Diving in? How Users Experience Virtual Environments Using the Virtual Theatre

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Abstract. Simulations are used in various fields of education. One approach of improving learning with simulations is the development of natural user interfaces, e.g. driving or flight simulators. The Virtual Theatre enables unrestricted movement through a virtual environment by a Head Mounted Display and an omnidirectional floor. In the experimental study presented (n = 38), the effects of objective hardware characteristics were being tested in two groups. The task was the same: Remembering positions of objects after spotting them in a maze. One group fulfilled the task in the Virtual Theatre, the other group on a laptop. Personal characteristics (gaming experience, locus of control) and perception measures for immersion (spatial presence, flow) were also assessed. Analyses show that the Virtual Theatre indeed leads to more spatial presence and flow, but has a negative effect on the task performance. This contradicts the common assumption that immersion leads to better learning.

Keywords: Immersion, Spatial Presence, Flow, Learning, Simulators, Natural User Interfaces.

1 Introduction

Simulations are used in various fields of education. By imitating real-world processes, personnel skills can be developed, increased or maintained. Especially if the learning process requires expensive equipment or usually would take place in a hazardous environment, the use of simulations is not only beneficial but absolutely necessary [1, 2]. Apart from the software, the user interfaces of the technological systems applied in the simulation environment can affect the learning process [3]. One approach of improving learning with simulations is the development of natural user interfaces. A common example is the use of flight simulators including authentic user interfaces within pilot training instead of using just the simulation on a regular desktop computer. According to the classical memory theory, if the context in which we use our knowledge i.e. in which we have to transfer it to new situations resembles the context in which we learned the information in the first place, our memory works better. Moreover, how well we can retrieve knowledge from our long term memory depends on the quality of how well we encoded the information [4]. In the case of

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computer-aided learning, encoding information can be considered as a task, which is partitioned in at least two parallel sub-tasks: Dealing with the content and controlling the learning environment with the respected user interfaces [5]. Therefore a lot of research and development activities follow the assumption that if the user can interface with the system in a natural way, more focus can be used for training than for the control itself [6]. However, to assume that hardware or software characteristics automatically lead to better learning outcomes is risky. Not every new approach which is technically feasible improves learning in the sense of task performance. The danger of designing complex and expensive virtual learning environments without having a positive impact on learning outcomes is obvious. However, judging the value of a virtual environment simply by its effect on task performance misses out on other factors which support learning. Boosting the students' motivation to deal longer, more steady or more effectively with the given content is also an important goal of virtual learning environments [7, 8]. Apart from learning outcome and motivation, a peak to a different domain reveals a third intended effect of virtual environments. According to the entertainment sector, the extent to which a game or in general a virtual environment can "draw you in" functions as a quality seal [1]. This phenomenon is often referred to as immersion. A figurative definition is given by Murray [9]: "Immersion is a metaphorical term derived from the physical experience of being submerged in water. We seek the same feeling from a psychologically immersive experience that we do from a plunge in the ocean or swimming pool: the sensation of being surrounded by a completely other reality, as different as water is from air that takes over all of our attention our whole perceptual apparatus" [9, Murray].

Enabling natural movement as the most basic form of interaction is considered an important hardware quality to create immersion [10]. Manufacturers of hardware that are supposed to enhance immersion claim that "Moving naturally in virtual reality creates an unprecedented sense of immersion that cannot be experienced sitting down" [11]. Almost 20 years ago, this could already be confirmed by Slater [10]. Another basic assumption in the context of virtual learning environments and natural user interfaces is that greater immersion means better learning and potentially higher training transfer [3, 6]. This suggests that immersion would be the precondition for better learning, caused by the qualities of the user interfaces. However, if virtual environments are used in educational contexts, those assumptions need to be confirmed by empirical evidence. The presented study therefore focuses on the following questions:

- Do natural user interfaces create a higher sense of immersion?
- Do natural user interfaces lead to better learning?
- Is immersion a necessary precondition for learning with natural user interfaces in virtual environments?

