BLEKINGE TEKNISKA HÖGSKOLA

BTH

Kandidatarbete i medieteknik, Institutionen för teknik och estetik, vårtermin 2023

Undisplayed BPM for Engaging Exercise

Using Heart Rate Data in a Lower Body VR Exergame

Ajsha Caca | Sejke Nord

Handledare Annika Olofsdotter Bergström

Examinator Sven Johansson

Abstract

This study has researched the use of undisplayed heart rate data as biofeedback in the context of a lower body VR exergame using a fitness bike, in collaboration with Ericsson Research. Most of the global population need to exercise more, but describe it as dull and monotonous. By making a VR exergame using heart rate data where the user's bpm is not displayed, but instead having a character tell the user when they need to speed up or slow down to reach the desired heart rate bpm range, the authors believed that the users would be less aware that they were exercising and be more engaged in the experience. During the study testing was used, as well as surveys and interviews. The results affirm the authors' hypothesis. At least half of the testers of the final iteration were unaware of heart rate data being used during the experience, despite being told of it before the testing started, saying that they were so engaged in the experience they did not think about much else. All testers of the final iteration preferred using a fitness bike with the VR exergame, all were willing to use it for longer periods, and all were willing to use it regularly, describing that they did not view the experience as exercising but as entertainment. The authors conclude from the results that there is a great demand for engaging exergames using undisplayed heart rate data, which could be used in different situations, e.g. healthcare.

Keywords Heart rate data, biofeedback, VR, virtual reality, fitness bike, health.

Abstrakt

Den här studien har undersökt användandet av pulsdata som biofeedback, där bpm inte visas för användaren, i kontexten av ett träningsspel i VR för nedre kroppen som används med en träningscykel i samarbete med Ericsson Research. En större del av den globala befolkningen behöver träna mer, men beskriver det som tråkigt och monotont. Genom att skapa ett träningsspel i VR där pulsdata som inte visas används, där en karaktär i spelet säger till användaren att öka eller sänka hastigheten när användaren hamnar utanför det rekommenderade pulsintervallet, förmodas det att användarna inte kommer vara lika medvetna om att de tränar och därför bli mer engagerade i upplevelsen. Under studien användes testning, enkäter och intervjuer. Resultaten bekräftar författarnas förmodan. Åtminstone hälften av testarna av den sista iterationen var omedvetna om att pulsdata användes under upplevelsen, trots att de informerades om användningen av pulsdata innan testningens början, och förklarade att de var så pass engagerade i upplevelsen att de inte tänkte på annat. Alla testare av den sista iterationen föredrog att använda en träningscykel med träningsspelet i VR, alla var villiga att använda det under längre perioder, och alla var villiga att använda det regelbundet, med beskrivningen att de inte upplevde det som träning utan som underhållning. Utifrån resultaten drar författarna slutsatsen att det finns en stor efterfrågan för engagerande träningsspel som använder pulsdata som inte visas för användarna, vilket hade kunnat användas i olika situationer, ex. inom sjukvård.

Nyckelord Pulsdata, biofeedback, VR, virtual reality, träningscykel, hälsa.

Introduction

The modern human is largely aware of the physical and mental benefits from regular exercise. Still, a large population finds it difficult to achieve their fitness goals, and describes fitness as dull and monotonous (Wolff et al., 2021). The World Obesity Federation (2023) has made a study which predicts that more than half of the global population will be living with overweight and obesity by 2035 if current trends continue. World Health Organization (2023) declares that overweight and obesity increase the risk for a number of chronic diseases, such as heart disease and stroke, which are the global leading causes of death. One way to lower the risk of overweight and obesity is to engage in fitness, especially regular fitness. Thus, there is a great need in creating new engaging and safe ways to exercise in our modern society. This study explores how heart rate data can be used in a lower body Virtual Reality (VR) exercise game (exergame), using a fitness bike, to encourage users to start the journey of improving their fitness.

When using heart rate data as biofeedback in exergames the common approach is to display the bpm to the users. The authors chose during this study to not display the bpm, in the belief that the users will be more engaged in the experience by not being as reminded of exercise. The user wears a heartbeat sensor secured to a finger for registering heart rate data, which is used in the VR exergame to provide biofeedback discreetly through the in-game-character Miloo who is lost and gets a ride home in the bicycle basket with help from the user. The user's heart rate is recommended to be in a different range depending on their fitness goal. When the user's heart rate is outside the recommended heart rate bpm range Miloo encourages the user to slow down or speed up to reach it, thus creating the best conditions for the user to achieve their fitness goal, and acting as a reminder to avoid overexertion.

