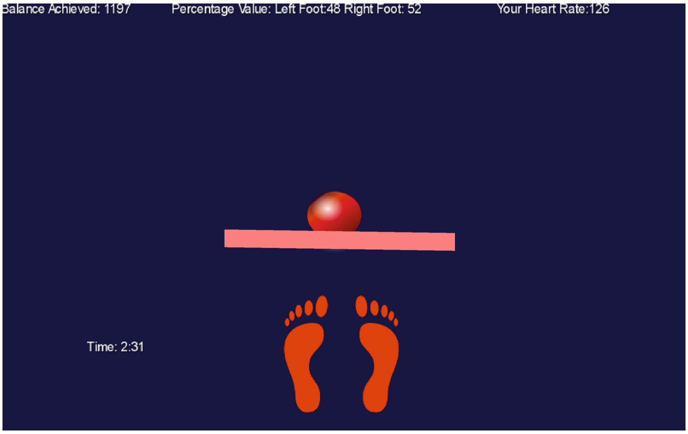

Fig. 2. The balance game, seesaw game

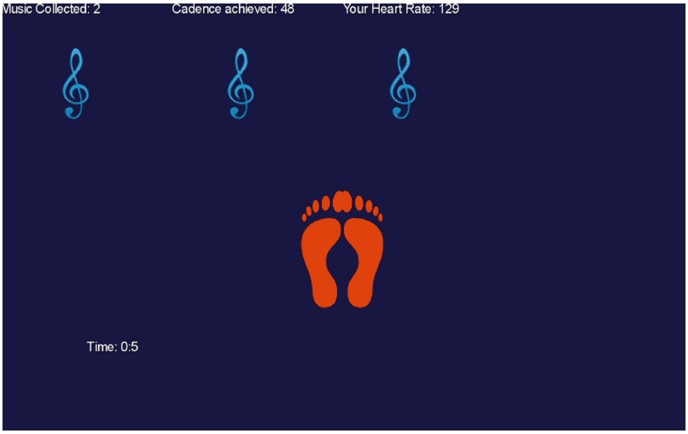

Fig. 3. The cadence game, catch the notes

designed aiming to encourage cycling as well as maintaining constant frequency. For this task, a game of catch the notes was implemented where once the cycling starts the cyclists feet start to move up the screen aiming at catching the flying music notes at the top of the screen. The game has two modes, speedy mode and relaxed mode, accommodating to the variation of users' physical state. The game session would last with time interval of the users input, the time counter is displayed at the bottom left of the screen. In the meantime, displayed at the top of the screen is the metric's value recorded by the sensor along with the heart rate of the user. The user's score is updated and shown at the top left of the screen. When time is up the user is transferred to the scoring screen with some animated fireworks and the score is displayed. Finally, the users can generate a graph presenting visual progress of their cadence throughout the entire workout.

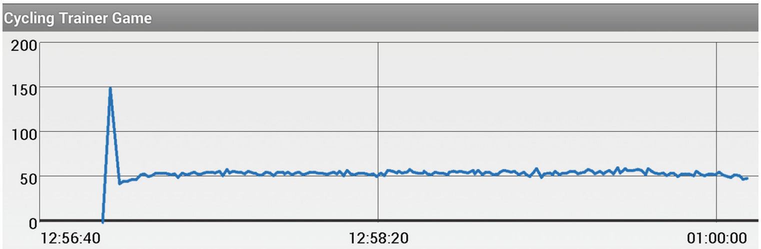

Fig. 4. The output graph at the end of the workout

This graphical visualization helps the user monitor their progress for the entire exercise. A graph example is displayed in Fig. 4.

4 Study Design

In this section, we discuss the user study and evaluation procedure which was conducted at the Intelligent Interaction Lab at DHBW Stuttgart, Germany.

4.1 User Study

The experimental design was as follows: The user group was split equally between four permutations of the following four exercises; Balance Game, Cadence Game, Data Application and Cadence Challenge. The Data application is where the user follows the progress using the ANT+ data while the Cadence Challenge is where the user is asked to maintain the same frequency without any aids. For each participant the user study would be a workout for ten minutes. Each participant carried out only three exercises from the four. Each exercise took three minutes in addition to a minute to warm up. The three minutes time-spam was adequate to retrieve the needed data for analysis. Next, the user group was divided equally into two groups. The first group started with the Balance Game then the Data Application exercise while the other group started vice versa. Consequently each sub user group was again subdivided equally into two groups; one group did the Cadence Game in the meantime the other subgroup did the Cadence Challenge.

User Evaluation. The users' feedback about the system and its features were gathered through quick survey conducted at the end of the experiment. The survey included a list of questions evaluating the users' interpretation of the system, its features and benefits. Each question in the survey targets specific criteria in the evaluation. Most of the questions were answered using the Likert Scale [11], the rating scale of five points.

User Group Profile. The user group was total of 20 participants. The group consisted of both males and females with 70% of the population were males. The biggest age group was between the ages of 20 and 25 years as shown in Table 1. The physique of the participants differed among the user group as well as being accustomed to riding a bike in their daily life. More than half the user group, about 55%, rarely rode bikes, while about only 15% rode bike daily and only 5% never rode a bike before. The users' familiarity with bike riding is displayed in Fig. 5

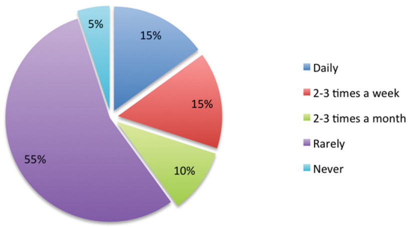

Fig. 5. Users' bike riding demographics

User Evaluation Feedback. More than half the user group, 65%, disagrees that they were mentally pressured when using the application, whilst, 20% were neutral on how mentally pressured they were, with the remaining user group agreeing to being pressured when playing the game. The users were asked after the experiment about the post-effect of the application on their cycling skills, three criteria were examined for that purpose. First, the users were asked if they thought they were successful in achieving the goal of the experiment. From the total user group, 75% believed they were successful with the experiment goal while 20% were impartial and only 5% thought they were unsuccessful.