If assessed in an experimental setting, the construct of immersion needs to be specified. Spatial presence and flow are considered key constructs to explain immersive experiences. In general, flow describes the involvement in an activity [12, 13], whilst spatial presence refers to the spatial sense in a mediated environment [10, 14]. Spatial presence, as indicated in the name of the construct, refers to the spatial component of being immersed, i.e. the spatial relation of oneself to the surrounding environment. If we experience spatial presence in a mediated environment, we shift our primary reference frame from physical to virtual reality [14].

2 Method

2.1 Experimental Setting

The study presented in this paper assesses the relationship between personal characteristics, objective hardware characteristics, subjective experiences and task performance. Their expected relationship is visualized in Figure 1.

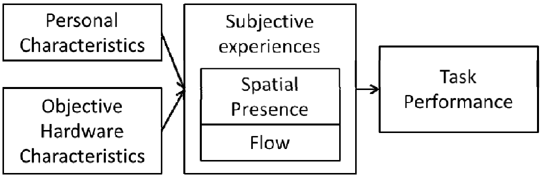

Fig. 1. Expected relationship between personal characteristics, hardware characteristics, subjective experiences and task performance

All participants had to solve the same task in the same virtual environment, which was a large-scaled maze in a factory building. Within the maze, 11 different objects were located. The first task for the participants was to navigate through the maze and to imprint the positions of the objects to their memory. For that, they were given eight minutes of time. The second task was to recognize the objects seen before in the maze. The third task was to locate the positions of the objects on a map of the maze. This was done on a self-programmed application on a tablet (Nexus 10) with a drag-and-drop control mode. The view of the maze in the first and second task is pictured in Figure 2.

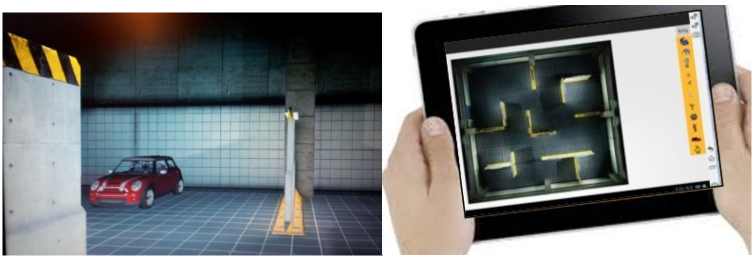

Fig. 2. View of the virtual environment used in the study in the first and in the third task

For both groups, the participants were given the chance to explore a test scenario (an Italian piazza) freely for about three minutes before the actual task started. This was in order to get used to the respected control mode. All experimenters who conducted the experiments were trained in advance by experienced researchers.

First they were being trained the functions of the hardware. In a second step, they took the observing position in a test run, and thirdly they conducted a test run on their own with the experienced researcher being the observer and giving feedback afterwards. Two groups of test persons were compared, having to use hardware which differed from each other regarding the following characteristics:

- control mode of the field of view,
- control mode of locomotion,
- display and
- body posture of the user.

Due to the composition of the simulator which was applied in the study, the hardware characteristics could only be tested in a certain combination and could not be isolated any further. The whole experiment took one hour. The complete procedure is visualized in Figure 3.

