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On the effect of free vs. restricted interaction during the exploration of virtual environments

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Abstract. Exploration of a Virtual Environment (VE) might vary as well in applied technology as in the conceptual design. A conceptual difference of exploring style and navigation type relates to the degree of freedom a user possesses. It ranges from completely unrestricted to completely restricted navigation. To assess the impact of different exploration styles, an experiment was carried out. Four different styles were compared in a large-scale VE. The navigation of the participants was either free or restricted in various levels concerning motion and viewing direction. During the exploration, the participants memorized the location of flags, which represented special events at these locations. The participant's task was to memorize position and color of the flags. Subsequently, they marked the positions and colors of the flags in a map of the scene. The performance in this task was captured, as well as data about their amount of experienced simulator sickness and subjective workload. Additionally, balancing tests were administered to investigate in an objective measurement of simulator sickness. Each condition showed the same achievement in the memorizing task and the subjective workload. Furthermore, the measured high variance in simulator sickness symptoms overrode other effects. In the balancing tests a basic influence of exposure with VE was found. However, subsequent interviews with the participants showed that the personal impression of the efficiency of exploration method was highly individual. By finding and matching exploration methods to individual persons, benefit by using Virtual environments could be enhanced.

Keywords: virtual environments, HMD, exploration, simulator sickness.

1. Introduction

Gaining local knowledge about a scenario and setting is essential for an efficient navigation and orientation. This is crucial for operations characterized by high levels of workload, such as for emergency or military forces. They have to be well aware of their own position and the location of dangerous areas in order to fulfill their tasks and missions swiftly and efficiently. One way to enhance local knowledge is to train and brief personnel before performing the mission. But commonly used paper maps have shortcomings because of an exocentric, birds-eye view and an abstract display. In contrast, Virtual Reality (VR) or Virtual Environments (VE) technologies allow an interactive and detailed exploration of new environments. This might enhance local knowledge because of additional interaction. It is expected that this enhances local knowledge and, thus, overall performance.

There are various ways to design the exploration of the according VE. They address technological issues (e.g. interaction device) as well as the conceptual design (e.g. exploration and navigation method and metaphor).

Besides other topics the exploration style itself can vary. A conceptual difference relates to the degree of freedom the user possesses for an exploration. With a completely unrestricted exploration style the user can navigate to any place and view in any direction. This is highly interactive, but might be less efficient. This is caused by too many degrees of freedom and users might get disoriented. To prevent this, the exploration style is usually restricted. *One way is to limit movement and orientation to certain patrol paths or

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surveillance areas. In this case, the movement path is restricted but the orientation of the view can still be user-controlled. A total restriction would result into restriction of both, path and view. The result would be similar to a movie. The experiment presented in this paper will investigate benefits as well as negative effects of different navigation styles.

In general, geographic orientation implicates the knowledge of the surrounding, the own position, the target position, and the direction of the own motion [7]. It is assumed, that performance and condition of the user in geographical orientation rely on factors addressing him, the environment, the task and the available technical aids.

In the following experiment, the participants were trained to navigate within the environment with a geocentric map as well as with an egocentric path through the scene. This was done to reduce the process of familiarizing with the scene. The landmark-route-survey model for gaining local knowledge differentiates between three types of knowledge: First, landmarks are registered, then following a special route is learned, and finally a cognitive map is gained [15]. This is assumed to be the basis of learning and memorizing additional situational information, like positions of acute problems, e.g. accidents or casualties. In the experimental setting flags were inserted, which are to represent such problems.

Geocentric and egocentric maps have an influence on the performance of the users in navigational tasks. Performance with egocentric maps was better than with geocentric maps [12][13]. This may be true not only for maps but also for pictures. Egocentric maps may have the same effect as pictures taken in a first-person-viewpoint. This may contrast to pictures taken in a viewpoint, the user could not take himself (third-person-viewpoint). Therefore, in the present study the acquired knowledge of positions of acute problems were tested in pictures in first- and third-person-viewpoint as well as in a geocentric map.

A relevant criterion for estimating usability and applicability is workload. Whereas the previous measures of performance are objective, workload reflects a subjective aspect of human performance. One way to measure workload is a subjective rating scale. Though they are characterized by large variance, they are still the most comprehensive approach [14].

