The Impact of Motion in Virtual Environments on Memorization Performance

Polina Häfner, Christina Vinke,
Victor Häfner, Jivka Ovtcharova

Institute for Information
Management in Engineering
Karlsruhe Institute of Technology
Zirkel 2, 76131 Karlsruhe, Germany
Email: polina.haefner@kit.edu
christina.vinke@student.kit.edu
victor.haefner@kit.edu
jivka.ovtcharova@kit.edu

Wolfgang Schotte

High Performance Computing Center Stuttgart
University of Stuttgart
Nobelstr. 19, 70569 Stuttgart, Germany
Email: schotte@hlrs.de

***Abstract*—Virtual environments are more and more used for educational and training purposes. In order to design virtual environments for these applications in particular, it is very important to get a deep understanding of the relevant design features supporting the user's process of learning and comprehension. Relevance and implementation of these features as well as the benefits of virtual learning environments over traditional educational approaches in general are rarely explored. Focusing on modes of interaction in this work, we examined the effect of different motion types on the knowledge acquisition of users in various virtual environments. For our study we chose a simple memorization task as approximation of low cognitive knowledge acquirement. We hypothesized motion types and immersion levels influence memorization performance in virtual environments. The memorization task was conducted in two virtual environments with different levels of immersion: A high-immersive Cave Automatic Virtual Environment (CAVE) and a low-immersive desktop virtual environment. Two motion types in virtual environments were explored: Physical and virtual walking. In the CAVE physical walking was implemented by using motion capturing and virtual walking was realized using a joystick-like input device. The results indicate neither motion types nor immersion levels in virtual environments affect memorization performance significantly.**

Keywords*—*cognition; human computer interaction; learning; memory; motion; virtual environment; virtual reality

I. INTRODUCTION

Virtual environments (VEs) are used in research and industry. One field of application is the educational sector. The virtual campus [1] is one example of such an interactive, 3-dimensional virtual learning environment. It opens new types of interactive, visual-spatial learning and therefore enables users to take advantage of its graphical representation of information.
The benefits of virtual learning environments over traditional educational approaches are yet rarely explored. Regarding the design of effective virtual learning environments (VLEs) it is important to know what features of Virtual Reality (VR) support cognitive processing [2]. In 2006 a study on primary school students evaluated two different VLEs in comparison to a traditional educational method [3]. A complete interactive VLE as well as a passive VLE were explored. The VLEs were designed as virtual playgrounds in a Cave Automatic Virtual Environment (CAVE). The passive VLE employed a virtual robot that guided activities. The results indicated that the complete interactive VLE aids the primary school students to solve problems, but does not lead to conceptual changes in their thinking. Surprisingly the passive VLE appeared to support the children's recall and reflection ability, therefore leading to signs of conceptual change in their minds.
The impact of different interaction modes on the human cognitive processing are rarely examined in VLEs. Therefore our approach was to explore the effect of motion types on memorization performance in virtual environments with different levels of immersion. Immersion will be referred to as degree of fidelity of sensory stimuli that are produced by VR systems [4]. This correlates not necessarily with the sense of presence where the users experience themselves as being a part of the virtual world. Regarding to our definition immersion is a feature of the technology used for producing the VE.
In our experimental design we chose a simple memorization task as approximation of low cognitive knowledge acquirement. This memorization task was conducted in a high-immersive CAVE and a low-immersive desktop virtual environment (DVE). Two different motion types in VEs were examined: physical and virtual walking.
The next sections describe related work and subsequently our hypotheses, experimental design and results with a followed-up discussion. To conclude we sum up our results and give a short outlook on our future work.

II. RELATED WORK

Prior research in 2012 investigated the impact of spatial presentation of information in CAVEs on memorization per-

The authors sincerely thank the scientific society "Wissenschaftliche Gesellschaft für CAD/CAM-Technologie Karlsruhe e.V." and the Lifecycle Engineering Solutions Center (LESC) of the Karlsruhe Institute of Technology (KIT) for supporting this work.