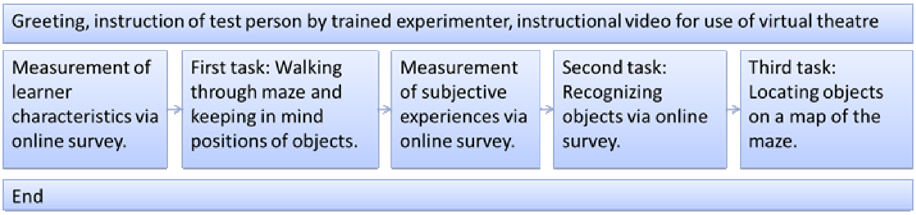

Fig. 3. Procedure of the experiments

2.2 Measurements

In this study, spatial presence was measured with elements of the MEC Spatial Presence Questionnaire of Vorderer et al. Several studies conducted by the authors strengthened the postulate of spatial presence being best explained as a two-level Model. This includes process factors (attention allocation, spatial situation model, self location, possible actions), variables referring to states and actions (higher cognitive involvement, suspension of disbelief), and variables addressing enduring personality factors (i.e. the trait-like constructs domain specific interest, visual spatial imagery, and absorption) [15]. Suspension of disbelief refers to the extent of how much a person pays attention to technical and content-related inconsistencies. The more a person can fade out the action of “looking for errors”, the higher the feeling of spatial presence will be according to the theory. In our study, instead of the subscales attention allocation and absorption, we used the Flow-Shortscale of Rheinberg. Flow is the mental state of operation in which a person performing an activity is fully immersed in a feeling of energized focus, full involvement, and enjoyment in the process of the activity. In essence, flow is characterized by complete absorption in what one does, as well as the feeling of smooth and automatic running of all task-relevant thoughts [12, 13].

The perception of a learning situation is highly likely not to be influenced just by objective criteria such as the technical configuration of the learning environment.

The strength of spatial presence experienced in a VE is supposed to vary both as a function of individual differences and the characteristics of the VE [3]. A general interest in the topic appeals to a person's curiosity and the motivation to learn something new. If chances to learn or experience something new are low, the motivation to learn decreases [7, 16]. However, we believe that not only interest in a topic but also in the way of presenting it can influence subjective experiences during the learning situation as well as learning outcome. The subscale domain specific interest of the MEC-SPQ refers to the topic of the medium, in our case the virtual environment. Because of the given considerations mentioned above and since interest in mazes didn't seem like a helpful operationalization for domain specific interest, we adapted it to interest in digital games. Additionally, participants were asked to state their gaming frequency, i.e. how many hours they played digital games per week. How well a person learns with the assistance of technology depends not least on whether a person has any experience with the respective technology and if not, feels capable of learning it quickly. The construct "locus of control regarding the use of technology" describes the extent to which a person believes that he or she can control technical devices in everyday life. It is a technology-related personality trait of human-computer interaction and was measured with the short scale from Beier [17]. Based on all theoretical considerations, the general hypothesis of the study was that natural user interfaces should have a positive effect on subjective experiences during the learning situation as well as on learning outcome, in our case operationalized in task performance.

The set of hardware characteristics functioned as the first independent variable in the presented study. Furthermore, the test persons' locus of control regarding the use of technology (second independent variable), interest in digital games (third independent variable) and gaming frequency (fourth independent variable) were measured before the first task. As dependent variables, spatial presence and flow were measured after the first task which had to be fulfilled either in the Virtual Theatre or at the laptop. As dependent measures of task performance, three different variables were analyzed: The number of objects that were correctly recognized in the second task, the third task reaction time and the accuracy of locating the objects on the map in the third task.

2.3 Hardware

Laptop. In the presented study, learning in a Virtual Theatre was compared to a somehow conventional learning with a laptop. The type being used was a Fujitsu Lifebook S761 with a 13,3 inch display and a 1366x768 display resolution. The field of view was controlled with a mouse. Locomotion was controlled by WASD-keys, where W/S keys controlled forward and backward while A/D keys controlled left and right. The hardware usually results in a sitting body posture while using the device.

Virtual Theatre. The Virtual Theatre is an innovative platform which enables unrestricted movement through a virtual environment and therefore is used in an upright body posture. The control mode of locomotion is walking naturally. The components of the Virtual Theatre which came to use in the study are pictured in Figure 4 and moreover described in the following sections. For a more detailed and complete description of the technical system see Ewert et al. [1] and Johansson [6, 18].