VR is used as the context in which heart rate data is explored in this study. The popularity of VR has increased during the last decade, especially when used as a means of elevating an experience to increase engagement for the user. Cmentowski et al. (2023) express that VR exergames provide engagement for the user, and increase motivation for exercising. However, while VR exergames mainly using the upper body have been widely explored, VR exergames using the lower body have barely been researched. Many popular upper body exergames have been created, such as Beat Saber where the player uses the default VR setup (headset and hand controls) to slice blocks coming toward the player in rhythm to music, and duck to avoid obstacles. The reasons for the lesser interest in researching lower body VR exergames may be because of the challenges a lower body VR exergame provides, such as the more explosive movements and the higher risk of instability that ensues with movements similar to running and jumping, which could result in an enlarged risk for accidents. Upper body VR games also do not require any additional hardware besides the default VR setup, which many lower body games would need to fully function (Cmentowski et al., 2023). Ring Fit Adventures, which is a full body exergame made for the Nintendo Switch where the player sets out on adventures and fight monsters uses additional hardware in the form of a pilates ring and a leg strap (Nintendo, 2019). Be that as it may, there are options of lower body fitness with less explosive movement that can be practiced in safer forms, which do not require the invention of new additional hardware.

When using a fitness bike for spinning the user sits upon the bicycle saddle and does not need to focus on balance to keep the fitness bike from tumbling over or be cautious of accidents resulting from explosive movement, thereby providing an excellent alternative for a user-friendly lower body VR exergame. Fitness bikes are readily available for the masses to purchase, and many keep them in their homes. The authors of this study identified through a survey that the majority of people who own a fitness bike do not use them as they find the experience to be dull and monotonous. VR exergames using a fitness bike have been previously made to make the experience more engaging. Nonetheless, the authors have to this date only seen VR exergames using a fitness bike providing another virtual environment, and not taking on a more game-like approach, e.g. interacting with another character in-game or introducing a quest.

Theoretical framework

Desnoyers-Stewart et al. (2019) describe a bioresponsive generative system that immerses two users in a virtual underwater environment, where their breathing controls the movement of a jellyfish. As the users synchronize their breathing, a virtual glass sponge-like structure starts to grow, representing their physiological synchrony. The interaction is designed to last around 5 minutes, and each time a glass sponge is completed a new structure is started, allowing users to continue the interaction as long as they prefer to. The resulting structure populates the virtual reef as more people interact with the system, providing complex and intriguing forms of biofeedback reacting to the users' internal state of synchronized breathing, creating the virtual world around them. Desnoyers-Stewart et al. (2019) state that immersive biofeedback connects users to their physiological state, and could be used to increase self-awareness. The study above was a great inspiration to this study, more precisely using biofeedback in VR where its synchronicity affects the experience. The authors of this study have used heart rate data as the bioresponsive system to generate biofeedback. The correctly synchronized heart rate data to the recommended heart rate bpm range for the chosen fitness goal affects the user's movement speed. Both forms of biofeedback, breathing and heart rate, depend on the input of analogical means, which are then digitalized into data and affect the VR experiences.

Soojeong et al. (2017) made a study where a VR exergame was created that changes the difficulty of the game depending on the users heart rate data and game performance. The authors of the study express that playing VR exergames increases the actual exertion while decreasing the perceived exertion, which raises the issue of overexertion. Soojeong et al. (2017) encourage all VR exergames to tailor its difficulty to each user so as to minimize the risk of overexertion. The authors of this study have kept the issue in mind by calculating the maximum heart rate data to tailor the heart rate bpm range to each user that starts the VR exergame.

Soojeong et al. (2018) further emphasizes the importance of avoiding overexertion in VR exergames, which otherwise potentially could lead to coronary problems and injuries, by presenting two ways for showing heart rate data in VR. In the study, heart rate data was used and visualized in the VR exergame “Snowballz”, where the user throws snowballs at oncoming enemies. Their system “ActiVR” was incorporated in the game to visualize the heart rate data, where the user can choose between two modes for displaying heart rate data. The first mode is a pulsating 3D-heart whose glow intensifies as the user’s heart rate accelerates. The second mode is a 2D-heart with the user's heart rate displayed next to it in numbers. In both modes the visual information will turn red with a pulsating heart icon when the user reaches 70% of their estimated maximum heart rate data, which has been calculated by subtracting the player’s age from 220, with the aim to avoid overexertion. Soojeong et al. (2018) states that integrating activity information in 3D VR games has not been widely explored yet, and that there is need for incorporating heart rate data to alert the user of potential overexertion, while not posing a distraction from the game experience. The authors of this study have engaged in integrating heart rate data into the VR exergame without displaying the bpm, while still guiding the user to stay in the right heart rate bpm range, thus assuming to avoid the problem of overexertion.