978-1-4673-4703-7/13/$31.00 ©2013 IEEE

formance. Ragan et al. [5] presented information either in front of a user at a single spot of the CAVE or wrapped around a user along the surround display walls of the CAVE. It was proved that spatial presentation causes significantly better memory scores on a simple learning task in contrast to non-spatial presentation at a single spot. Their work differs from ours in respect to examining the impact of spatial presentation on memorization performance and regarding to the use of a CAVE system without stereo vision.

In 2009 a prior study of Bowman et al. [2] revealed that the increase of the immersion level can improve procedural training tasks performance significantly. Compared to Bowman et al. [2] we explored the effect of different immersion levels on memorization performance, but instead of examining procedural training tasks we chose a simple memory task for our study design.

Overall in contrast to Bowman et al. and Ragan et al. [2,5] we set our focus on the impact of motion within VEs. This has not yet been addressed except for the work of Zanbaka et al. and Järvinen et al. [6,7]. In 2004 Zanbaka et al. [6] analysed the impact of different types of travel on cognition in different VEs. The term travel is used in this respect in the sense as we define motion. The results of Zanbaka's et al. [6] study indicated the type of travel causes no significant differences on memorization performance in VEs. Virtual travel in a desktop virtual environment and physical travel using head-mounted displays (HMD) were explored as types of travel. Suggested by Zanbaka et al. [6] physical walking using HMDs could provide benefits in the following two cases. The first case are applications in VLEs where the interpretation of the exhibited material and problem solving is important. The other one are tasks in VLEs where there is less opportunity to train in real life. In comparison to our work Zanbaka et al. [6] did not use a high immersive CAVE but a less immersive HMD.

According to a study of Järvinen et al. [7] in 2011 interaction mapping affects the sense of presence and spatial memory significantly when navigating in VEs. The user's navigation was mapped to two different types of motion in the virtual environment. The same physical interface was used for both types of motion. Tracked physical motion was mapped to a mode of travelling analogue to walking and another mode analogue to vehicle driving. In comparison to Järvinen et al. [7] interaction mapping was not used for our work.

III. Hypotheses

Prior work implicated sense of presence as well as spatial memory are significantly affected by interaction mapping [7]. Therefore we hypothesized the user's memorization performance to be varying with different motion types in VEs. Because spatial presentation affects memory performance in CAVEs [5] as well as increasing the immersion level can significantly improve procedural training tasks performance [2], we hypothesized the memorization performance will depend on different levels of immersion in VEs.

IV. Experiment

The experiment was designed to explore the impact of motion types and different levels of immersion in VEs on memorization task performance. A simple memory task was used as approximation of low cognitive knowledge acquisition.

Fig. 1: Memorization task scene

A. Memorization task

According to results of Rajsic et al. and Alvarez et al. [8,9] a coloured, 3-dimensional scene showing a room with 20 items (see Fig. 1) was designed for being presented to the participants in different virtual environments. The design of the scene aimed at forcing the participants to change their scene view positions in the virtual scene by using navigation tools in order to see all items in detail, but no objects were hidden. The participants were given 60 seconds to view and interact with the scene. Then they were given another 120 seconds to recall as many items as possible in written form.

B. Experimental design

Within the experimental design we controlled immersion levels and motion types in VEs as between-subjects variables in order to test our hypotheses. The immersion levels in VEs had two parameter-values: CAVE and desktop virtual environment (see section E for technical details). Motion type had two parameter-values: physical motion and virtual motion. Therefore four possible between-subjects conditions resulted. The condition with desktop virtual environment and physical motion was hard to implement for technical reasons and therefore three between-subjects conditions remained:

1. CAVE and physical motion (PM): Participants used the optical head tracking of the system in order to navigate by

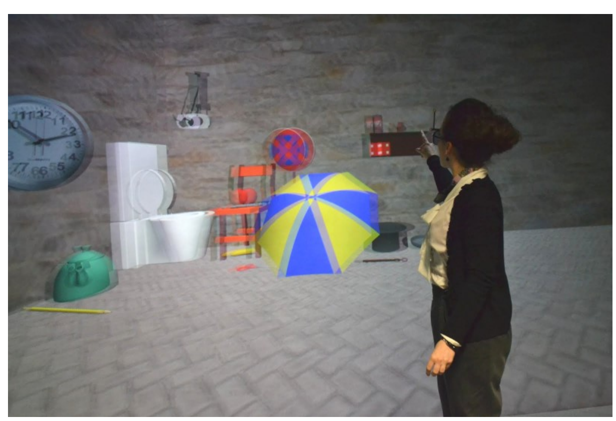

Fig. 2: Condition: CAVE and physical motion

Fig. 3: Condition: CAVE and virtual motion

walking in the CAVE. They could move around freely on a 6m^2 carpet lying on the floor. The carpet was positioned in such a way that participants were prevented from going too close to the CAVE projection walls and thus avoiding tracking discontinuity. Another reason for employing the carpet was preventing the users from the discomfort of wearing special shoes. These special shoes are usually used in order to protect scratch-sensitive floor projection screens but might interfere with free walking. Every participant had to start from the same geometrical starting position (see section E) and had to wear polarisation glasses during the whole procedure in order to enable stereo vision.

2. CAVE and virtual motion (VE): Participants used the physical device "ART Flystick2^{TM}" (see section E) in order to navigate in the CAVE. The ART Flystick2^{TM} has six buttons in order to provide many different ways of interaction. Only the joystick was enabled for a very restricted navigation to the right and left side. The participants had to remain at the same prior defined position (see section E) wearing polarisation glasses.

3. Desktop virtual environment (DVE) and virtual motion (VM): Participants were sitting in front of a computer display, using a keyboard in order to navigate in the DVE. Navigation to the left and right was enabled by pressing the left and right arrow key. No stereo vision was enabled.

Each participant was assigned to one of these three conditions and had to accomplish the memorization task (see section A) according to the assigned condition. The number of recalled items was determined as dependent variable and will be referred to as recall rate (RR).

C. Participants

The study sample included 114 university students. Due to time restriction problems within the pretest phase (see section D for further description) 8 participants were excluded from the study. One was excluded because of showing no serious commitment. The age of the remaining 105 students (56% male, 44% female) ranged from 18 to 32 years with a mean age of 23 years. The majority were university students from the Karlsruhe Institute of Technology. The participant's subjects of study covered architecture, cultural studies, computer studies, mathematics, geosciences, design, medicine, physics, psychology, education, engineering and economics. While 72% of the students had prior experiences with VEs, only 14% of the students stated to have been to a CAVE before.
The participants were screened with a pretest (see section D for further description) in order to identify individual differences in memory performance. Then the participants were assigned pseudo-randomly to three groups by the scores of the pretest and by gender, so that each group had 35 members, approximately the same amount of women and an equal average memory score. This was done according to the results of Barrett et al. and Halpern et al. [10,11].

D. Procedure

The course of the study (see Fig. 4) consisted of the following five steps:

1. The pre-questionnaire aimed at gaining information about the participants prior experience with VEs, their current self-estimated ability to concentrate, their prior use of mnemonic techniques and their general self-estimated memory performance.

2. The pretest was targeted on screening the participants in regard to their individual visual memory performance. It was a simple memorization test. On a computer screen a coloured, 3-dimensional, static scene showing a room including 20 objects was presented to the participants for 60 seconds. Neither stereo vision nor navigation were enabled. Afterwards,

