The Physical Benefits of VR games

Oona Kivelä * Toni Kuosmanen Timo Lämpsä

Leevi Mustajärvi Joonas Soudunsaari

Keywords

VR; Exergames; Heartrate;

1. INTRODUCTION AND MOTIVATION

The aim of this study is to detect the physical benefits in virtual reality (VR) gaming. To get to the goal the heart rate of the subjects is going to be measured in rest and during the game. Also, subjects are interviewed about their exercise and gaming habits. There is also going to be questions about the VR game experience. The goal is to see whether VR games have physical effects to user and if user enjoys exercising with the VR game.

Motivation to exercise by exergames have been studied. Finkelstein et al. (2011) designed a game called Astrojumper which forces the user to move his/her whole body while playing. Player flies in outer space and swerve around, duck under and jump over virtual planets. They studied the effectiveness of this kind of game by measuring the heart rate before the game session and after the game session. One game session lasted 15 minutes. To get more information about the motivational part of the game they also asked the test users to fill pre- and post-questionnaires. Pre-questionnaire included more general information about user's exercise habits and experiment with video games. In post-questionnaire the questions were focused on to the game session. It was shown that virtual reality games have strong potential to motivate to physical activity both adults and children.

Finkelstein et al. (2011) made their research seven years ago and the VR equipment are highly improved since then. In their Astrojumper study a user had a control backpack in his/hers back with many wires leading from there. The game setting in Astrojumper is highly different than what it is nowadays. The monitors are placed around the user while today user needs VR glasses with wireless control sticks. Movement trackers are on the forehead, wrists and waist in the Astrojumper. Finkelstein et al. (2011) had problems with heart rate measurements during the game session.

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2. RELATED WORK

2.1 Virtual reality games

If the system consists a human operator, a human-machine interface and a computer it can be called a virtual environment. Environment has three-dimensional space where the objects are placed. [3]. Virtual reality games are characterized by high level of presence and immersion, or the feeling of really being a part of the virtual environment [18].

Adaptation of VR systems has been partly hampered by many users experiencing a set of symptoms similar to motion sickness. This set of symptoms is commonly called cybersickness. Possible symptoms include but are not limited to nausea, dizziness, headaches and fatigue. Studies have estimated that 30 % - 80 % percent of VR users experience these symptoms to some extent [14].

2.1.1 HTC Vive, Oculus and Sony Playstation

In recent years, many new consumer virtual reality systems have entered the market. Commonly these systems include an immersive head mounted display (HMD) and motion controllers. Popular examples of these systems include products such as Oculus Rift, HTC Vive or Playstation VR. Advanced head tracking and motion controllers combine to produce a high level of immersion and allow the user to explore and interact with their immediate surroundings in a natural fashion. Although Amazon sales rankings have recently shown a declining interest in VR devices [6], millions of devices have been shipped worldwide.

2.1.2 Exergames

Exergame term is widely used when video games are played to promote physical activity [12]. Children are easier to motivate to exercise with a fun way and childhood obesity can be prevent by exergames [17]. According to Staiano et al. (2013) children who were competitive exergames did not lose weight while cooperative "exergamers" did. Studies with elderly shows that with them the fun is not the driven force to play but the usefulness of the related physical and cognitive abilities is. [2]

Study conducted by Plante et al. (2003) found evidence that combining VR with physical exercise can boost the mood benefits associated with normal exercise. In the study people who were immersed in a virtual environment while riding an exercise bike generally reported feeling more energized and less tired than the people in the control group [13].

Fitzgerald et al. (2010) have shown that exergames has

been used successfully also in therapy. They used a wobbleboard based on video game to motivate the patients. Their results show that patients are more motivated for training when comparing to those who does similar exercises at a class with a therapist. Dynamic stability in both test groups gained and there were no significant differences between groups. [5]

2.2 Heart rate and exercise intensity

Heart rate measurements have long been used to monitor exercise intensity [1]. A common way to represent exercise intensity using heart rate is to calculate the current heart rate as a percentage of the maximum heart rate:

$$\%HR = \frac{HR}{HR_{max}} \tag{1}$$

Although the maximum heart rate varies greatly between individuals, it can be estimated without measurement if the persons age is known:

$$HR_{max} = 210 - 0.5 * age \tag{2}$$

Many different versions of the formulas exist, although none have been found to be very reliable [16]. Gulati et al. (2010) propose a slightly different age scaling factor of 0.88 for women. as the most acceptable estimate of maximum heart rate. Gulati et al. [7] propose a slightly different age scaling factor of 0.88 for women.

