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Cybersickness and Desktop Simulations: Field of View Effects and User Experience

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ABSTRACT

We used a desktop computer game environment to study the effect Field-of-View (FOV) on cybersickness. In particular, we examined the effect of differences between the internal FOV (iFOV, the FOV which the graphics generator is using to render its images) and the external FOV (eFOV, the FOV of the presented images as seen from the physical viewpoint of the observer). Somewhat counter-intuitively, we find that congruent iFOVs and eFOVs lead to a higher incidence of cybersickness. A possible explanation is that the incongruent conditions were too extreme, thereby reducing the experience of vection. We also studied the user experience (appraisal) of this virtual environment as a function of the degree of cybersickness. We find that cybersick participants experience the simulated environment as less pleasant and more arousing, and possibly also as more distressing. Our present findings have serious implications for desktop simulations used both in military and in civilian training, instruction and planning applications.

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Keywords: cybersickness, affective appraisal, field of view, desktop simulation

1. INTRODUCTION

Cybersickness is the phenomenon of people getting sick from actively playing computer games of passively watching them[18]. Cybersickness can be categorized as visually induces motion sickness, similar to simulator sickness[2]. The main symptoms include nausea, oculomotor disturbances such as eye strain, disorientation, vertigo, and postural instability[14]. For many years driving, flying and sailing simulators have been known to cause sickness, which negatively affects the effectiveness of these trainings. Recently, cybersickness with desktop systems has become an important issue due to the increasing use of these systems for serious gaming applications.

Cybersickness appears to be a multifactor problem[18,23]. Some of these factors are related to technical features (optical distortion, field-of-view, flicker, motion platforms, refresh rate, resolution, transport delays, update rate). Other factors are related to user characteristics (experience, gender, field independence, age, illness, mental rotation ability, postural instability, susceptibility to motion sickness); and again others related to exposure schedules (duration, repetition). Because of its anticipated relatively large impact we focused in this study on the effects of FOV on cybersickness. In particular, we examined the effect of differences between the internal FOV and the external FOV on the incidence of cybersickness.

In military contexts, desktop gaming and simulation environments are increasingly being used for training and instruction, simulating for example operations in unfamiliar (foreign) urban areas and cultures in situations where emotions influence performance[4,8,20], or to simulate asymmetric[5] or information[6] warfare. In these applications, it is essential that the environment evokes the right atmosphere to create for instance the desired sense of urgency and impending danger, since this determines the emotional experience of the trainee, which in turn influences his reactions and judgments. In civil contexts, desktop simulations of physical environments have become indispensable tools for professionals such as architects, landscape planners[11,13], and environmental researchers, to communicate design and planning impacts[7,17] and to investigate human perception of environments[9]. These simulations can be considered as valid when they evoke cognitive, emotional and affective user responses that are similar to those that would be evoked by a real equivalent. Only then can we expect the user to experience the simulated environment in a similar way as the corresponding real one. According to Russell's attribution hypothesis[21], a person's affective appraisal of a perceived

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environment may be influenced by the affective state she is in. This may implicate that people may erroneously misattribute their own feelings to the environment they perceive. Thus, participants in a serious game may experience the simulated environment as less pleasant, and possibly also as more distressing, when they suffer from cybersickness. In this study we investigated the effects of cybersickness on the affective appraisal of an environment simulated on a desktop computer system.

The rest of this paper is as follows. Section 2 presents an experiment in which we used a desktop computer game environment to study the effect of both internal and external Field-of-View (FOV) on cybersickness. Section 3 describes an experiment in which we studied the user experience (appraisal) of this virtual environment as a function of the degree of cybersickness. In Section 4 we discuss the main findings of this study and their implications for serious gaming applications of desktop systems.