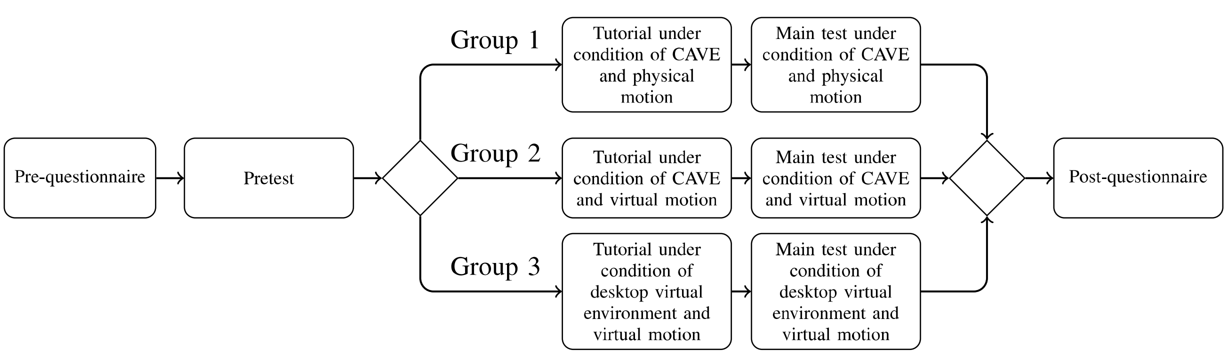

Fig. 4: Course of the study

Fig. 5: Pretest

the participants had to write down all recalled objects within a time frame of 120 seconds. Then they were assigned to three groups according to their recall scores of the pretest. Each group consisting of 35 participants was assigned to one of the three conditions: CAVE and PM, CAVE and VM, DVE and VM (see section B).

3. The tutorial aimed at familiarizing the participants with their type of VE and their mode of navigation. As illustrated in Fig. 6, the scene used for the tutorial differs from the pretest scene (see Fig. 5).

4. The main test was targeted on screening the participants in regard to their individual visual memory performance in different VEs using different types of navigation. Every participant accomplished the memorization task (see section A) according to one of the following conditions: CAVE and PM, CAVE and VM, DVE and VM (see section B). The number of recalled objects was determined as individual recall rate (RR).
As illustrated in Fig. 1 the scene used for the memorization task of the main test differs from the scenes of the tutorial (see Fig. 6) and of the pretest (see Fig. 5). All scenes show different items. No item was shown twice to the participants.

5. The post-questionnaire aimed at testing the participants commitment and gaining information about the use of mnemonic techniques during the pretest and the memorization performance assessment phase by the participants. Furthermore participants should estimate their present physical state and evaluate the enabled navigation methods.

The course of the study was organized as follows:
After completing the pre-questionnaire the participants had to accomplish the memorization task of the pretest and were assigned to three groups by their recall scores of the pretest and by gender. Each group was assigned to one of the three conditions: CAVE and PM, CAVE and VM, DVE and VM (see section B). After that the participants took part at the tutorial. They fulfilled then the memorization task of the main test according to their assigned condition. Finally they completed the post-questionnaire.

E. Apparatus

The VR setup consists of a highly immersive CAVE environment running PolyVR virtual reality framework. The reference system is a standard desktop environment including keyboard and mouse. All 3D scenes visualized in both environments were created with Blender, a free and open-source 3D computer graphics software.
The CAVE (see Fig. 7) is a three projection surface distributed visualization system with a total resolution of 12 mil. pixels. The virtual reality scene is rendered perspectively correct in 1:1 scale with stereo vision available and from the correct perspective of the user. Stereo vision is achieved by combining projectors with circular polarisation filters and polarisation glasses for the user. To compute the correct perspective of the users sight, there is an optical ART^{TM} tracking system, that enables head tracking for the dynamic adaptation of the perspective in real-time. Additionally this system tracks the position and orientation of the ART Flystick2^{TM}.
The application for visualisation and navigation for the main test in the immersive CAVE environment was generated with PolyVR. PolyVR is a virtual reality software framework including a VR 3D engine developed at our institute since 2009, based on open-source libraries like OpenSG [12] and OpenGL.