Another method used to gauge the exercise intensity is the heart rate reserve [8]). Instead of scaling the heart rate directly to the maximum heart rate, the subjects heart rate reserve is calculated using the formula:

$$HR_{RESERVE} = HR_{MAX} - HR_{REST} \tag{3}$$

Relative heart rate can then be used to detect the changes in the heart rates. Relative heart rate is calculated with the following formula:

$$HRR = \frac{HR - HR_{REST}}{HR_{RESERVE}} * 100\% \tag{4}$$

During training, different target heart rate zones can be set, depending on the goal of the exercise. For example, Fitdigits, a smart device based fitness application, suggests HRR values of over 50% for light aerobic recovery and values of over 60% for endurance training [4].

3. DESIGN

To evaluate the potential health benefits, we chose two VR games available on the Steam platform. The two games were chosen based on their metabolic equivalent (MET) scores provided by VR Institute of Health and Exercise [11]. The first game chosen was an arcade style archery simulation called QuiVR. VR Health Institute rates the game at 2.73 METs, roughly equivalent to walking or doing light housework. For the second game, we chose a more intense rhythm game called BeatSaber. In the game the player must cut moving colored blocks and dodge around obstacles. VR health institute gives the game an average METs score of 6.24, roughly equivalent of playing tennis or jogging. Our aim in choosing two games with different MET scores was twofold. First, we wanted to find out if even a game of modest activity could be considered exercise. Second, we wanted to see if a more active game be comparable to traditional physical exercise.

We chose the users heart rate as the main measure of exercise intensity. For measuring the heartrate, we obtained two Fitbit Charge HR activity bracelets. The device measures the heart rate at an interval of five seconds. The measurements are stored on the device until they are synced to the Fitbit cloud service using a connected mobile phone. Afterwards, the heart rate data could be retrieved using a third-party application called Pulse Watch [15].

To compliment the heart rate data, we decided to also capture motion data from the VR game set. The set includes an HMD unit and two motion controllers. The position of each of these devices is tracked by two beacons. For logging this positional data, we prepared a simple program that could be ran parallel with the chosen games. While active, the program samples the device position and orientation at a rate of 5 Hz and outputs the data to a csv file.

We prepared a multi-part interview to gain information if VR games increase exercise motivation. The first part of the interview dealt with participants gaming and exercise background and was held before the first game session. The second part of the interview was completed after first game session, and last part was after both sessions. Participants are asked to answer questions about their general background, exercising background, gaming background and about the VR game experience.

3.1 Cybersickness and heart rate

As mentioned earlier, many VR users experience some degree of cybersickness. High levels of nausea can lead to increased heart rate without any physical activity [10]. In order to find out if the observed increase in heart rate is caused by onset of cybersickness instead of exercise, we decided to include the standard Simulator Sickness Questionnaire (SSQ) [9] as part of our survey. The SSQ, which was originally developed for military air simulation use, has been widely used in cybersickness research. The SSQ measures 16 different symptoms on a four-point scale. The symptoms are grouped to three different categories: oculomotor symptoms, disorientation, and nausea. From the raw data a score for each of the three main symptom categories and a total score can be calculated (SSQ-O, SSQ-D, SSQ-N, and SSQ-T respectively). SSQ was filled immediately after the participants had completed both game sessions. Since nausea is the symptom mostly linked with increased heart rate, we paid special attention to the SSQ-N scores.

4. EVALUATION

4.1 Evaluation plan

Our VR gaming device which included HTC Vive visor, two motion controllers and two base stations which were set Ubicomp demo room inside Oulu university faculty of information technology and electrical engineering. We gathered 17 participants to play two different games. The experiments took place between 30.10 – 1.11.2018, during which a 30-minute time session was reserved for each participant.

At the beginning of their sessions the participant was sat down, and the Fitbit activity bracelet was attached to their wrist and the heart rate measurements started immediately.