2. EXPERIMENT I: FOV EFFECTS

In this experiment we studied the effect of Field-of-View (FOV) on cybersickness in a desktop computer game environment. In particular, we examined the effect of differences between the internal FOV (iFOV, the FOV which the graphics generator is using to render its images) and the external FOV (eFOV, the FOV of the presented images as seen from the physical viewpoint of the observer). We hypothesized that incongruent iFOVs and eFOVs would lead to a larger incidence of cybersickness.

2.1 Method

The experiment was performed in a dimly lit room, using two similar set-ups separated by black curtains. Each set-up consisted of a Toshiba TDP-P6 projector, which projected at the back of a frosted rear-projection screen. Subjects faced the other side of the screen. Both screens measured 1.46 cm (h) by 1.09 cm (v). The screen resolution was 1024 x 768 pixels. Screen refresh rates were 75 Hz.

The projectors were connected to fast Dell XPS computers. One machine was an XPS700 with Intel Core2 Duo 6600 chipsets running at 2.4 GHz, 2 GB memory, and dual NVIDIA GeForce 7950 GX2 graphics cards. The other machine was an XPS600 with a Pentium 4 processor running at 3.6 GHz, 1 GB memory, and dual NVIDIA GeForce 7800 GTX graphics cards. Both machines easily provided the frame rate of 75 Hz at which the projectors were running.

A total of 20 people (15 male and 5 female) ranging in age from 19 to 31 years (with a mean age 22.8 years and a standard deviation of 3.1 years) participated in the experiment in return for monetary compensation. Only 6 participants were avid first person shooter (FPS) players; the rest had little or no experience in playing FPS games. The experimental protocol was approved by TNO Human Factors internal review board on experiments with human participants. The participants gave their informed consent prior to testing.

All subjects participated in three sessions on separate days over a period of one week, always at the same time of the day. To minimize aftereffects the sessions were at least 48 hours apart. A simplified version[3] of the Motion Sickness Susceptibility Questionnaire[10,19] was used to assess the susceptibility of the subjects to motion sickness.

Subjects were seated in a comfortable chair with their head against a raised headrest. Their visual straight ahead was aligned with the centre of the screen and the viewing distance was either 203 cm or 58 cm, resulting in a vertical eVOF of 30º and 60º respectively, and a horizontal eFOV of respectively 49.6º and 103.1º. In the 'congruent' condition the iFOV was equal to the eFOV; in the incongruent condition the iFOV and the eFOV had opposite values (see Table 1).

Subjects viewed a simulated walk through a virtual environment. The virtual environment was generated with the graphics engine of the game Half-Life 2 (the 'Source' engine) and comprises rural, mostly coastline, areas, an industrial vista and an urban area, depicting a city with mixed European architecture (Fig. 1). The virtual walk took place at a simulated speed of 13.6 km/h. An erratic swaying scene rolling motion about an axis at foot level and with a peak amplitude of 16º was superposed on this translation to increase the imagery's potential to provoke sickness. The walk lasted for about 12 minutes and was repeated about four times, resulting in a movie with a total length of 50 minutes.

Before starting the experiment, participants filled out a questionnaire about their physical and mental state, their experience with computer games, and their past susceptibility to motion sickness and related phenomena. The participants were then seated at the correct distance from the screen and the virtual tour started. Just before the start of the tour the participants wrote down their MISC score (MIsery Scale: 0 = no problems at all, 1-5 = any symptom except nausea, 6-9 = nauseated, 10 = vomiting[3]). After two minutes the tour was interrupted for a few seconds allowing the participants to rate their MISC level again. This was then repeated every five minutes. Hence, a total of 12 MISC scores was obtained. After the end of the tour (i.e., after 50 minutes) they assessed their MISC level for one more time. The participants were instructed that they could stop the experiment at any time when they felt too sick to continue, which would generally be at a MISC level of 6 or higher. This occurred in 12 sessions and involved 8 subjects.

Fig. 1. Locations encountered during the virtual walk. (a) View of the coastline area. (b) Coastal road along an industrial area. (c-f) Some typical cityscapes.