Fig. 4. Head Mounted Display and omnidirectional floor of the Virtual Theatre

Head Mounted Display. In the Virtual Theatre, the field of view is controlled by natural head movement. It presents the user with a seamless 3d visualization of a virtual environment. All head movement is instantly reproduced within the simulation, so the user can look around freely. Visual feedback is received via a zSight [19] Head Mounted Display (HMD), providing a 70° stereoscopic field of view with SXGA resolution for each eye. The HMD weighs 450 grams. It is powered by rechargeable batteries which are located in a vest which the user wears while using the Virtual Theatre. The HMD can be adjusted to the shape of the user's head as well as to his or her eye distance. On a rough scale, the lenses inside the display can be adjusted to short-sightedness and farsightedness.

Omnidirectional Floor. The user can move around within the environment by just walking in the desired direction. The omnidirectional floor consists of polygons of rigid rollers with increasing circumferences. Each polygon constitutes 16 rollers and together all polygons form 16 sections with an angle of 22.5 degrees. Each section consists of one roller from each polygon, which means from cylinder origo towards the periphery, the rollers are parallel and increasing in length. Rollers are driven from below by a belt drive assembly to minimize distance between sections. In the central part of the floor there is a circular static area where the user can move without enabling the floor. Floor movements here would only cause the feet of the user to be drawn together. As the user moves outside the static boundary, the floor begins to move according to a control algorithm [18].

Tracking System. To track the movements of a user, the virtual theatre is equipped with 10 infrared cameras. They record the position of designated infrared markers attached to the HMD and an additional hand tracer. The position of the HMD serves on the one hand as an input for controlling the omnidirectional floor: The inward speed of the rollers increases linearly with the measured distance of the HMD to the floor center. On the other hand it is used to direct the position and line of vision of the user within the virtual environment [6, 18]. The position of the hand tracer serves for triggering emergency shutdown: As soon as the hand drops below 0.5m, e.g. in the event of a user falling down, all movement of the omnidirectional floor is immediately stopped. It should be noted at this point that throughout all studies conducted so far with the Virtual Theatre, this never happened.

2.4 Participants

A total of 38 students between 20 and 33 years (M = 24.71; SD = 3.06; n = 13 female) volunteered to take part in the study. The sample therefore represents a potential user group of virtual environments in higher education. They responded to a call for participation which was hung out at bulletin boards throughout the university but also posted on the front page of the virtual learning platform of the university and on several research and learning related blogs, social media platforms and news feeds. As an incentive and as a sign of appreciation, all participants took part in a drawing for a cordless screwdriver. All participants were healthy and highly interested in participating in the study. They did not report suffering from any physical or mental disorders. To rule out effects due to ametropia, participants were asked in advance to bring their corrective lenses just in case. If participants had been assigned to the Virtual Theatre group, they were asked to wear sturdy shoes.

3 Results

3.1 Correlational Approach

To gain further information regarding the relationships of the characteristics of the person, the subjective experiences, and the task performance an explorative approach was taken. Thus we calculated correlations between relevant constructs. Results are displayed in Fig. 5.