Figure 1: Participants had two game sessions, each for 10 minutes. Order of game sessions was randomly chosen. Participants played BeatSaber and QuiVR games.

This was done in order to get an estimate of the participants resting heart rate. Participants were asked to fill a consent form (Attachment 1) and the first part of the survey. To protect the privacy of all the volunteers, each participant was assigned an ID number which was then used to connect heart rate, movement data and survey answers together.

The order in which the games were played was alternated between participants. At the start of both gaming sessions, the participants were given a brief tutorial to get them accustomed to the controls. When the tutorial was completed, the motion logger was turned on and the actual gaming session was commenced. Both gaming sessions lasted for ten minutes (Figure 1). The start and end times were recoded, so that the heart rate data could be synchronized afterwards. After the first game session the participant was asked to rate the physical intensity of their game session. If their heart rate had increased noticeably, they were also given a small break so that the heart rate could climb down back to the levels observed before starting the first gaming session.

The SSQ was administered immediately after the second gaming session had concluded. The participants were asked if they had any of the listed symptoms and if they did, they were asked to rate the severity of their symptoms on a four-point scale. The final part of the survey, which dealt mainly with how the participant felt about VR based exercise based on their experience, was also filled.

4.2 Research data

During the game session we gathered three types of data from test users. We gave them a Fitbit bracelet which measured heart rate in real time. We collected qualitative data from users by interviewing users before game session, after first game session and finally after second game session. We also had SSQ interview to participants. We gathered movement data from hand consoles and VR glasses via capture software which was run parallel to the VR game.

4.2.1 Data from interviews

During the first part of the survey, the participants were asked for some general background information. Participants age was recorded in order to calculate theoretical maximum heart rate. Gender was also recorded, but the low rate of women participants prevents data comparison between genders. Participants were asked to describe their weekly amount of physical exercise and how many hours a week they spend playing console or video games. Participants were also asked if they had used VR applications before.

Table I: Survey results.
Q1: How many times a week you do sports? (at least 30 mins of exercising per time)
Q2: How many hours do you usually play computer games or console games in a week?
Q3: Could you see yourself playing virtual reality games more often just for fun?
Q4: Could you see yourself playing a virtual reality games more often for exercise purposes?
Q5: Would VR playing encourage you to exercise more?
Q6: Would you recommend VR gaming as an exercise for anyone?

ID	Q1	Q2	Q3	Q4	Q5	Q6
3	2	10	5	5	4	5
4	3	0	5	3	3	3
7	3	7	5	3	2	4
8	4	0	4	4	2	2
10	3	3	5	4	2	3
12	4	1	4	2	4	5
13	2	2	5	3	2	5
16	3	25	5	1	1	2
17	4	0	4	1	3	2
18	5	4	4	1	1	2
22	4	5	4	3	2	2
23	2	5	5	3	4	2
25	1	0	3	4	2	5
26	1	30	5	4	3	3
27	10	4	5	3	2	4
29	3	0	5	4	4	4
30	1	2	5	2	4	5
Avg	3.2	5.8	4.6	2.9	2.6	3.4

After first game session interview was continued by asking how user was feeling after the game. Users' were also asked how intense they would rate the game session in a scale from one to five. After second game session participant was asked again how they feel, and how intense they would rate the game session. At the last part of the interview participant was asked whether he/she sees himself/herself playing VR games for exercise meaning and for fun in scale one to five. Whether participant would play virtual reality games in exercise context and would he/she recommend that to others in scale one to five. Participants had also a chance to say any comment about the whole experience. Results from interview are shown in Table I. Intensity of the game session results are shown in Figure 2.

To ensure that the increase in subjects heart rate was not caused by the onset of cybersickness, we asked each subject to answer the simulator sickness questionnaire immediately after the second game session. The questionnaire consists of a list of sixteen symptoms associated with cybersickness. Simulator sickness questionnaire data was gathered from users after game session and the data is summarized to show three main symptom clusters of the questionnaire. Answers