The iFOV and eFOV were combined to create the following four conditions (see also Table 1):

1. Wide angle image; viewed from near by (congruent condition)
2. Wide angle image; viewed from far away (incongruent condition)
3. Tele lens image; viewed from near by (incongruent condition)
4. Tele lens image; viewed from far away (congruent condition)

Table 1. Condition numbering scheme

FOV		Internal	
		30°	60°
External	30°	4	2
	60°	3	1

Our primary dependent variable was the MISC rating. From all MISC scores the subjects wrote down during an experimental session the maximum value was taken (dubbed MaxMISC). Some subjects reached this maximum well within the period of 50 minutes, while others showed persistently increasing ratings, suggesting higher ratings would have been obtained if the exposure would have been longer. As an additional measure we therefore estimated the level that would eventually be reached by fitting the function

$$MISC(t) = A\,(1-\exp(-t/\tau)) \qquad (1)$$

to each set of individually obtained MISC scores. Here A will be the saturated value of the MISC and τ the time it takes to reach 63% of this value. The parameter A was limited to a value of 10.

We used a Balanced Incomplete Block Design in which each subject received three of the four conditions. Therefore, each of the four conditions was measured with a group of 15 subjects.

2.2 Results

The MSSQ yielded a mean score of 21.5 ±27 (minimum=0, maximum=84.9, SD=27.3), which is below the 50th percentile of a normal population (MSSQ=37), indicating that most of the test subjects were less prone to motion sickness than average.

A typical time course of the MISC during a session can be seen in Fig. 2, together with the exponential fit according to Eq. 1. The crux of the experimental result is summarized in Fig. 3. Clearly, the two incongruent conditions (2 and 3; eFOV≠iFOV) have the lowest scores and the congruent conditions (1 and 4; eFOV=iFOV) have the highest scores. An ANOVA revealed the effect of condition to be significant ($F(3,35) = 12.3$, $p < .0001$ for MaxMISC and $F(3,35) = 3.4$, $p = .028$ for A). A post-hoc Tukey test revealed all the MaxMISC differences between the various conditions to be significant, except between conditions 1 and 4 and between conditions 2 and 3. A post-hoc test on A only shows the difference between conditions 1 and 3 to be significant.

To illustrate the effect of habituation, Fig. 4 shows the average MISC-ratings for the different sessions. The effect of session order is only significant for MaxMISC ($F(2,35) = 3.9$, $p = .029$) and not for A. A post-hoc Tukey on MaxMISC identifies the difference between session 1 and 3 as significant ($p = .047$).

