ABSTRACT
In this paper we compare simulator sickness symptoms produced by racing game in three different conditions. In the first experiment the participants played the Need for Speed car racing game with an ordinary 17” display and in the second and third experiments they used a head-worn virtual display for the game playing. The difference between experiments 2 and 3 was in the use of stereoscopy, as in the third experiment the car racing game was seen in stereoscopic three-dimensions. Our results indicated that there were no significant differences in sickness symptoms when we compared the ordinary display and the virtual display in non-stereoscopic mode. In stereoscopic condition the eye strain and disorientation symptoms were significantly elevated compared to the ordinary display. We conclude that using a virtual display as an accessory in a mobile device is a viable alternative, because the non-stereoscopic virtual display did not produce significantly more sickness symptoms compared to ordinary game playing.

Categories and Subject Descriptors
K.8.0. Personal computing: General: Games; I.6.8 Gaming

General Terms
Human Factors

Keywords
User experience, Simulator sickness, Head-worn display, Virtual display, Near-to-eye display, Games, Mobile gaming

1. INTRODUCTION
When a mobile device is used in game playing, the user can select the playing location freely. This is a significant benefit, as the user is not confined to a single room, but can spend time with game playing entertainment in many different situations. However, some results suggest that the excitement offered by the game is reduced when a small display is used [1]. Because of this, a head-worn display that could be connected to the mobile device might be a good accessory for mobile gaming devices. There are several benefits in using a head-worn display. Firstly, the game playing experience is probably enhanced by the large virtual display and immersive environment. Secondly, a modern virtual display is small, so it can be easily carried around with the gaming device [2].

However, a virtual display might induce sickness symptoms that reduce the enjoyability of the game playing [3-5]. These symptoms are related to different aspects of interaction of the perceptual systems and the virtual display. For example, strong movements in the visual field might produce a conflict between signals from the visual system and signals from the vestibular system. This conflict might produce nausea and disorientation for the user. Similarly, stereoscopic stimuli may produce a convergence-accommodation conflict in which the normal relationship between the accommodation and convergence systems of the oculomotor system is disrupted. Subjectively the physiological conflicts are indicated by adverse sickness symptoms [6]. The symptoms typically include nausea, eye strain and disorientation that vary according to the technology, content and individual user characteristics.

Because the entertainment experience might be disrupted by the sickness symptoms, it is important to design the head-worn displays and contents in such a way that the users experience as little symptoms as possible. In this study we wanted to compare the simulator sickness produced by an ordinary display, a head-worn virtual display and a head-worn virtual display with stereoscopic game. We used a fast-paced car racing game that includes fast movements and quick changes in camera angles so that we could obtain as large symptom values as possible.

2. METHODS
2.1 Participants
Twenty users participated in each experiment, so the total number of participants was 60. The mean age of the participants was 27.8 years with a range between 19 and 48 years. The participants were paid for their participation. In the experiment 1 there were 16 males and 4 females, and in experiment 2 and 3 there were 11
males and 9 females. In the results analysis the participants who had significantly higher Simulator Sickness Questionnaire (SSQ) values in their pre-test questionnaire results were excluded from the main analysis. A 0.05 significance level was used in this exclusion and as a result three participants were excluded from each experimental group.

2.2 Devices
In experiment 1 the participants viewed the game from 17” Nokia CRT display and in experiments 2 and 3 from Olympus EyeTrek FMD-700 head-worn display. Olympus EyeTrek is a binocular display providing a resolution of 800 x 600 pixels and field-of-view of 30 degrees x 30 degrees. In experiment 3 Wicked3D drivers were used to convert the game graphics to stereoscopic stimuli. In the CRT display condition the viewing distance was approximately 40 cm.

2.3 Procedure
Before the experiment the participants went through a visual screening procedure in which we tested near and far visual acuity, stereoscopic acuity, horizontal and vertical phoria and near point of accommodation.

