KiVR Sports: Influencing the Users Physical Activity in VR by using Audiovisual Stimuli in Exergames

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Figure 1: Images depicting player activity during game-play: The player use the VR controllers to shoot arrows (left), destroy the virtual targets (center), and eventually dodge targets by crouching or jumping.

ABSTRACT
In traditional fitness or exercise situations, people often lack motivation. Fitness video games try to enhance exercise by combining cognitive game demands with physical activity and body coordination. Building on results of interdisciplinary game research, we designed and evaluated a dynamically-adaptive fitness game environment that has motivating effects and can be used besides, or as an alternative to standard fitness programs. In this work, we explore the effects of game design elements (e.g., music, lighting) on engagement in a VR exercise game suitable for HIIT (High-Intensity Interval Training)[13]. Participants reported a higher perceived incentive to perform well when the music tempo depended on the measured heart rate. A lower incentive was reported when the heart rate influenced in-game lighting. Static lighting produced significantly higher heart rate. Further displaying a score was effective on both heart rate and perceived incentive.

1 INTRODUCTION
Traditional gym and fitness exercise regimes are currently being enhanced with innovative technology and interactive gamification systems. Exergames1 combine cognitive game demands with physical activity and body coordination. This approach can further be enhanced by implementing dynamically adaptive game-balancing mechanisms, and specially designed full-body-motion controllers, to yield a physically demanding but not overexerting play/training session. The current state of VR Technology comes with new possibilities of combining gaming with sports in an engaging environment and therefore offers a chance to help people to come to a more active lifestyle. In this paper, we want to examine if and how we can guide users in VR so that they can perform training playfully. Our goal is to determine, which components and mechanics of an exergame lead to a fast and engaging play style and are therefore suitable to be utilized for sports. For that purpose, we developed KiVRSports. This game requires a wide range of fast movements which help the user to quickly engage in a demanding activity, exploring the effects of typical game elements and configurations such as the presence of music, lighting, and engagement in players.

1combined from "exercise" and "gaming"
2 RELATED WORK

Previous works show several positive effects of combining sports and gaming, in a literature review Papast et al. found that active games have the potential to enhance physical fitness, motor skills and motivation for exercise in young people [15]. Ijsselsteijn et al. report that a more immersive exercise environment leads to higher motivation in participants [6]. These findings indicate that VR-environments are especially promising for exergames. Similarly, Kosoris and Chastine report a user preference for activities in AR games compared to games without AR components [9].

A study conducted within the VR exergame Astrojumper with players from the age of 5 to 60 showed a significant increase in heart rate directly after playing, together with high reported motivation and enjoyment in participants [5]. Nickel et al. developed a second version of Astrojumper that supports HIIT and reported that players showed a higher energy expenditure and heart rate increase compared to the classic game version [12]. It has been shown that heart rate is a proper measurement for engagement in exercises because it is less prone to environmental circumstances than alternatives [4]. Egan et al. furthermore report that the heart rate is not influenced by being in VR itself [3]. One of the main advantages of HIIT over traditional training plans is that it is less time-consuming. As Bartlett et al. summarize, multiple studies show beneficial effects such as muscle adaptations and insulin efficiency with a time investment of 4-6x 30s plus resting phases compared to traditional 40-60 minutes of training [2]. They found that study participants rate the experience of HIIT as more enjoyable compared to traditional training, and assume that the reported enjoyment could also lead to an improvement in exercise adherence [2]. Similar results were found by Ong et al., who conducted a HIIT study with pregnant women [14].

In addition, it has been shown that music can have a beneficial effect on motivation and physical performance [11][7][18]. In a similar fashion we were interested in the effects of lighting as most of us felt more motivated to exercise when the sun was shining. Many games (and sports) use points to measure performance, give immediate feedback and reward players. This mechanism is also used for motivational purposes in gamification [11][16]. This purpose of immediate feedback can be applied to the other conditions which leads to them being controlled by the heart rate are based on the idea of immediate feedback, similar to points.

3 EXPERIMENT

The main goal of the game that we developed for our study was to encourage the player to use many different movement patterns to succeed. Furthermore, we wanted to provide a narrative with an inherent goal for those players who are not primarily motivated by game mechanics or competition. In KiVRSports the player is surrounded by multiple targets that they can shoot with bow and arrow. If a target is hit it fires an oriented row of projectiles back at the player which the player needs to dodge. A hit target releases fruits that are then picked up by a little Kiwi companion. Each target also has a randomly chosen lifetime between 8s and 12s. At lifetime – 4 seconds, the target begins to linearly change its color to red. From lifetime – 2 seconds on, the target stays red. At the end of its lifetime the target explodes and fires projectiles at the player without releasing the fruit (see figure 2).