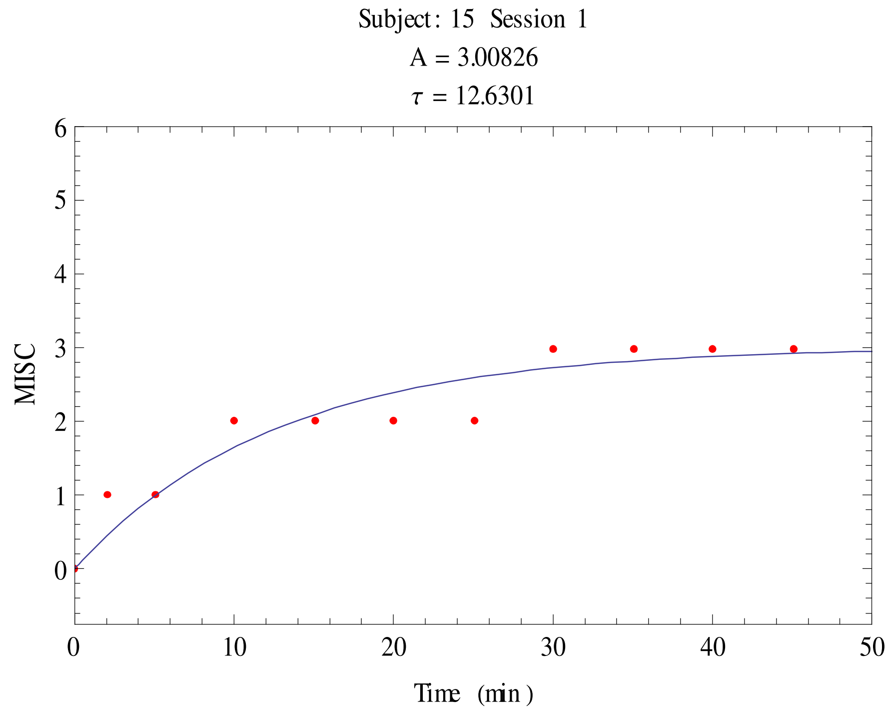

Fig. 2. Typical set of MISC scores recorded during the course of a session.

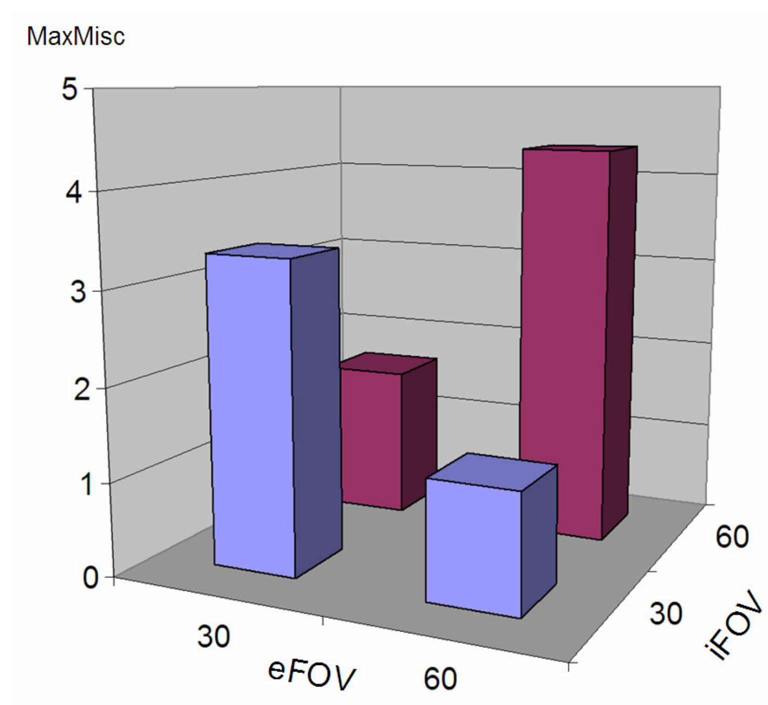

Fig. 3. MaxMISC as a function of internal and external FOV.