For practical usability the appearance of negative physiological side-effects like e.g. nausea, headache, or disorientation has to be considered as well. These effects are subsumed by the term “cyber sickness”. Cyber sickness is a special type of simulator sickness, which occurs with all kinds of virtual simulation. The symptoms are alike, but the intensity of these symptoms varies between simulator and cyber sickness [18]. Therefore, cyber sickness is often measured and analysed by means of simulator sickness. Simulator sickness is influenced by characteristics of user, system, and task [10]. In this study the system characteristic “exploration style” is investigated. As a side-effect the experience in using a VE is captured. The experience is applied by the session schedule and, thus, the number of VE experiences. Past studies show that the type of display causes negative side effects because of the degree of immersion [1].

Although it would be desirable to measure simulator sickness during the VE experience, no reliable method of measurement is available to date. Instead, subsequent questionnaires are used. A commonly used questionnaire is the “Simulator Sickness Questionnaire” (SSQ) by Kennedy et al. [9]. The degree of subjective sickness is measured by rating 16 items of individual state. [18].

Besides subjective measurements, there have been intentions to measure simulator sickness by means of objective physiological measures subsequently to VE exposure. In a dynamic test, participants went a special path, while balancing with arms was restricted. As indicators for simulator sickness performance and number of steps were analyzed. Correlations between performance and SSQ were found [4]. In another study a correlation of force distribution while walking on a force plate and simulator sickness was found [19]. A static measurement of simulator sickness was done by analyzing the head movements of users standing upright while the walls around them were moved [16]. Based on these findings, own approaches to measure simulator sickness objectively after VE exposure were tested.

Nowadays, VEs are used for many applications and new operational areas. One trend in this is the impact of gaming technology. By utilizing rendering capabilities of games, the quality and vividness of the displayed virtual scene is increased. Moreover, available tools and examples for scene generation suggest an application even for scientific purposes reasonable [1]. Gaming software, which allows this kind of modification, is for example Half-Life 2 [20], Crysis [5], or Quake 3 [8].

2. Hypotheses

The baseline hypothesis expects an enhanced local knowledge about a place with growing levels of interaction during the exploration. This should result into the accurate reproduction of the number and the accurateness of the positions of landmarks in the virtual scene in a map. Furthermore, the performance in first-person-viewpoint pictures should outnumber the performance in a third-person-viewpoint picture.

But enhanced interaction may also result into increasing negative after-effects, as simulator sickness and workload. This is addressed in a further hypothesis, which considers simulator sickness and workload as a dependent of exploration style.

Furthermore, an effect of simulator sickness in static and dynamic balancing is expected.

3. Method

3.1. Participants

Originally, n=36 participants took part in our experiment, but 4 had to be excluded because of mission depth viewing acuity and another 4 had to end the experiment earlier because of simulator sickness. Consequently, n=28 participants (30.3 +/- 7 yrs; 20 male, 8 female) successfully finished the experiment.

The participants were randomly assigned to one of four groups, so each group consisted of 5 male and 2 female subjects.

3.2. Apparatus

The simulated urban area was projected on a binocular head mounted display (NVISOR SX HMD [11]) with a stereo-projection and a single display for each eye. The HMD provides a diagonal field of view of 60° and a resolution of 1280 * 1024 pixels with a color depth of 24 bit and a refresh rate of 60 Hz. This resulted in a horizontal field of view of 47° and a vertical field of view of 35°. To achieve field of regard of 360° the system was enhanced with a infrared-tracking-system. Therefore passive infrared-markers were affixed to the HMD. A 5-camera-tracking-system (AR-Track [2]) captured the orientation of the HMD. Pitching and yawing movements of the user were used for matching the displayed scene with his line of sight. To control translational movement, a wireless gamepad was used.

A virtual scene based on serious gaming was used (Quake III Arena, id-Software [8]). The level was designed by Mr. T. Barrett, Sydney, Australia, whom we would like to thank for his grateful support. It consists of a set of houses, picturing a small village. The overall area of the scene was approx. 115m * 105m.

3.3. Exploration

Exploration of virtual environments requires interaction of the user and the display system. The design of the interaction can grant many degrees of freedom to the user or it can be guided.