Cmentowski et al. (2023) discuss the importance of balanced workouts in VR exergames and the need to train the lower limbs as most VR exergames use the upper body, which have led to less research of VR exergames using the lower body. The authors of the study present a VR exergame focused on vertical jump training that aims to explore full-body exercise applications. The game includes four levels of increasing difficulty to prevent injuries and foster the learning process. Jumping is a fundamental human movement and a good indicator of a person's fitness level, functional performance, and muscle composition. Regular physical exercise is essential for overall fitness and can even delay the natural aging process. Short-time studies also suggest that exergames provide great motivation for exercising (Cmentowski et al., 2023). The study above inspired the authors of this study in making a VR exergame depending on a lower body movement, in this case using a fitness bike.

Information and methods

This study has been made in collaboration with Ericsson Research, with regular meetings where feedback has been provided and discussions have ensued. Different design methods and data collection methods have been used, which can be viewed in their respective sections.

Design methods

The most important aspects, according to the authors, have been compiled into two sections below; one entailing the visualization of heart rate data, and the other providing a short description of the environment and characters in the exergame that functioned as the context in which the undisplayed heart rate data was used.

Heart rate data

For achieving their fitness goal the users need to be in different heart rate bpm ranges. Because of time limitations this study focused only on the fitness goal “Lose Weight”, which is the fitness goal with the lowest required heart rate bpm range (see figure 1).

Figure 1. The recommended heart rate bpm range for different fitness goals (Sundried, 2023).

It was decided that an approximate estimation of the maximum heart rate data was to be deduced from the user’s age and fitness habits, which in turn would be used to adjust the recommended heart rate bpm range for achieving the user’s chosen fitness goal. The alternative would be to have every user partake in a thorough fitness test before using the lower body VR exergame, which would be time consuming as well as exhausting. So as to not make the experience less engaging and entertaining it was decided that the approximate maximum heart rate would suffice. The method used for estimating the approximate heart rate data is to subtract the user’s age from 220, which is widely used in different settings where the exact maximum heart rate data is not necessarily needed, e.g. the study by Soojeong et al. (2018), and recommended by Steding-Ehrenborg (2017), a physiotherapist and assistant professor at the medical faculty at Lund University.

Instead of clearly showing the bpm to the user, as is most common and was done by e.g. Soojeong et al. (2018) in their VR exergame Snowballz, the authors of this study wanted the heart rate data to be incorporated in a discreet way and, if possible, even go unnoticed by the user. This is because of several reasons. The authors did not want the users to focus too much on their bpm, and so the notion of exercise, but to be distracted from the sometimes dull experience of exercising, while staying in the recommended bpm range. The authors also wanted the game to feel more immersive by not stating the user’s bpm in the UI to make the experience more engaging. Lastly, the authors did not want to show the bpm to the user because of the sometimes inaccurate data that the heart rate sensor provided, which could have led to unnecessary worry and stress for the user, and which also in turn could have impacted the bpm shown.

During the concept stage and early development, the game looked very different from its later iterations. The small characters were planned to run alongside the bike, with no character in its basket. The characters would help the user lay bridges so the user would be able to continue the journey onward. At first the characters were planned to only lay the bridges if the user's bpm was in the recommended range, and a score counter would view how many bridges the user passed. The authors decided not to use that approach, as it could be seen as punishing the user for not being in the right bpm, and because it would be difficult to set a recommended time for the exercise if the user exercised with the aim of beating the high score, which could result in overtraining. It could also have been alarming to experience the bicycle in VR continuing towards a gap between platforms where no bridge has been laid and either fall into the hole or stop in front of the edge. The new approach was to have the characters lay the bridges no matter if the user was in the recommended bpm range or not, but having the characters speed up if the bpm was too high, and having them slow down if it was too slow. The authors, however, deemed that there was not much point in counting bridges and keeping scores if they kept going no matter what the user did. The authors therefore decided to take another approach without bridges where a character placed in the bicycle basket would tell the user to speed up or slow down to stay in the right bpm range. The speed of the bicycle would also slightly increase or decrease depending on the user's bpm. To increase the feeling of it being a game, and less as exercise, a quest was added where the user would help the lost character get home, which would make a clear goal to strive for and mark the completion of the exercise.

The authors decided to only have the character tell the user to slow down, speed up, or keep going in the same manner, through text in a chat bubble. Icons could also have been used, but would have been needed to make the message clear to the user. It is possible that it would have been harder for the setting of the game to make sense to the user if no text was used to convey that the character was lost and wanted help to get home, and more difficult to understand the instructions for staying in the recommended bpm range. The authors considered using audio instead of text, or combined with text, but chose not to during the study. Audio recordings would probably be triggered to go off or change very often as the heart rate data sometimes was inaccurate and led to the text in the chat bubble changing, which could have been an irritating experience for the user.