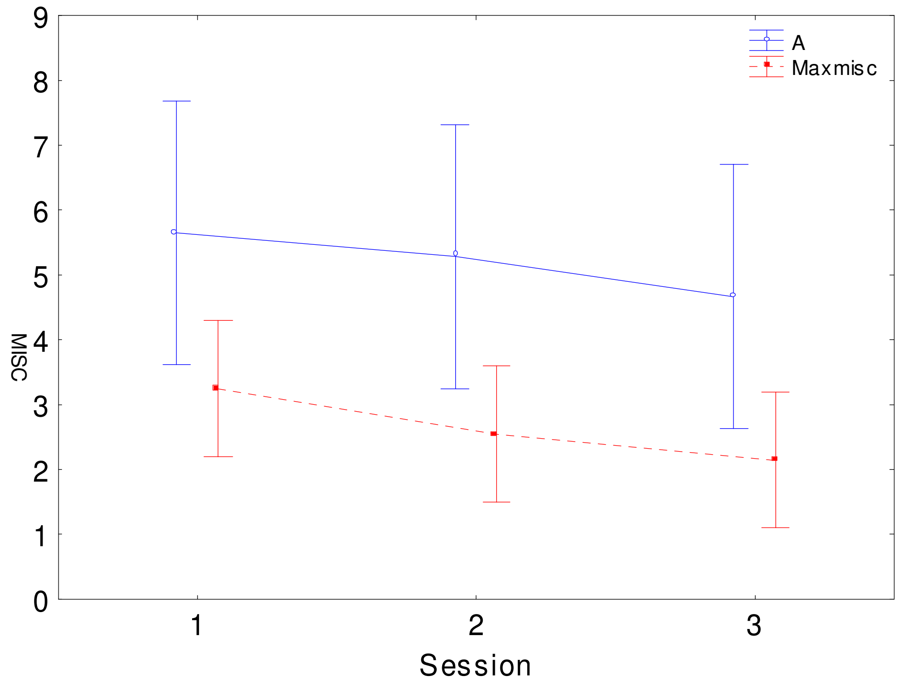

Fig. 4. Effect of habituation.

2.3 Conclusions

A popular view is that the design viewpoint of simulator imagery should coincide with the actual viewpoint in order to lower the chance of cybersickness to occur[15]. In this experiment we have found the opposite to be true: incongruent internal and external FOVs (conditions 2 and 3) lead to lower average levels of sickness An explanation may be that the susceptibility to cybersickness is not a monotonous increasing function of the difference between iFOV and eFOV. It may be that for small differences sickness increases with the difference, but decreases at large differences. A possible explanation may be that the incongruent conditions were too extreme, thereby reducing the experience of vection (the sense of self-motion induced by optic flow in a stationary observer).

In the current experiment we did not find clear (significant) MISC differences between the high and low FOV displays. This suggests that, although vection is known to be "stronger" with larger FOVs, absolute FOV size itself not necessarily affects sickness.

There is, lastly, clear evidence of habituation: on average, misery was less at each succeeding session.

3. EXPERIMENT II: THE EXPERIENCE OF SIMULATED ENVIRONMENTS

In this experiment we studied the effect cybersickness on the user experience of a virtual environment simulated on a desktop computer. Our hypothesis was that cybersick participants would find the environment less pleasant.

3.1 Method

In this experiment participants viewed a simulated walk through the same virtual environment that was also used in Experiment I (Fig. 1). Passive viewing was used to ensure that every participant had the same impression of the environment. The virtual walk took place at a simulated speed of 13.6 km/h. Our aim was to induce cybersickness without hindering the formation of an affective appraisal. To increase the imagery's potential to provoke sickness, we used a large eFOV (60º) in combination with an erratic swaying camera motion about an axis at foot level and with a peak amplitude of 8º. These parameter settings were likely to induce cybersickness within a relatively small amount of time, before participants would get bored (which might confound the affective appraisal). Previous research indicated that motion sickness related symptoms are most prevalent when either a roll or pitch motion is performed[1,16]. We used a roll motion since this ensures less distortion of the scenery to be appraised.

The simulated walk started at a beach and ended in a city, and lasted about 12 minutes. At the end of the first walkthrough, the presentation started over and ran for another five minutes before stopping at a designated part in the city. The participant was asked to appraise the environment displayed at that moment.

The degree of cybersickness was rated using the Misery Scale (MISC)[3]. MISC scores range from no symptoms (0), undeterminable symptoms (1) and slight determinable symptoms (2) gradually upwards to vomiting (10).

The affective appraisal of the virtual environment was rated using a slightly modified version of the eight point semantic differential scale developed by Russell and Pratt[22]. This scale describes the affective qualities of a molar environment as a 2D space, with the independent dimensions unpleasant-pleasant and arousing-sleepy on the two main axes. Diagonally through these axes are the dimensions exciting-gloomy and distressing-relaxing, which can optionally be inferred from the two main axes. Participants rate a list of 40 affective adjectives which are then grouped into the two dimensions comprising the appraisal.