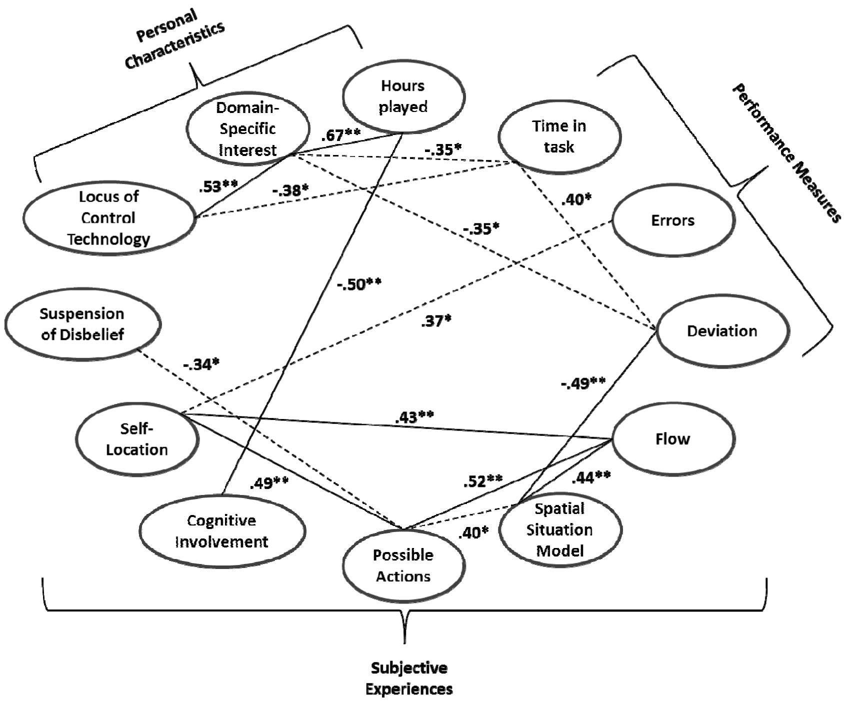

Fig. 5. Correlations between personal characteristics, subjective experiences and task performance

3.2 Comparing Hardware Conditions

Furthermore hypotheses regarding influences of hardware conditions on subjective experiences and task performance measures were tested with ANOVAs. With regard to the effects of the Virtual Theatre and the laptop on flow, significant differences were found (F (1, 36) = 4.18; $p < .05$). Thus more flow has been experienced in the Virtual Theatre (see Fig. 6). Taking a closer look on subscales there is a highly significant difference between conditions in self-reported absorption (F (1, 36) = 10.63; $p < .01$), but not in smooth and automatic running. There are also effects of hardware conditions on spatial presence. Self location in the Virtual Theatre was rated significantly higher (F (1, 36) = 15.79; $p < .001$), which refers to the feeling of actually being in the virtual environment. Similarly, participants in the Virtual Theatre show higher scores on the possible actions subscale of spatial presence (F (1, 36) = 4.90; $p < .05$). There were no further significant effects regarding spatial presence (see Fig. 6).

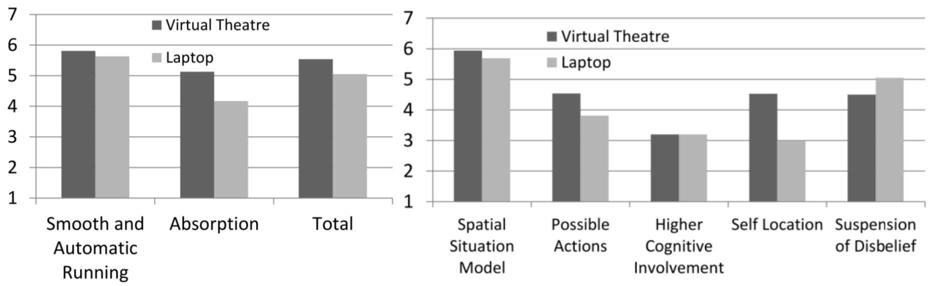

Fig. 6. Effects of Objective Hardware Characteristics on Flow and Spatial Presence

In addition to that we calculated the effects of hardware on task performance measures. In the recognition task of the objects from the virtual environment, participants in the Virtual Theatre condition made significantly more errors (F (1, 36) = 10.93; $p < .01$), which opposes our hypothesis (see Fig. 7). There were no differences regarding time on task and deviation between the two treatment conditions.

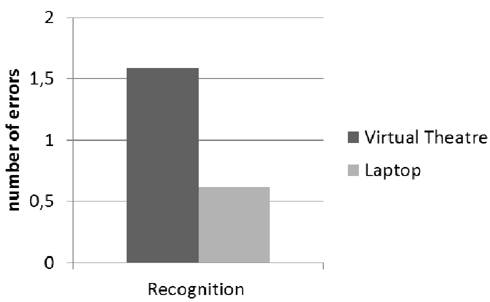

Fig. 7. Effects of Objective Hardware Characteristics on Task Performance, here: Recognition of previously presented objects

4 Discussion

Two different types of hardware as well as personal characteristics were analyzed regarding their effect on subjective experiences and task performance. Concerning the effects of natural user interfaces, the results show that the Virtual Theatre indeed leads to more flow. This is due to a higher self-reported level of absorption in the Virtual Theatre group. Although flow is an activity related construct, this result is in line with the theoretical assumptions that hardware which allows natural walking can support the feeling of "diving" into the virtual environment, which in general terms is often referred to as immersion.