During iteration 1 the authors noticed that the testers did not necessarily pedal, as the bicycle in VR continued going without needing the user to pedal. In iteration 2 it was needed to pedal and reach 20% of the user's resting heart rate for the bicycle in VR to start moving. Two hot air balloons were also added in iteration 2, that change their flying height depending on the user's bpm, for visual aesthetics. A high bpm results in the balloons flying higher, while a low bpm results in them flying lower. Limits were added so the hot air balloons could not fly too low or too high. To make the heart rate data more reliable, three filters in C# were added after iteration 1. The first filter was made to create an average value of the registering of bpm instead of using the raw bpm. The second filter was to improve the use of relevant bpm data, and not allow data that changed too fast and drastically. The third filter was to remove junk data.

Environment and characters

The authors wanted the VR exergame to contain round and soft shapes to make the user feel safe when exercising (Ekström, 2013). The vegetation, elements in the environment, and especially the characters were therefore made with that knowledge in consideration.

Many variations of character concept art were produced in the AI Midjourney, which were then browsed through and a handpicked few made more consistent and uniform by editing. The selected options were shown to a group of five people who were asked which set of characters they would prefer to be supported by in a fitness experience. The most preferred option was the one containing the roundest characters, who the test group said made them "feel safe" and "like they wanted to spend time with them". The characters were then 3D-modeled in Blender to be entered into Unity. In iteration 1 the theme was a forest of green color (see figure 2), which creates a sense of health, nature and harmony (Sloan, J. S. R., 2015).

The VR exergame contains sounds of nature in the background, e.g. bird song, as a VR experience in virtual nature without sounds of nature can frighten the users as they may expect something dangerous to appear (Annerstedt et al., 2013).

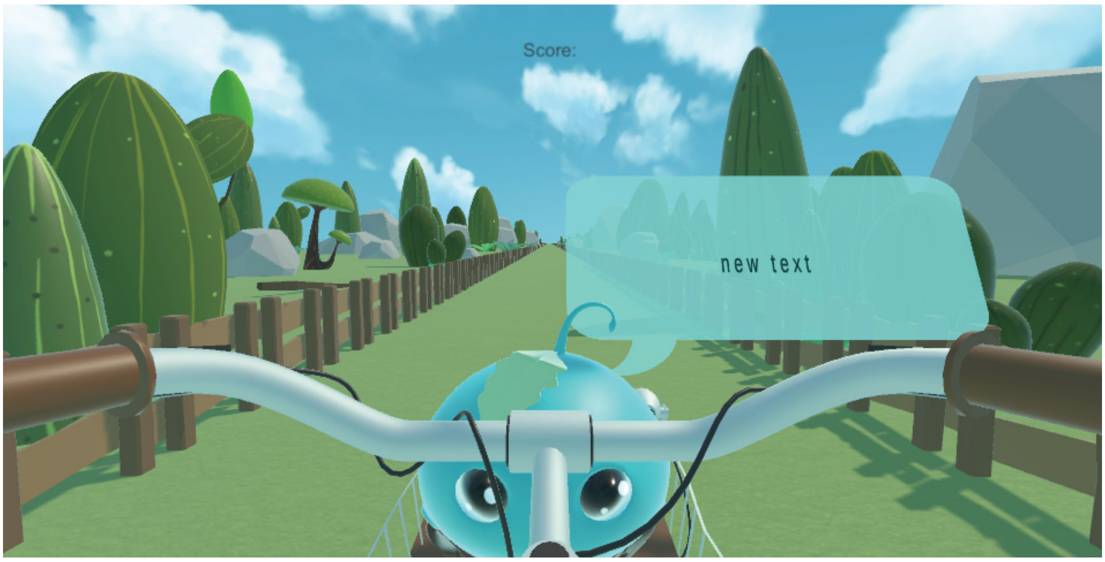

Figure 2. Screenshot of iteration 1.

After the testing of iteration 1 the VR exergame changed visually. The testers requested an exotic environment, and the theme was changed from a green forest to an orange desert, with cacti, a waterfall, and yellow stripes by a modern road (see figure 3). The color orange brings enthusiasm, joy and fun, while yellow brings cheerfulness, joy and sunshine, which were values that the authors wanted the users to experience (Sloan, J. S. R., 2015). The road was changed into a modern road to show that urban development was nearby, and thereby providing the users with a sense of safety as the environment of a natural desert may seem unsafe. More variation was added in the environment, the road was no longer straight, but curved gently. A grand statue with a particle system was added, and a clearly defined settlement for the characters to call home. Some storytelling was added, portraying information about the character Miloo and the quest of helping the character home.