Before the experiment we collected background data. The users were asked to tell their gender, age and experiences related to head-worn displays and computer game playing. We also asked about the amount of near work they conducted during a typical day and the amount of eyestrain symptoms that they experienced during the work. Finally, we asked the participants to rate the frequency of headaches and motion sickness that they experienced in their daily life. After the visual screening and the background questionnaire the participants played A Need for Speed game for 40 minutes.

Simulator sickness was measured with Simulator Sickness Questionnaire (SSQ; [6]). The SSQ consists of sixteen questions in which the user has to rate the severity of specific symptoms (e.g. eye strain, headache etc) using a scale “none”, “slight”, “moderate” or “severe”. Four scores can be calculated from the resulting data. The total score reflects the general symptom level in the experiment The three factor scores that are calculated are nausea, oculomotor and disorientation factors. The SSQ was administered before and after the experimental task. The pre-task scores were used to exclude participants with high existing symptom levels. In other words, participants who for example had a severe headache when they came to the experiment, were excluded from the final analysis. The post-task scores were used to evaluate the severity of sickness symptoms in the experiment.

3. RESULTS
The results show that the sickness symptoms were elevated in the condition where stereoscopic depth was used with head-worn display (Figure 1 and Figure 2). Especially the total score (Figure 1) and the disorientation score (Figure 2) were significantly elevated. On the other hand, the virtual display gaming without stereoscopic depth produced similar symptom levels as playing the game with tabletop CRT display.

Statistical analysis indicated that there were significant total effects in SSQ/Total scores (ANOVA, F(2,48)=6.00, p<0.01), in SSQ/Nausea scores (ANOVA, F(2,48)=8.207, p<0.01) and in SSQ/Disorientation scores (ANOVA, F(2,48)=3.644, p<0.05).

Post-hoc comparisons with Tukey HSD test indicated that most differences were between the CRT condition and the virtual display with stereoscopic graphics condition (SSQ/Total p<0.01, SSQ/Nausea, p<0.01, SSQ/Disorientation, p<0.05). The differences between virtual 2D experiment and CRT experiment or virtual 3D experiment were not statistically significant.

The gender, age, motion sickness susceptibility, headache susceptibility, near work symptoms score, computer game experience or any of the vision related variables did not significantly affect the symptom levels.

4. CONCLUSIONS
The results suggest that simulator sickness is not a major problem in virtual display gaming. Even with a fast-paced car racing game the sickness scores were not significantly different from game playing with an ordinary CRT display. Many captivating games are much more static and thus induce much less symptoms compared to the game used in this experiment. Consequently, using a virtual display as an accessory to a mobile device is probably not affected by adverse symptoms experienced by the participants.
When stereoscopic graphics were used in the virtual display, the symptom levels were much higher. This is probably related to the convergence-accommodation conflict that is produced in the participant’s oculomotor system when the game is viewed. However, it should be noticed that the depth levels used in this game were high, which probably increased the symptom levels significantly. Other results suggest that using smaller depth values in stereoscopic contents can significantly reduce the experienced symptom levels [7, 8]. Some studies suggest that stereoscopic gaming might enhance the entertainment experience in game playing [9], so in future studies it might be useful to vary the depth magnitudes and try to find the optimal range of depth values that does not produce too much eye strain but still creates a better game playing experience.

4.1 Observations
The purpose of this experiment was to measure simulator sickness with virtual displays. However, informal observations suggest that this approach might not have been sufficient in capturing the complete user experience with the virtual display. The person conducting the experiments noticed an interesting phenomenon with the virtual display experiments 2 and 3. Specifically, many participants expressed spontaneously the superiority of the game playing experience with the virtual display in experiments 2 and 3. Furthermore, some of them even wanted to continue playing after finishing the experiment. Because we did not measure excitement or fun, we could not quantify these effects, but this observation is worth mentioning as it puts the symptom levels in our results into a new perspective. If we would have measured the positive experiences in the experiments, we might have noticed that the participants are having more fun with the virtual display even if they get more symptoms. Furthermore, the experience of fun might even override the adverse symptoms that the participants were experiencing. Because of these observations, we have included questionnaires measuring positive experiences in our other game playing studies [10].

5. REFERENCES