Table 1. Users' demographics

Age	# Females	# Males
<20	0	1
20–25	5	9
26–30	0	2
>30	1	2

4.2 Data Analysis

Cadence Data Processing. For each user, the data values for the cadence from the data task and the assigned task, the game and the challenge, were retrieved and mined. To calculate the cadence consistency; the percentile values were calculated for the two datasets for each user. Cluster analysis was computed on each percentile dataset into 8 clusters. A random user was selected from among the user group to illustrate the Data Mining process carried out. User 7 was assigned to the Game Task and had no physical background. User 7 achieved consistency in the Game task of a value of 73 from cluster 7, 4 and 1, while achieved a value of 64 in the Data task from clusters 7, 4 and 8. The summation of the three clusters was calculated and recorded for each user twice, once for the Data task and once for the Assigned task. These numbers represents the ability of the users to maintain their consistency through out the experiment and were used to carry out the rest of the data analysis.

Each related group was gathered separately for investigation. The participants of each assigned task, the Challenge Task and the Game Task, were grouped together and further split according to their physique nature. This further splitting was needed to distinguish between the outcomes of the participants according to their physical capabilities, since the experiment is dependent highly on their physical background. Four Paired Sampled T-Test were computed, first, for participants with cycling background two paired t-test were calculated. One between the Game and the Data task that the statistics showed that there was a significant difference between the data ($M = 80.50$, $SD = 5.00$) and game ($M = 66.00$, $SD = 4.69$); $t = 7.17$, $p(0.006) < 0.05$. These results suggest that the Data Task affects the participants with physical background more consistent with their compared to the game task. The second test was between the Challenge and the Data task. The statistics showed that there was no significant difference between the data ($M = 71.00$, $SD = 7.57$) and challenge ($M = 76.00$, $SD = 3.91$); $t = 1.132$, $p(0.340) > 0.05$. The same was carried out for participants with no cycling background. For the Challenge-Data test, the statistics showed that there was no significant difference between the data ($M = 69.83$, $SD = 10.28$) and challenge ($M = 66.50$, $SD = 5.12$); $t = 1.055$, $p(0.340) > 0.05$. As for the Game-Data task, the statistics showed that there was a significant difference between the data ($M = 63.83$, $SD = 3.18$) and game ($M = 69.00$, $SD = 2.68$); $t = 3.893$, $p(0.011) > 0.05$, this can be summed up in Table 2.

Balance Data Processing. For each user, the data values for the pedalling balance from the Data task and the Game Task were retrieved and mined. The pedaling balance was evaluated according to how many times the participants were able to achieve complete equilibrium, reaching a value of **50**, retrieved from the vector sensor whilst cycling. Therefore, for each participant the number of occurrences for the value **50** was computed twice, once from the data values retrieved from the data application task and once retrieved from the game application task. The statistics showed that there was none statistical significance between the game ($M = 13.00$, $SD = 11.07$) and data ($M = 11.65$, $SD = 9.54$); with a pvalue$(0.388) > 0.05$.

Table 2. Paired sample T test results

Type		P-value	Significant <0.05
With cycling background	game-data	0.006	Yes
	challenge-data	0.340	No
Without cycling background	game-data	0.011	Yes
	challenge-data	0.340	No

5 Conclusion and Future Work

In this paper, an introduction of a persuasive HMI exergame was embedded in a cycling trainer. A user study was conducted to test the system. From the users' evaluations, we gathered that they prefer the gaming environment while exercising more than the usual dull data application. Cyclists agreed to performing better while using the game application and stated they were not mentally pressure nor felt any difficulty imposed by cycling while using the game. They appreciated being provided with a feedback system to follow up on their progress on their own without the need of the help of a personal trainer. Finally, almost all users enjoyed their cycling activity due to having the gaming environment embedded in it. The data analysis that was carried out on the data retrieved from the sensors that tracked the performance of the user for the entire workout, had some limitations. First, due to the permutation of the experiment the data were not consistent on all users. Furthermore, the tiring nature of the user experiment could have influenced the data with some unavoidable noisiness. The data analysis showed that there were significant results in the cadence game over the data application while there was no significance between the data application and the cadence challenge. In the meantime, the balance game did not show significant difference from the data application. However, for participants, who performed better with the game application, had an overall better performance over those who performed better with the data application. This shows a higher probability of the success of the balance game but with some counter measurements; such as, all users should follow the same sequence, who have the same cycling background and with higher number of participants. The challenge task showed that the users require some visual aid that facilitates the monitoring of their progress. From what we gathered from previous work done in this field; is that exergaming could highly affect the population positively and encourages them to exercise while influencing them with a fun factor. However none of the mentioned monitoring the user's exercise progress or gave the user any feedback whilst exercising. We can conclude from this analysis that the addition of visualization and HMI system does have a positive effect on the population. This field has many promises to the exercising world and could benefit from the wide range of opportunities it might provide.

There are few areas which require further investigation. Professional cyclists could highly benefit the analysis with their input to the system. In addition, long term testing is encouraged to monitor the progress of the cyclists after using the system for a longer period of time. Finally, the permutation of the user study could be altered to foresee the resulting analysis.

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