Next, the effects of the hardware on spatial presence are analyzed in more detail. Students who used the Virtual Theatre reported a higher self-location in the virtual environment which indicates that they had shifted their primary reference frame from the physical to the virtual world. Although the given task didn't require any further non-mental actions but navigating through the virtual environment, students in the Virtual Theatre reported higher on the subscale of possible actions. However, for the other subscales, no differences were measured. Their role will be discussed when looking at the results of the explorative correlations.

According to the results of this study, immersion is not the precondition for better learning in virtual environments with natural user interfaces. Thus, the underlying model of the study (see Fig. 1) needs to be adjusted for further research. The only effect of the Virtual Theatre on task performance was a negative influence on recognition. This result is contradictory to the assumption that immersion leads to better learning. It seems that controlling the hardware was less intuitive than expected. This probably lead to the typical situation for learning with virtual environments: Dividing the available cognitive resources on the two parallel sub-tasks of dealing with the content and controlling the learning environment with the respected user interfaces [5]. Moreover, the combination of an HMD and real physical locomotion could lead to cognitive dissonance. When wearing the HMD, the user can see, where he or she walks in virtuality, but not in physical reality. Therefore the user takes a risk and has to trust in the technology in order to continue his or her actions. Last but not least, walking on the omnidirectional floor is a new experience for users and therefore could result in the fear of falling. All interpretations for the given results are going to be addressed in a follow-up study, where previous participants of the study will be interviewed on their experiences.

When we look at the correlations of the different constructs which were under study we see a slightly different picture: Although not all results are discussed in detail, we want to put the most relevant ones into focus. The positive correlation of self location and errors is in line with the previously discussed results, but therefore also contradictory to the assumption that immersion leads to better learning. However, the negative correlation of the self-reported spatial situation model and deviation supports this assumption. Domain specific interest i.e. interest in digital games correlated negatively with deviation and with time, just like locus of control regarding the use of technology and time. Therefore, in this experimental setting, the experience with virtual environments and the belief of being able to control technology had a bigger influence on those two performance measures than flow and spatial presence, the two indicators for immersive experience. The fact that flow correlated highly significant with the self-reported spatial situation model, possible actions and self location indicates that the constructs are two related facets of immersive experiences. The only correlation between personal characteristics and subjective experiences was between gaming frequency and higher cognitive involvement. In other words, experienced gamers were not challenged enough in this experimental setting.

5 Limitations of the Present Study and Future Research

Finally, some limitations of the present study are considered that should be pursued for future research. One limitation refers to the type of hardware examined. Since the different technical characteristics of the Virtual Theatre can only be tested in a set, it is not possible to isolate single effects. Moreover, the relationship between spatial presence and learning is not clear yet, since one subscale (self location) correlates with worse performance (making more errors) whilst another one (spatial situation model) correlates with better performance (less deviation when locating objects on a map). The other aspect concerns the task chosen for this experiment. Low levels of cognitive involvement in both groups indicate that the whole sample might not have been challenged enough. Since challenge is an important precondition for the motivation for learning, more challenging tasks are going to be tested in the future.

This first exploratory study on the effects of the Virtual Theatre on subjective experiences and learning confirmed a few theoretical assumptions but also contradicted others. In a next step, interviews with participants from both groups are going to be conducted. A deeper insight on the participants' experiences will allow a more differentiated view on the subject of our research. With a constant validation of the relationship between personal characteristics and hardware, it is possible to predict the level of subjective experiences to a certain extent. Thus, a profile could be developed, for whom the Virtual Theatre would have the most additional benefit. Moreover, different scenarios could be developed for different user types.

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