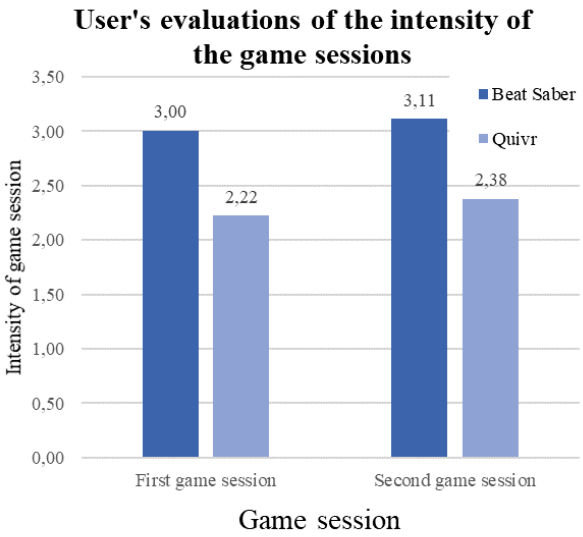

Figure 2: Users evaluation of intense of game session. Users, who played BeatSaber first, evaluated the intense of the game session in average 3.00 in scale one to five, and users playing QuiVR first 2.22. Users who played BeatSaber in second game session evaluated the intense of the game in average 3.11, and users who played QuiVR in second game session 2.58.

to these questions are ranked to be 0 if user don't have the symptom, 1 if user feels slightly to have a symptom, 2 if user feels the symptom as moderate and 3 if user feels the symptom being severe. Different clusters are oculomotor (SSQ-O), disorientation (SSQ-D) and nausea (SSQ-N). SSQ-O includes the results about general feeling, fatigue, difficulty concentration, eye strain, difficulty focusing, blurred vision and headache. SSQ-D includes the results about difficulty focusing, nausea, "fullness of head", blurred vision, dizziness with eyes open and closed, and vertigo. SSQ-N includes the results about general feeling, difficulty concentrating, nausea, stomach awareness, increased salivation, sweating and burping. SSQ total (SSQ-T) is calculated from the three clusters as a total value. Formulas used to get SSQ-O, SSQ-D, and SSQ-N scores are as follows:

$$SSQ - O = \sum O - cluster * 7.58 \quad (5)$$

$$SSQ - D = \sum D - cluster * 13.92 \quad (6)$$

$$SSQ - N = \sum N - cluster * 9.54 \quad (7)$$

And the total SSQ is calculated as the sum of the all the symptoms and multiplied with 3,74. Results are shown as a graph in Figure 2.

4.2.2 *Heart rate data*

Heart rate data was captured in real time by Fitbit bracelet. The bracelet measured the heart rate five seconds. The raw data was exported from Fitbit cloud storage using the PulseWatch application. Out of the 17 test users the data was successfully gathered from 14 participants. The data from three test subjects was lost due to connectivity issues with the Fitbit device.

Participants maximum heart rate and relative heart rates were estimated using formulas 2, 3 and 4. Resting heart rate was measured from the participants while they were being interviewed for the first part of the survey. The average relative heart rates for both game sessions are shown in figure 3.

Table II: Average relative HR values before and after the game sessions. n=14

	Start		End		
Game	Avg HR	STD	Avg HR	STD	Dif. HR
QuiVR	36	7	41	10	5
BeatSaber	37	7	57	10	10

4.2.3 *Movement data*

Test user's movement data was collected using the capture program which was running parallel to the VR game. The program sampled the position and orientation data from all the three devices at a rate of 5 Hz. Each sample, including the current timestamp, was saved as a row to a result file. By calculating the displacement between each successive row, an estimate of the distance travelled by each device was obtained. The total distance was calculated by simply summing the travelled distance from all three devices. The total distance travelled by each user is shown in Figure 4.

4.3 Analysis of the data

4.3.1 *Analysis of interviews*

Users did enjoy the game sessions. They said that gaming experience was fun, and some of them said that it was challenging. Participants rated BeatSaber slightly more intense game than QuiVR (Figure 2). As shown in Table I, participants ranked 4.6 out of five that they would play VR games for fun. Participants had neutral answers (2.6 out of five) to question, if VR games would encourage them to exercise more. Although, participants were more willing to recommend the VR games as an exercise form to someone else (3.4 out of five). Participants background with exercising or with videogames were irrelevant to the results.

The simulator sickness questionnaire did not show any critical results. Results are shown in Figure 3. User with an ID 12 had high weighted value of SSQ-D but the raw data includes only answers "slight" (value 1). SSQ-N results are shown higher peaks, but SSQ-N includes the weighted values from increasing sweating. Sweating is most likely caused by moving during games.