Figure 3. Screenshot of iteration 2.

Data collection methods

Lowdermilk (2013) states that user-centered design has immense importance and that testing should be a central point when creating anything to be used by anyone else. Involving users, especially from the target group, is the best way to ensure that an application will become what people want and need. Testing was therefore readily used, and changes to the game have been made according to the feedback received.

During iteration 1 data was collected through testing and surveys. The testers entered the testing room one at a time to try the VR exergame followed by answering an online survey. Only one test leader was present during the testing, as two test leaders and one tester could make the tester feel inferior, which in turn could affect the data (Trost, 2010). Surveys were used as the the authors wanted to minimize influencing the testers' data, and to create an environment where the testers could answer the questions anonymously and freely state their opinions without any stress or pressure to influence them. This was especially important as the authors needed the testers' blunt truth to smoothly develop the software further. In the survey, questions about the testers' training habits were asked, which for some people can be a sensitive subject (Ejlertsson, 2014). The testers were also asked if they preferred using a fitness bike with or without the VR exergame, which could be difficult for the testers to answer honestly in an interview with its creator, especially in such an early state of the VR exergame. The questions in the survey were created with the checklist Trost (2014) provides in mind, e.g. stating the questions as neutrally as possible, avoiding the use of negations, and separating follow up questions so as to not confuse or affect the testers.

5 people were testers of iteration 1. As the mechanics were in focus, and as several problems already had come to light with the testers, the chance was high that additional testers of

iteration 1 would mention the same areas to develop that had already been mentioned. A decision was therefore made where the mechanics were updated to allow ample time for the testing of iteration 2.

The authors realize that the survey could have been replaced by interviews for iteration 1. Most of the testers wanted to speak about their experience and the questions in the survey after filling it out, so as to elaborate their answers. The main reason for using a survey was to collect honest data about the mechanics. Having an elaborate interview going in depth was not needed at this stage. The authors recognize, however, that short interviews could have been a better alternative to surveys in iteration 1 as the testers still wanted to voice their thoughts. It would therefore have been more efficient and time-saving for both the testers and the interviewer.

For iteration 2 the survey was replaced by interviews. As mentioned above, using interviews was deemed more efficient, and the authors also wanted to get a deeper understanding about the testers' assessment of iteration 2. Both authors chose to be present for iteration 2, one having the main focus of leading the testing, and the other having the main focus of leading the interview, as both wanted to get a fuller understanding of the testing and interviews. Trost (2010) states that the use of two interviewers to one tester is appropriate in cases where both interviewers are attuned, with the aim to get a fuller understanding of the interview together. Trost (2010) further explains the importance of researchers being present for all interviews to get a deeper understanding of them, as recordings and notes never can replace the impression one gets during an interview. Of course, there is a risk of the tester feeling inferior being in the presence of both authors. By having one of the authors passive while the other one leads hopefully reduces the risk. The authors also deem it more effective for this study to keep notes of the interviews instead of taking audio recordings. An audio recording does give more detailed documentation. However, that further detail is not always needed.

6 people were testers of iteration 2, and participated in interviews. The testers' replies were very similar to one another and the feedback was substantial.

Results

During the course of the study 2 iterations were made. The results are described below in two sections; one for the first iteration, and one for the second iteration.

Iteration 1

During iteration 1 five testers were asked if they preferred using a fitness bike with or without the VR exergame that they had tested. The results varied, with a majority replying that they would prefer it with the VR exergame (see figure 4). The tester who preferred it without the exergame motivated the answer with the prematurity of the development, and added that they would like to use the app for exercising when fully developed. The tester who had no preference declared that the reason was because the environment was of a green forest, which felt familiar to them and therefore was not especially entertaining, adding that an unfamiliar environment would improve the experience. The testers who preferred the exergame specified that the experience, especially making it more game-like by having a quest, made exercise more fun, entertaining, and motivating, while providing a distraction from their everyday life. One of the testers specifically asked for the character's name in the bicycle basket, and wanted to get to know the character better. The testers had a tendency to not look around, and did not seem fully engrossed in the experience. Some testers did not pedal throughout the experience as they noticed the bicycle continued on its own. One of the testers compared the VR exergame to Ring Fit Adventure.