The setup and the viewing conditions were the same as in Experiment I. Participants were seated in a chair with a headrest, at approximately 1.2 meters viewing distance. Occasionally, when a participant got highly nauseous, they were allowed to sit slightly further away from the screen, as this probably wouldn't influence the mental representation of the virtual world[12].

The test group consisted of N = 32 persons. Two persons had to forfeit prematurely because they reached a MISC score of 8 or higher relatively early in the experiment (after 7 and 9 minutes), which was the preset ceiling of this experiment. Imposing the participants to continue while feeling very sick was considered unethical, thus for the end result the Valid N = 30. The average age was 45.8 years, with the minimum age being 20 years, the maximum age 68 years and SD = 15.2 years. However as a possibly confounding factor, the ages aren't evenly distributed, with participants being either college students, or normally distributed around the age of fifty. 15 Persons were male and 17 persons female. The persons that quit prematurely were a 68 year old man (also the oldest participant), and a 47 year old woman.

Before starting the experiment participants filled in three questionnaires. First, they answered questions about their physical and mental state, their experience with computer games, and their past susceptibility to motion sickness and related phenomena Second, they rated their proficiency with virtual environments, first FPS games and Half-Life 2 in particular. This was important, as people who recognize the scenery from the game may recall the set pieces in the game from the corresponding environments, which may in turn influence their affective appraisals. Two people reported having played Half-Life 2, but when prompted after the experiment neither said they recognized any locale. Second, participants appraised the affective qualities of a picture of a neo-renaissance building that resembled the target area of Fig. 1f, according to a shortened (12 adjective) version of Russell and Pratt's[22] scale. This was done to accustom the participants with the appraisal measurement scale, and to ascertain the participant's affective appraisal of this type of cityscape. The scores show a homogeneous liking of this architectural style (Fig. 5). After completing the three questionnaires, the participants were delegated to the darkened experiment room and seated in the setup. There they watched the tour of the virtual environment, during which they were regularly prompted to note down their MISC scores. At the end of the presentation the camera froze on the target area depicted in Fig. 1f. Then, the lights in the room were turned on dimly, and the participants appraised this particular part of the environment with Russell and Pratt's affective scale[22].

As Fig. 5 shows, prior to the experiment nearly all participants found the exemplary neo-renaissance style architectural cityscape to be pleasant and, for the greater part, slightly sleepy. Our hypothesis was that cybersick participants would find the environment less pleasant.

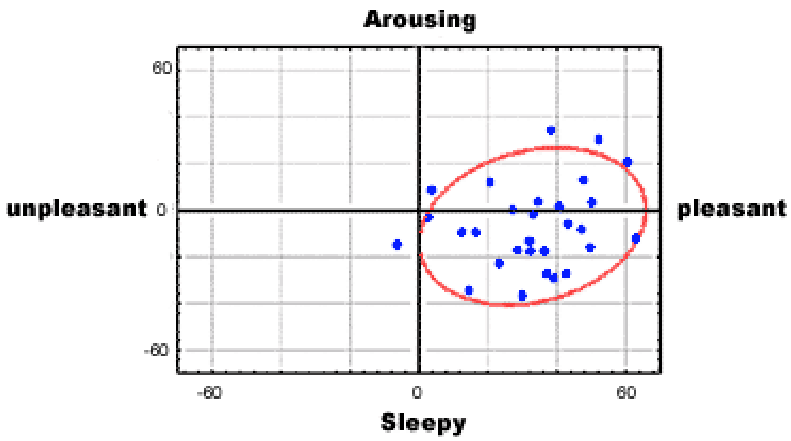

Fig. 5. Scatterplot with 95% confidence ellipse detailing the affective appraisals of the photograph.