In order to ensure that the strain of playing matches the player’s abilities, we implemented an adaptive difficulty: New targets initially spawn every 2.0s. This time is increased by 0.2s up to a maximum of 4.0s whenever the player gets hit (indicating that the player was not fast enough). After each second without a hit, the time is decreased by 0.05 seconds. Using a bow and arrow engages the arms and upper body while avoiding projectiles requires lower body movement. The hungry Kiwi provides a narrative that is consistent within the game world and supposed to engage players who are not motivated purely by competitive aspects.

The playing field lies in the center of the environment. It provides a 4m * 4m area for the player to move within, surrounded by four areas in which targets can spawn. The baseline spawn-probability depends on the location of the spawn area: Front and back begin with a probability of 0.4 each while the sides start with 0.1; to encourage a high amount of rotating movements. Over time the spawn probabilities change depending on where the last target spawns so that there remains a higher probability for opposite spawn locations (for an overview see figure 2).

Apparatus

The experiment took place in a 12m * 6m laboratory room with a carpeted floor. We instructed the participants to wear an HTC Vive HMD, which provides a resolution of 1080 ×
were within the virtual environment and unaware of their surroundings. The participants received instructions via text displayed within the virtual environment. Two HTC Vive controllers were used as input devices and for simple haptic feedback (vibration). A set of over-ear headphones provided the participants with auditory cues during the whole experiment and music in the music conditions. The participant’s heart rate was collected via the HTTP interface of the NEULOG Heart Rate and Pulse Logger and used for real-time adaption of the game as well as general data collection. The sensor was attached to the index finger of the participant’s non-dominant hand and fixated with medical tape. Figure 2 shows the complete setup. For rendering, system control, and logging, we used a computer with an Intel 3.5 GHz Core i7 processor, 32GB of main memory and two Nvidia GeForce GTX 980 graphics cards. The application was created using the Unity 3D Engine. As a non-distracting environment that fits the sports-theme of our application, we created a typical park scene with trees, a water fountain, and a large central area covered in grass.

**Design**

In order to determine potential influencing game elements and factors, we conducted a set of pre-studies where we tested various variables, including game music, scene lighting, pulsing targets, score and shooting mechanics. Most of them are static as well as adapted to the measured heart rate, leaving us with a total of 6 conditions for the main experiment:

1. A default condition with disabled music, no performance cues, and no direct lighting.
2. A music condition, where the background music was played with static speed.
3. A dynamic music condition, where the background music adapted its speed according to the heart rate.
4. A condition with constant direct lighting enabled.
5. A condition with direct lighting that adapts its intensity to the participant’s heart rate.
6. A condition which displays the score as performance cue.

Each participant started with a tutorial session, followed by a training session to reduce learning effects. The participants played all conditions of the game in Latin square order to avoid ordering biases. Each condition was played for two minutes, followed by a cooling phase in which the participant was brought to his or her individual base pulse. This procedure is based on high-intensity interval training, where short but intense exercise periods are followed by a recovery period [10]. Between the conditions, the participant rested within the VR scene with the light and the music turned off and the bow and the arrows invisible. The participant’s heart rate was measured and logged during the whole experiment.

Before and after the experiment we asked the participants to fill out questionnaires, containing a questionnaire about physiological impairment and experience with VR and 3D, the Simulator Sickness Questionnaires (pre- and post-study, SSQ), the Slater-Usoh-Steed questionnaire (SUS) and demographics [8]. Furthermore, we added specific questions about the experiment, goals, and experiences of players on different conditions.

**Participants**

Nineteen participants took part in the study, mainly members of the department of informatics (4 females, 15 males) with ages from 20 to 59. Only one participant was left-handed, nine had used the HTC Vive HMD, three had used a different HMD, and seven had never used an HMD before.

**4 RESULTS**

In order to create meaningful variables, we calculated the heart rate baseline for each participant in each condition using the mean of the heart rate data measured before the start of the condition. We subtracted the baseline from the mean heart rate to get comparable mean heart rate changes. Applying a repeated measures ANOVA showed a statistically significant difference between conditions (Mauchly’s Test: $W = 0.25, p = .288 > .05$. ANOVA: $F = 43.35, p = .000$). Tukey’s Multiple Comparisons showed statistically significant results for the default conditions over the score condition ($p = .014$) and the light condition ($p = .000$), the
dynamic light ($p = .005$), music ($p = .000$), also for dynamic music condition ($p = .000$) over the light condition, and the music ($p = .002$), also for dynamic music ($p = .021$) over the score condition.

Furthermore, we analyzed the maximum pulse delta, calculated by subtracting the baseline from the maximum pulse. A repeated measures ANOVA showed a statistically significant difference between conditions as well (Mauchly’s Test: $W = 0.15, p = .06 > .05$. ANOVA: $F = 4.21, p = .002$). Tukey’s Multiple Comparisons showed statistically significant results for light over music ($p = .006$), dynamic music ($p = .009$) and default condition ($p = .015$). Figure 4 shows an overview of the data in the form of boxplots.