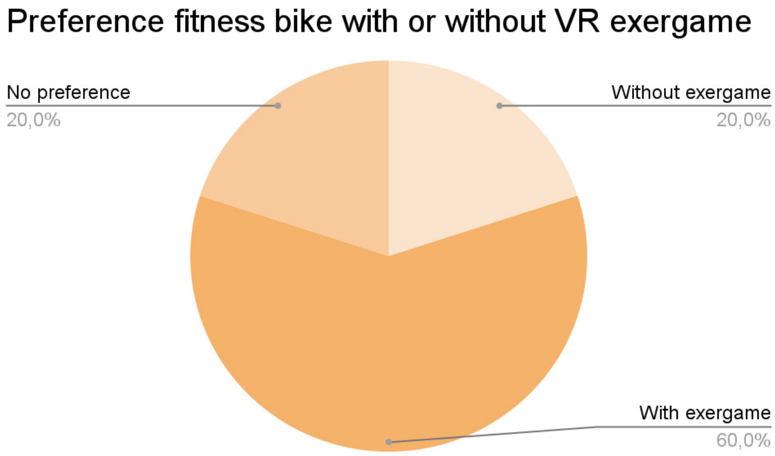

Figure 4. Diagram of preference, iteration 1.

Iteration 2

During iteration 2 six new testers were asked the same question above, if they preferred using a fitness bike with or without the VR exergame that they tested. In this case all testers were positive, and replied that they preferred using it with the VR exergame (see figure 5). The testers added that their experience had been fun, motivating, and distracted them from thinking of it as exercise. The game-like aspects of the exergame were mentioned with enjoyment by two testers in particular and compared by both to the software Ring Fit Adventure, which one of them said had big problems determining heart rate data correctly, while the other said it determined heart rate data okay for the most. One tester added that the exotic environment, especially the waterfall, was a big contribution for wanting to use the exergame more. Worth noting is that one of the testers felt the speed of the bicycle in the exergame to be somewhat slow, and explained that it probably was because they use an electric bicycle everyday and therefore is used to a higher speed. The tester had previously tried using a fitness bike at a gym with another experience, and said that experience felt far too slow. Comparing the two experiences, the tester said the exergame had acceptable speed and motivated the user more with its cute characters. The speed of the bicycle was not mentioned by any other testers. The authors noticed that the testers seemed more engrossed in the experience and looked around the environment, which probably is a result of the added variation. When the road curved the testers tried to tilt their bodies following the path of the curve. After being told that they did not need to tilt the testers quickly stopped tilting. The testers of iteration 2 pedaled throughout the whole experience, presumably because the bicycle did not start on its own as it did in iteration 1. The users did not report any nausea or dizziness during the experience, but said they felt slightly uncomfortable at the beginning when the bicycle started moving, and the end when the bicycle stopped.

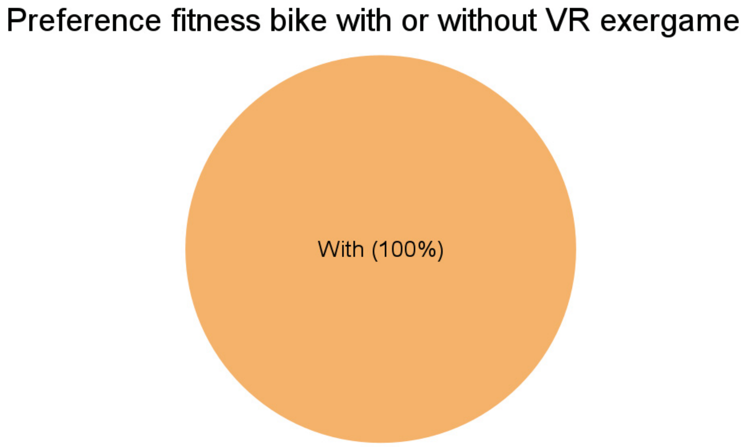

Figure 5. Diagram of preference, iteration 2.

The testers were asked if they would use the VR exergame for a longer period of time (45 minutes), which all testers replied yes to (see figure 6). One tester was in addition also pondering if the prolonged experience in VR would increase the risk for negative side effects, such as nausea or dizziness. Another tester who was exceptionally smitten by the cute characters, proposing possible future merchandise alternatives, suggested more changes in the environment in a prolonged version, such as exploring the characters' village and more storytelling to get to know the characters better.