Four different levels of guidance vs. freedom in interaction with the virtual environment have been dinvestigated. In the “free” level, the distance of the point of view to the virtual ground was defined; rotational as well as translational locomotion was controlled by the user. In the other exploration levels, the path leading through the virtual village was predefined. The viewing direction was varied in three different levels.

In the first level (”guided”), the viewing direction was defined only by the rotational movements of the user.

The second level of restriction was designed with regard of a car passenger. The person’s viewing direction changed according to the direction, the car takes. Additionally it was possible to influence the viewing direction at any given moment. So the user was able to scan the environment according to his interests.

In the last condition the viewing direction was fixed like in a movie. However, in all conditions the users were able to stop the motion for scrutinizing at any given moment. Time on task was limited to 8 min to avoid strong symptoms of simulator sickness.

3.4. Memorization task

The scene of the village was enriched with 16 flags in 8 different colors representing acute problems or points of interest (Figure 1). The participants’ task was to explore the scene and memorize the positions and colors of the flags.

Figure 1: Snapshot: Virtual scene ("village") with flag

3.5. Experimental design

The study was based on a one factor design (exploration style) with repeated measures. The factor "exploration style" had the four treatments "free", "guided", "passenger", and "fixed". To minimize series effects the sequence of the treatments was balanced according to the squared experimental design [3]. All data were tested for normal distribution by Kolmogorow-Smirnow-Tests and then analyzed by means of single factor within-subjects design [6], [17] .

Each participant took part in 5 sessions: In the first session the participants were trained concerning scene and interaction metaphors. In this way, learning effects according to navigational knowledge of the village-scene and the interface should be minimized.

3.6. Dependent variables

3.6.1. Performance

The participants mapped the memorized positions and colors of the flags in a map of the scene as well as in pictures. Viewpoints of the picture were the users themselves (first-person-viewpoint, Figure 2, left) as well as third-person-viewpoints (Figure 2, right). This was done to be able to assess the mental model, which the participants gained during the sessions. Therefore, time on task, precision of the positions and number of flags (map) and error rate (pictures) were measured.

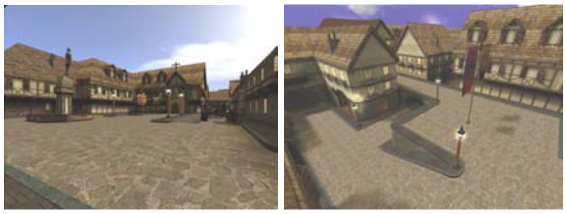

Figure 2: Picture with user-based viewpoint (left) and third-person-viewpoint (right)

3.6.2. Simulator sickness

Simulator sickness was evaluated by means of the SSQ [9]. It consists of three subscales for "nausea", "oculomotor symptoms", "disorientation", and additionally a total score based on all 16 questionnaire items. The SSQ was administered before and after the memorization task, and additionally one hour after the competition of each session.

3.6.3. Static and dynamic balancing tests

As new objective approach to measure simulator sickness, a static balancing test was administered. A Kistler-force plate (Type 9286A) was used. Participants took a Romberg's balancing test on it before and after the exploration task. The shifting of the center of gravity was measured.

For the dynamic test the participants went a distance of 3 m by placing one foot in front of another. The trajectory of the head was tracked by a infrared-tracking-system and markers, which were placed on the participant's head. Balancing with the arms was suppressed.

3.6.4. Task difficulty

To assess the difficulty of the task, the ZEIS-questionnaire in German language was administered. This questionnaire provides a two-level-system. In the first level a rough estimation of the task difficulty is given, in the second level the estimation is refined [14]. The range of the scale is 0-100.

4. Results

For estimating performance and task difficulty the data of four sessions were analyzed. The data from the training-session was not analyzed due to potential learning effects. However, the data from the training session was used for the analysis of simulator sickness, as the effect of adaptation was addressed.

4.1. Performance

A mean of 13 (+/- 2.9) out of 16 flags was positioned in the map, the divergence from the original positions was 2.37cm (+/- 1.67cm, Figure 3), which equals ca. 12m in the virtual scene. Task completion time was 185.5s (+/- 59.6s). Neither number of flags ($p=0.45$), nor divergence ($p=0.33$) showed a significant effect on exploration mode. However, time on task showed almost significant data ($p=0.05$).