The target heart rate for high intensity lies between 80% and 95% of the maximum heart rate. We computed the maximum heart rate for each participant with the formula $208 - 0.7 \cdot \text{age}$ [17] and used this to compute the intensity for each participant in all conditions, see figure 5. While we did not find statistically significant differences between the conditions (ANOVA: $F = 0.32p = .903$) we found that the heart rate was close to 80% of the maximum heart rate. This suggests that KIVRSports is suitable for HIIT.

Besides the heart rate data, we also examined the shooting behavior of players. Players shot an average of 49 arrows in two minutes. Even though they had to move and shoot fast, participants hit targets with an accuracy of 85.8% on average. (no statistically significant difference between conditions ANOVA: $F = 0.79, p = .562$). With this shooting speed and accuracy, participants missed 17% of the spawned targets on average, which exploded on their own. (no statistically significant difference between conditions ANOVA: $F = 0.99, p = .428$). Counting targets hit by an arrow and targets that exploded by themselves together, players were able to evade 86.7% of the shots the targets fired at them on average. (no statistically significant difference between conditions ANOVA: $F = 0.46, p = .805$).

We measured a mean score for SSQ of $M=2.84$ (SD=2.85) before the experiment, and a mean SSQ-score of $M=6.11$ (SD=4.48) after the experiment, with the increase mainly caused by sweating. The mean SUS score for the sense of being present in the virtual environment was $M=4.763$ (SD=0.81), which indicates a high sense of presence (where a score of 7 represents a normal experience of being at a place).

An analysis of the questionnaire data using the repeated measures ANOVA revealed a statistically significant difference between the perceived helpfulness in each condition (Mauchly’s Test: $W = 0.33, p = .221 > .05$, Greenhouse-Geisser $p = .07$ with $F = 4.05$). Tukeys Multiple Comparisons showed statistically significant results ($\alpha = 0.05$) for the score condition ($p = .042$) and music ($p = .028$) over the default condition. Figure 6 shows an overview for the data in the form of boxplots.

14 participants used a free text field for additional comments. Six of them reported a positive overall impression (e.g. "fun game!", "very entertaining, very funny (translated from German)", "Best virtual sports game ever (...) "). Remarks concerning the conditions were: "Dynamic Music reduced my tension when speeding down. Regular Lighting condition was slightly bright and thus reducing the comfort", "the dynamic sound was very distracting. The score condition pushed me to give it all".
5 DISCUSSION
The statistical analysis up to this point is preliminary. The statistically significant differences between heart rates in different conditions require further examination as they are not at all self-explanatory. One interpretation of the conflicting results in maximum and mean heart rate would be that participants who reached a very high maximum heart rate consequentially engaged in resting behavior during the respective conditions. That interpretation could, for example, indicate that the music conditions help players to stay continuously engaged (e.g., driven by the rhythmic nature of the music) while the light condition encouraged them to give their best for a short amount of time which lead to exhaustion afterward. A combination of both effects could be especially promising with regards to HIIT. Based on the average maximum in heart rate, a majority of players reached the required values for HIIT at least once. Further analysis is necessary in order to determine how stable those high heart rates are over time and within the conditions.

The connection between self-reported helpfulness of conditions and measured heart rate shows that either the heart rate data is misleading or that there are additional influences to the player ratings. However, the analysis so far is based on mean values, and a possible coherence between self-report and performance could become visible when we examine the particular relations of both variables for each player.

6 CONCLUSION AND FUTURE WORK
The preliminary results of the statistical analysis show significant effects in heart rate. However, further research is needed in order to understand these results better. The participants’ remarks and the results from the SUS questionnaire indicate that we were able to reach our design goals: Players enjoyed the game and they experienced a high amount of presence in the game world. We also reached the goal to help players to become active during the game. The shooting behavior analysis shows that in addition to turning to find targets and moving to evade shots, players also achieved a high rate of fire. All this makes our game physically challenging. The comparison of hit and missed targets shows that the task was not too difficult (players hit more than 80% of the targets) which the questionnaire also reflects. With regards to HIIT, the measured maxima in heart rate seem promising as they indicate that KiVRsports supports users to reach a heart rate in the HIIT range.

Future work is necessary in order to examine the possible influences of game mechanics and design details on performance and to decide whether or not KiVRsports also supports full HIIT intervals. An additional variable combined from the tracked movement data would allow us to evaluate the quality of the heart rate measurements and would provide a second measure of activity. The conditions where light or music adapted to the heart rate suffered from the speed at which the heart rate changes. It might be interesting to increase the tempo of the music or the intensity of the light with a constant factor.

REFERENCES