4.3.2 *Analysis of heart rate data*

Average heart rate data from 14 participants (Table II) shows that in BeatSaber game session participants relative heart rates raised approximately 20 percent, while in QuiVR heart rates stayed in the same. Twelve subjects reached the target HR zone of 50% their maximum heart rate while playing BeatSaber.

4.3.3 *Analysis of the movement data*

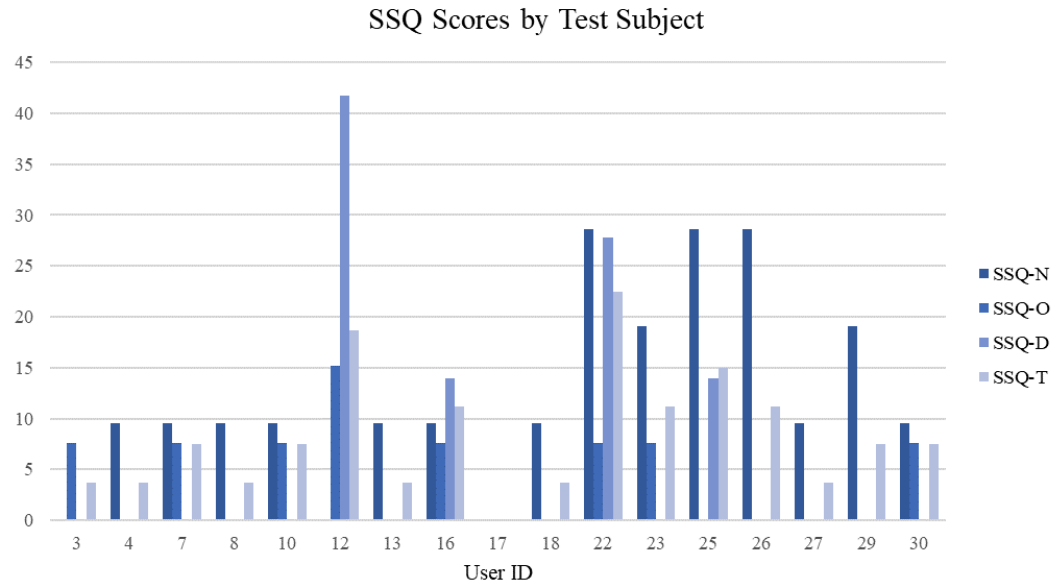

Figure 3: Simulator sickness questionnaire results from each participant. SSQ-N results shows weighted results of nausea symptoms, SSQ-O results shows weighted results of oculomotor symptoms, SSQ-D shows weighted results of disorientation symptoms and SSQ-T shows total results.

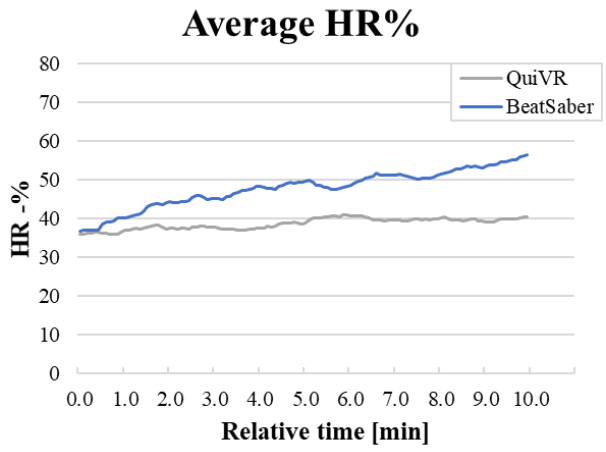

Figure 4: Average heart rates of participants at each game session.