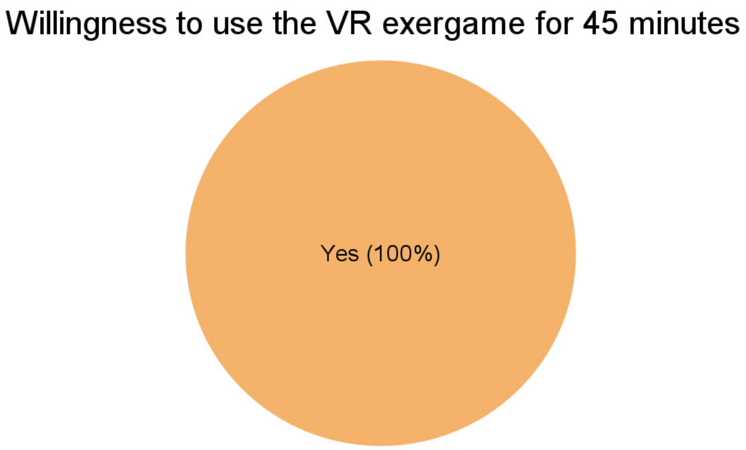

Figure 6. Diagram of willingness to use the exergame for 45 minutes.

The testers were asked if they would use the VR exergame regularly if there were additional environments to choose from, which all were positive about (see figure 7). However, one tester brought up the cost of buying a VR-set and a fitness bike as potential problems. Several of the testers suggested adding hills and varying the resistance of the fitness bike to insinuate climbing the hill, which could be used to add variation if the fitness bike used allowed for changes in resistance.

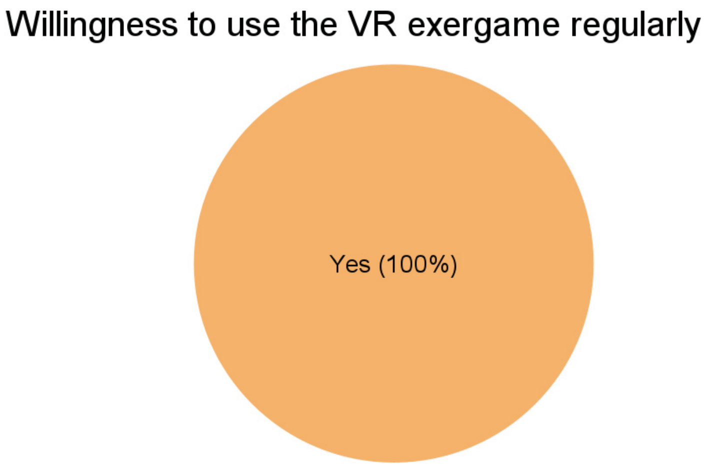

Figure 7. Diagram of willingness to use the exergame regularly.

The testers were asked if they were aware of the VR exergame using heart rate data during the experience, which half of the testers answered no to (see figure 8). Before the testing started all testers were told that they were wearing a sensor that measured heart rate data. Afterwards, half of the testers said they were not aware of heart rate data being used during the experience, saying that they were very immersed in the experience and did not think about much else except playing the game. When asked what they thought determined the speed of the bicycle those three testers believed it was how fast they were pedaling, when in fact the speed was determined by the user's bpm. One tester was aware of heart rate data being used during the experience, and claimed that wearing a heart rate sensor on the finger functioned as a reminder. Worth noting is that the tester had to finish midway into the exergame as a new bug was discovered, that most likely appeared because of unprecedented deviation from the recommended heart rate bpm range. Two testers were unsure if they were aware of the heart rate data during the experience.

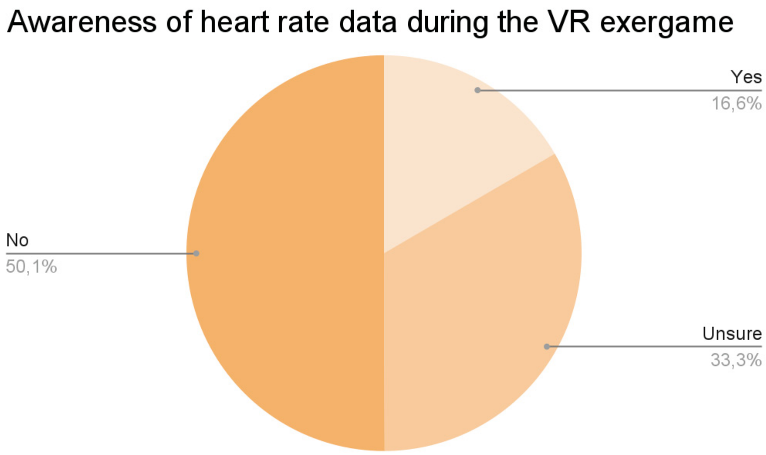

Figure 8. Diagram of awareness of heart rate data during the experience.