3.2 Results

30 People finished the experiment. Of these, 7 reported no effect at all during the whole exposure, and 13 ended feeling fine. The last MISC report was used as the criterion for the following statistical analysis, as it most accurately described the person's wellbeing during the appraisal task. 16 Participants reported different degrees of cybersickness, although the MISC scores they reported were unevenly distributed over the spectrum, with 19 participants scoring a 0 or a 1, and a nearly even distribution of the remaining MISC scores. The small number of people per MISC score meant that an accurate decomposition of the effect of different degrees of cybersickness on the affective appraisal of virtual environments was problematic. This was further complicated by the fact that people could stop after reporting an 8, while the onset of nausea, which would hypothetically lead to the highest change in affective appraisal, doesn't start until level 6. Although a simple multivariate regression did return a significant result, the small amount of people that ended with cybersickness and the apparent high variation per MISC score, gives the model a low fidelity.

Therefore the participants experiencing cybersickness were pooled into a single group, which allows a more robust comparison. The MISC score can be divided into four categories: participants experiencing no effect (0), participants experiencing undeterminable symptoms (1), and participants experiencing determinable symptoms in varying amounts of severity (2-10).

As determinable cybersickness starts at a score of 2, this semantic divide was chosen as the demarcation criterion (incidentally nobody scored a two, hence the de facto divide is 0-1 and 3 and higher). Consequently two groups were formed, one consisting of 19 participants who were deemed physically well, and one consisting of 11 participants, who were deemed cybersick. These two groups can then be compared with a One-Way ANOVA, with the cybersickness grouping as categorical predictor and the four different affective dimensions as dependent variables. The plot of this test can be seen in Fig. 7, where the affective dimensions differ significantly as a result of the cybersickness: $N = 30$, Wilks$\lambda = 0.52$, $F(2,25) = 5.723$, $p < 0.003$. A high score on the arousing-sleepy scale corresponds to a high level of arousal, while a low score indicates a low arousal (or highly sleepy). Likewise, a high score on the pleasant-unpleasant dimension corresponds to a high level of attributed pleasantness; a high score on the exciting-gloomy dimension indicates the participant found the environment exciting; and scoring high on the distressing-relaxing scale means the environment is distressing. Fig. 7 shows even more change than was initially hypothesized. Participants who are cybersick not only appear to experience the environment as being less pleasant, but also as more arousing, and possibly as more distressing.

Examining these scores with a post-hoc Tukey test reveals that the significant result of the four dimensions combined is mostly due to a significant effect on the pleasant-unpleasant dimension ($p < 0.05$), while the effect on the arousing/sleepy scale barely reaches significance ($p = 0.051$). Differences in the exciting/gloomy and distressing-relaxing scale are insignificant however, so the regression line representing distressing-relaxing should be regarded with caution. If the possible outlier in the second quadrant is deleted, excluding this person from the scores still makes the overall affective appraisal significantly different for the cybersickness predictor ($N = 29$, Wilks$\lambda = 0.55$, $F(4,24) = 4.995$, $p < 0.005$), but the singular significance in the post-hoc Tukey tests disappears for both arousal-sleepy and pleasant-unpleasant.

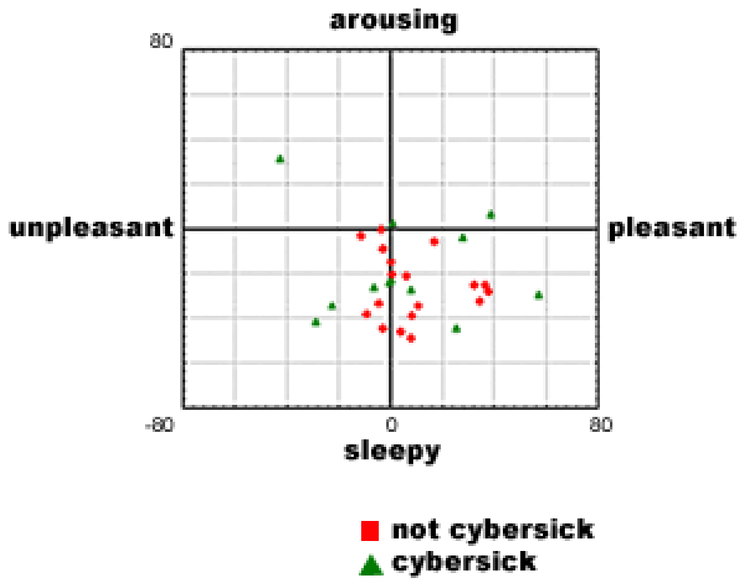

Fig. 6. The affective appraisals of the target area shown in Fig. 1f.