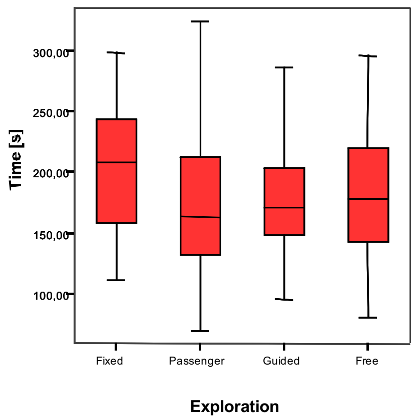

Figure 3: Boxplot of time on task (median and quartiles) as a function of exploration mode

At positioning the flags in pictures, exploration mode showed no significant influence on divergence, time on task or error rate ($p>0.18$). However, the different viewpoints led to varying error rates ($p=0.001$). While the error rate for first-person-viewpoint was 0.9 (+/- 0.8)) for first-person-viewpoint, it turned out to be 1.89 (+/- 1.0) for third-person-viewpoint.

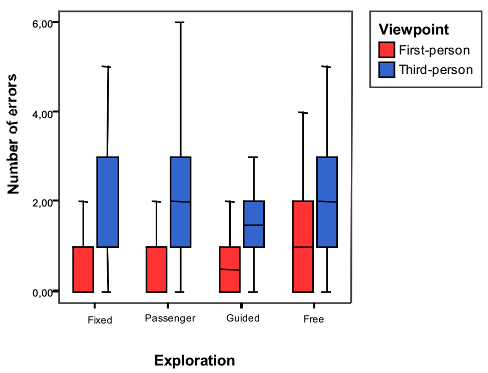

Figure 4: Number of errors in first/third person viewpoint pictures (median, quartiles and outlier) as a function of exploration mode

4.2. Simulator sickness

Most of the participants showed at least a few symptoms of simulator sickness during the exposure to the stereoscopic virtual environment. Those, which ended their participation early, experienced high simulator sickness scores up to 116.

The scores after the session varied very much (Figure 5). While each participant gained at least some simulator sicknees symptoms in at least one exposure ($SSQ_{min}=3.74$), others experienced serious symptoms ($SSQ_{max}=82.3$). After the session, mean turned out to be 7.4.

The scores after the exposure were significantly higher than before ($p=0.04$), one hour after each session the scores were significantly lower in session 3-5 ($p_3<0.01$; $p_4<0.01$; $p_5=0.026$) but not in session 1 and 2 ($p_1=0.055$; $p_2=0.065$).

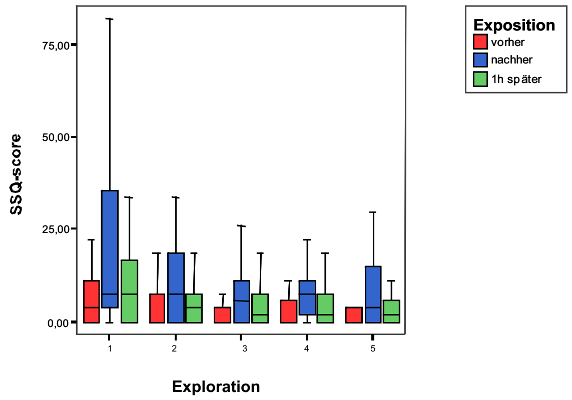

Figure 5: SSQ-scores (median, quartiles and outlier) as a function of schedule

There was no significant influence of exploration mode on simulator sickness ($p=0.567$, see Figure 6).

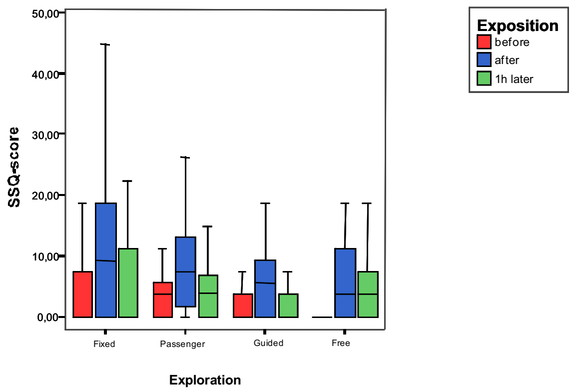

Figure 6: SSQ-scores (median, quartiles and outlier) as a function of exploration mode

4.3. Balancing tests

In the static balancing test the shifting of the center of gravity was found to be significantly altered by VE exposure (p=0.044). The exploration showed no significant influence (p=0.31. Figure 7).