Discussion

From the results there are several aspects of interest to discuss. After changing the environment to be more exotic to the testers and adding more storytelling of the characters, as requested during the testing of iteration 1, all testers of iteration 2 preferred using a fitness bike with the VR exergame for exercising compared to using a fitness bike without the exergame. All were willing to use it for 45 minutes, and all were willing to use it regularly to exercise. The testers were overall very positive, claiming that the VR exergame made exercising more engaging and entertaining, and commenting that they did not feel like they were exercising, as they believed training at home or at a gym to be dull and boring. The authors believe that the changes in environment between the iterations made a difference. The testers from iteration 1 wanted the environment to be more exotic and less familiar to them, explaining that they could easily access a green forest by going outdoors, and claimed that VR could not compete with experiencing an environment in real life. An important aspect to keep in mind is that the testers lived in Sweden, where green forests are common, where there are no deserts, and natural waterfalls are rare. By showing an exotic environment which is more difficult for the users to access, in this case a desert and a waterfall, the authors believe the testers became more engaged in the exergame, leading to less awareness of the use of heart rate data during the experience. The authors do not know, however, to what extent the familiarity of the environment affects the awareness of heart rate data during the experience, and would find it interesting to research further by providing users with environments differing in familiarity.

The authors believe that using the environment to distract the user from thinking of their everyday life may decrease the feeling that they are exercising. In that regard it would be interesting to research collaboration between users in exergames and having them synchronize their undisplayed heart rate data, similar to the study by Desnoyers-Stewart et al.

(2019) where users collaborated by synchronizing their biofeedback by breathing. It would be interesting to see how working together affects engagement and the users' awareness of heart rate data during the experience.

The biofeedback, heart rate data, in the lower body VR exergame was used discreetly, as was intended by the authors, and went by completely unnoticed for at least half of the testers. Before the start of the testing of iteration 2, all testers were told that they were wearing a heart rate sensor on their finger. Yet at least half of the testers forgot that heart rate data was used during the experience, and believed that their speed of pedaling the bicycle changed the speed of the bicycle in VR, adding that they were very immersed in the experience and did not think about anything else. The only tester who claimed to have been aware of the heart rate data while experiencing the VR exergame had to cancel the exergame halfway because of the discovery of a new bug. It is possible that not being able to experience the entire exergame could have made the experience less engaging and immersive and in turn have increased the awareness of the use of heart rate data. The tester mentioned that having a heart rate sensor on the finger was a constant reminder that heart rate data was used during the exergame. It is also a possibility that the heart rate sensor was fastened too tightly, which could have affected the awareness of the use of heart rate data. The authors believe that using a heart rate sensor fastened in another way, e.g. a smartwatch, would further decrease the awareness of the use of heart rate data as it is more comfortable, easily adjustable, and in addition would provide more accurate data. This also raises the questions of availability of the equipment. Not everyone has access to a VR setup, a fitness bike, or a smartwatch, nor the funds to buy them. It could, however, be an excellent alternative for those already in possession of part of the equipment, such as an unused fitness bike, or those with the funds. The necessary equipment could also possibly be made available in gyms, where other virtual experiences and exergames are currently being used.

The authors believe that undisplayed bpm in exergames can be used in many situations and contexts, e.g. healthcare. If the user is able to view their heart rate data while exercising they may become stressed, which may affect the heart rate data, and in turn stress the user further. By using undisplayed bpm, where the user can't see their bpm, but someone looking at the software in Unity would be able to, the authors believe that the registered bpm is closer to the user's actual bpm. This could provide healthcare personnel with more accurate information about patients which could make a difference in evaluation and treatment.

Another interesting aspect is that three of the eleven testers during the iterations compared the VR exergame to Ring Fit Adventure. The comparison and the claim of possible inaccuracy in providing heart rate data tell the authors there is demand for exergames using biofeedback, and that the technology for providing heart rate data may still have its difficulties with accuracy.

Conclusion

The authors have researched the use of heart rate data as biofeedback in the context of a lower body VR exergame, and have concluded that undisplayed bpm has great demand. All testers of iteration 2 preferred using a fitness bike with the lower body VR exergame compared to using a fitness bike without it, all were willing to use it regularly, and all were willing to use it for exercising for longer periods of time. The testers described that training at a gym or at home with a regular fitness bike is dull and boring, while the VR exergame made it fun and distracted them from thinking of the experience as exercise. By using undisplayed bpm the users perceived it less as exercise and more as entertainment, and at least half of the testers were unaware of the use of heart rate data while using the exergame.

The current trends predict that half of the global population will be living with obesity or overweight in 2035, which increases the risk for chronic diseases that are the global leading causes of death. New and engaging ways to exercise are needed. The authors believe that using technology incorporating undisplayed biofeedback and taking on a game-like approach could be used to break those current trends. The authors hope that undisplayed heart rate data in exergames will be further researched and developed for the population to use in achieving their fitness goals, or for use in other contexts, e.g. healthcare.

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