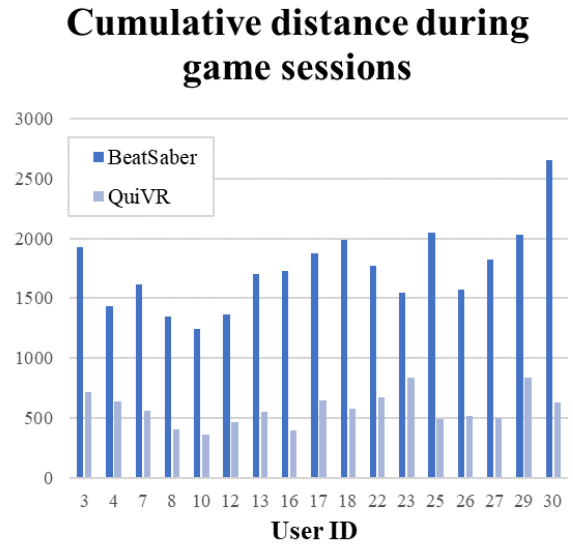

Figure 5: Movement data (total distance travelled) from each participants shown from different game sessions.

Users movements were detected during game sessions, and distance participant moved during game sessions were calculated. In Figure 5, it can be seen that users moved more while playing BeatSaber than QuiVR.

5. DISCUSSION

During the interviews, the subjects did not rank either game as being very intense, with QuiVR and BeatSaber receiving average scores of 2.3 and 3 out of five respectively. The subjects felt unsure if VR games could motivate them to exercise more. However, most viewed the experience positively and some could see themselves recommending VR games as exercise for someone else even if they felt they did not benefit from it themselves. Even VR equipment have become more frequent, they still are quite expensive and cannot be found in every home. This might be a reason participant did not see themselves playing VR exergames as an exercise purpose.

As can be seen from Figure 4. the heart rate in BeatSaber game raise during the whole game session and it probably have been raised higher if the game session had been continued more than 10 minutes. In QuiVR game session the heart rates of participant did not raised, and it is hard to predict if it has been raised if the game session has been longer.

It is confirmed with the movement data (Figure 5) that heart rates did not raise just because the game was excited. It can be seen clearly that participant had more movements when they played BeatSaber.

In some cases when a person is playing a VR game, he/she experience cybersickness. One symptom of cybersickness is rising heart rate. To exclude the heart rate rising due to cybersickness, participant also had simulator sickness questionnaire by Kennedy et al. (1993). This questionnaire confirmed that no one of the test users had cybersickness. Used games, BeatSaber and QuiVR, are popular and one reason of that is their good quality.

6. CONCLUSIONS

Active VR games can raise the heart rate to levels comparable to normal exercise. The game with more relaxed gameplay did not manage to raise heart rate to similar levels. Although the participants viewed VR games in a positive light, the effects on exercise motivation are hard to gauge based on the small sample size and cross-sectional nature of our study. In the future it would be interesting to see how a VR based exercise regimen might affect exercise motivation in the long term.

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8. CONTRIBUTIONS

Kivelä, Oona: Design, performing an experiment, writing, presentation, analysis of results, recruit participant, project manager

Kuosmanen, Toni: Design, performing an experiment, experiment setup, coding, writing, presentation, analysis of results, recruit participants

Lämpsä, Timo: Design, performing an experiment

Mustajärvi, Leevi: Design, performing an experiment, experiment setup, writing, presentation, recruit participants

Soudunsaari, Joonas: Design, performing an experiment, experiment setup, recruit participants

9. REFERENCES

[1] J. Achten and A. E. Jeukendrup. Heart rate monitoring. *Sports medicine*, 33(7):517–538, 2003.

[2] C.-K. Chen, T.-H. Tsai, Y.-C. Lin, C.-C. Lin, S.-C. Hsu, C.-Y. Chung, Y.-C. Pei, and A. M. Wong. Acceptance of different design exergames in elders. *PloS one*, 13(7):e0200185, 2018.

[3] N. R. Council et al. *Virtual reality: Scientific and technological challenges*. National Academies Press, 1995.

[4] Fitdigit. Determining your heart rate training zones. http://www.fitdigits.com/personalized-heart-rate-zones.html. Accessed: 16.12.2018.

[5] D. Fitzgerald, N. Trakarnratanakul, B. Smyth, and B. Caulfield. Effects of a wobble board-based therapeutic exergaming system for balance training on dynamic postural stability and intrinsic motivation levels. *journal of orthopaedic & sports physical therapy*, 40(1):11–19, 2010.

[6] J. Fruhlinger. Consumer interest in vr is declining according to sales data trends. https://media.thinknum.com/articles/sales-data-shows-that-consumer-interest-in-VRis-waning. Accessed: 19.9.2018.