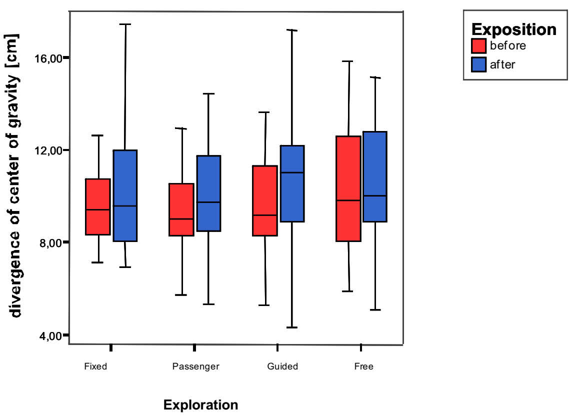

Figure 7: Divergence of center of gravity (median, quartiles and outlier) as a function of exploration mode

In the dynamic balancing test the exploration with VE showed a significant influence on the drift of the head (p=0.037). Exploration mode showed no influence (p=0.14).

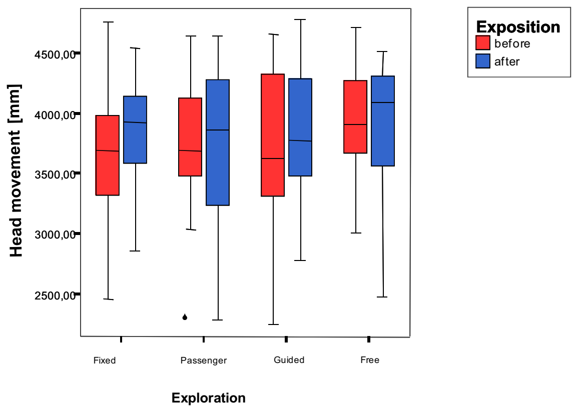

Figure 8: Head movement (median, quartiles and outlier) as a function of exploration mode

4.4. Task difficulty

Task difficulty rating varied widely (from 8 (very easy) to 100 (very difficult). There was no significant effects of exploration mode (p=0.56).

5. Discussion

The results have shown that the overall performance was not influenced by the exploration mode. An identical number of flags were memorized with their positions and colors. The knowledge of the positions was reproduced with less error in first-person-viewpoint pictures than in third-person pictures. This indicates that the positions of the flags were not totally included in the cognitive map of the scene. Therefore, mapping of relevant locations and positions can be supported by using first-person viewpoints.

Simulator sickness was also not influenced by the exploration mode. A reason for this can be the overall variance of induced simulator sickness between persons. Although the mean SSQ-score for all participants was considerably low, some participants still rated high scores and, thus, experienced a high level of simulator sickness. However, experienced users of VEs reduced the simulator sickness symptoms as expected. Exploration style did not influence the experience process.

Subjective task difficulty and workload were also rated with a very broad variance, almost covering the whole scale. It is assumed that exploration style has no influence on subjective task difficulty or is covered by the overall variance.

With regard to an objective measures of simulator sickness (i.e. the balancing test performed after the experiment) the effect of VE on head drift (dynamic) and shifting of center of gravity (static) have been found in accordance with [4][19][16].

In subsequent interviews participants expressed preferences for single exploration modes of the VE, but no overall preference could be deduced.

6. Conclusion

The results did not support our baseline hypothesis and, thus, no effect of exploration style on local knowledge was found. We have also not found any consistent occurrence of simulator sickness. Objective measures showed promising potentials, which should be explored in further experiments. Individual interviews of the participants revealed large inter-subject differences which showed a vast variance of subjective preferences, exploration styles and ratings. This made it difficult to find significant effects. Therefore, subsequent experiments to individual application of different exploration methods are planned for the future. By identifying and matching exploration methods to individual persons, benefit by using VE could be enhanced.

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