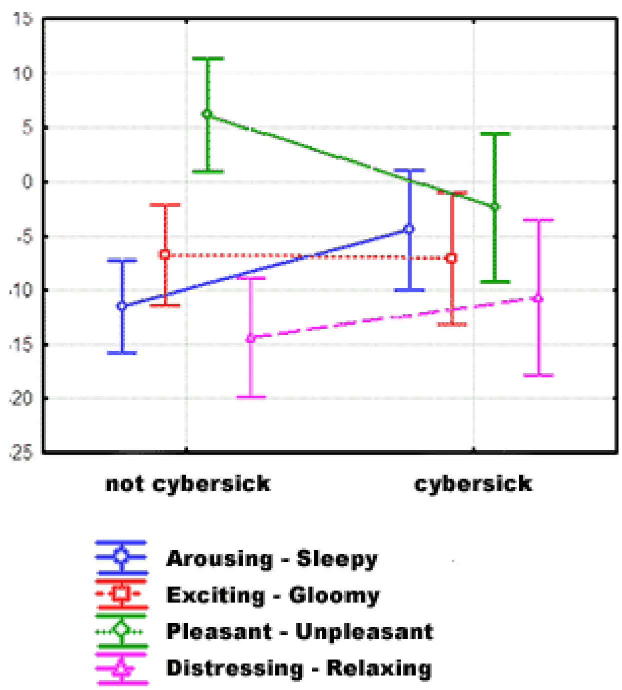

Fig. 7. The effect of cybersickness on the affective appraisal.

3.3 Discussion

It is well known that cybersickness causes physical discomfort. In addition, our present results show that cybersickness also changes the way people experience virtual environments. Exactly how cybersickness influences the experience of a virtual environment is not yet clear however. A significant difference has been found on the pleasant-unpleasant dimension, and a possible significance on the arousing-sleepy dimension. Although this wasn't tested during this experiment, it gives some circumstantial support to Russell's attribution hypothesis[21], that a person's affective appraisal of the environment is influenced by the affective state a person is in. It would implicate that people consider the buildings of a city less pleasant when they do not feel well themselves. Likewise it is conceivable that due to increased heart rate and sweating from the cybersickness, a person's self-assessment of arousal increases too, and is subsequently misattributed to the environment.

4. CONCLUSIONS AND DISCUSSION

For a simulated walk through a virtual environment shown in a desktop environment we find that:

- The incidence of cybersickness decreases when the internal and external FOVs of the simulation become more dissimilar.
- Cybersick participants experience the simulated environment as less pleasant and more arousing, and possibly also as more distressing.

Our current data then suggest an increase in the incidence of cybersickness for decreasing differences between the internal and external FOVs If this is true (experiments with more intermediate iFOV/eFOV values are required to confirm this trend), this leads to the following prediction: The ever increasing display sizes that gamers use tends to decrease the currently existing differences between game iFOV and eFOV. Therefore, gamers will steadily approach the sweet spot of the eFOV/iFOV curve that will cause maximal cybersickness.

It appears that cybersickness not only causes physical discomfort, but also changes the way people experience virtual environments. Cybersickness may therefore compromise the effectiveness of serious gaming and simulation applications. For instance, when desktop simulation environments are used to train soldiers for operations in unfamiliar (foreign) urban areas and cultures negative emotions induced through cybersickness may influence their performance, resulting in an unrealistic training behavior. The development of means to alleviate cybersickness is therefore of great importance.

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