[7] M. Gulati, L. Shaw, M. Lauer, R. Thisted, H. Black, C. Merz, R. Wicklund, A. Al-Hani, and M. Arnsdorf. Heart rate response to exercise stress testing in asymptomatic women: The st. james women take heart project. In *CIRCULATION*, volume 112, pages U885–U885. LIPPINCOTT WILLIAMS & WILKINS 530 WALNUT ST, PHILADELPHIA, PA 19106-3261 USA, 2005.

[8] M. J. Karvonen. The effects of training on heart rate: a longitudinal study. *Ann Med Exp Biol Fenn*, 35:307–315, 1957.

[9] R. S. Kennedy, N. E. Lane, K. S. Berbaum, and M. G. Lilienthal. Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The international journal of aviation psychology*, 3(3):203–220, 1993.

[10] E. Nalivaiko, S. L. Davis, K. L. Blackmore, A. Vakulin, and K. V. Nesbitt. Cybersickness provoked by head-mounted display affects cutaneous vascular tone, heart rate and reaction time. *Physiology & behavior*, 151:583–590, 2015.

[11] V. I. of Health and Exercise. Vr exercise ratings. https://vrhealth.institute/vr-ratings/. Accessed: 5.12.2018.

[12] Y. Oh and S. Yang. Defining exergames & exergaming. *Proceedings of Meaningful Play*, pages 1–17, 2010.

[13] T. G. Plante, A. Aldridge, R. Bogden, and C. Hanelin. Might virtual reality promote the mood benefits of exercise? *Computers in Human Behavior*, 19(4):495–509, 2003.

[14] L. Rebenitsch and C. Owen. Review on cybersickness in applications and visual displays. *Virtual Reality*, 20(2):101–125, 2016.

[15] N. Ricci. Pulse watch. https://iccir919.github.io/pulseWatch/public/index.html, 2018. Accessed: 10.12.2018.

[16] R. A. Robergs and R. Landwehr. The surprising history of the" hrmax= 220-age" equation. *Journal of Exercise Physiology Online*, 5(2):1–10, 2002.

[17] A. E. Staiano, A. A. Abraham, and S. L. Calvert. Adolescent exergame play for weight loss and psychosocial improvement: a controlled physical activity intervention. *Obesity*, 21(3):598–601, 2013.

[18] J. Steuer. Defining virtual reality: Dimensions determining telepresence. *Journal of communication*, 42(4):73–93, 1992.

APPENDIX

A. CONSENT FORM

Consent for participation in research and data acquisition /

Suostumus tutkimukseen ja tutkimusaineiston tallentamiseen

We collect research data that contains field observations, video, pictures, heart rate, motion and data from the questionnaires. Your name and contact information may be used to contact you but are not analyzed in combination with the collected data. The collected data will be anonymized and will be identified only by an assigned ID number. We share some data with research partners and in scientific publications. This data will be summarized to minimize the chance that your personal information is exposed. The image or video material may be used as part of educational presentations, conference presentations or scientific publications.

Keräämme tutkimustietoa, joka sisältää kenttähavaintoja, videoita, kuvia, sykedataa, liikedataa ja kyselylomakkeisiin täytettyä tietoa. Saatamme käyttää yhteystietojasi ollaksemme yhteydessä sinuun, mutta yhteystietoja ei analysoida yhdessä kerätyn datan kanssa. Kerätty data tallennetaan nimettömänä. Saatamme jakaa kerättyä dataa tutkimuskumppaniemme kanssa tai tieteellisissä julkaisuissa. Jaettu data esitetään summatussa muodossa. Kerättyjä kuvia ja videoita voidaan käyttää opetustilaisuuksissa, konferensseissa tai tieteellisissä julkaisuissa.

I have read the above information and consent for saving the data /
Olen lukenut tutkimustiedotteen ja hyväksyn aineiston tallentamisen

__ YES / KYLLÄ
__ NO / EI

I give my consent for video and photographic recording of the experiment/
Suostun kokeen videointiin ja kuvaukseen

__ YES / KYLLÄ
__ NO / EI

Signature and name in capital letters / Osallistujan allekirjoitus ja nimenselvennys	*Time and place / Aika ja paikka*