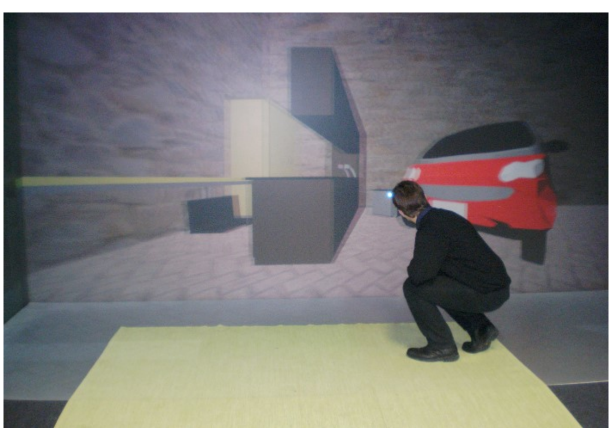

Fig. 6: Tutorial under condition CAVE and physical motion

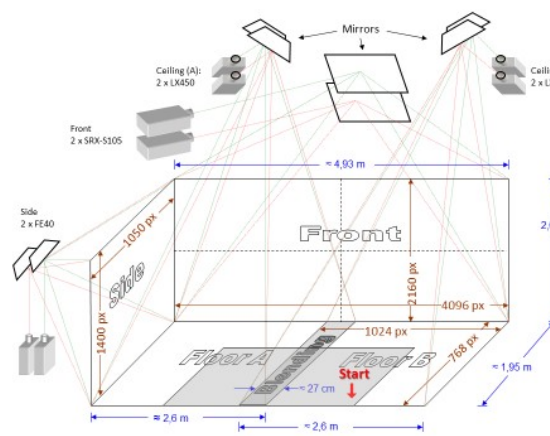

Fig. 7: CAVE setup

TABLE I: Descriptive Analysis of RRD_j

j	Arithm. mean of RDD_j	Standard deviation	Min	Max	N
1	0.9429	2.22212	- 5	6	35
2	1.5714	2.51216	- 3	7	35
3	0.5714	2.82099	- 5	6	35

The modular architecture facilitates the extensibility with new features and the flexible hardware support makes it scalable. Important characteristics of PolyVR are the flexible integration of tracking systems over libraries like ART^{TM} dtrack or the open peripheral library VRPN and the flexible software configuration of different hardware systems for distributed visualization on computer cluster. It can be deployed on visualization clusters for CAVE environments, HMDs as well as on desktop or 3D displays.

The engine facilitates the data import like 3D content in form of mesh or CAD data or numeric results like point clouds or volume data and enable their real-time visualization. Additional interaction paradigms for navigation and manipulation in the virtual environments are provided and animation, sound or physics simulation can be easily integrated.

The reference desktop workstation possesses a 19 inch non-stereoscopic display with a resolution of 1280 x 1024 pixels. This system does not include head or motion tracking respectively.

V. Results

A. Experimental data

In order to take all gained experimental information into account for our analysis, we defined the recall rate difference RRD_i for every participant i as difference between the recall rate of the main test RR_i^2 and the recall rate of the pretest RR_i^1:

$$RRD_i = RR_i^2 - RR_i^1 \tag{1}$$

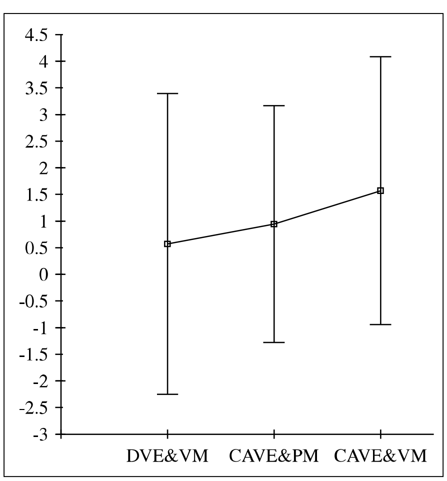

Fig. 8: Arithmetical means and standard deviations of RRD_j under conditions: DVE&VM, CAVE&PM and CAVE&VM

TABLE II: Analysis of variance (ANOVA) on RRD

	Value of F	P-value	Effect size	Power
Type of motion	1.08	0.301	0.010	0.177
Type of VE	2.733	0.101	0.026	0.374

$$i \in [1, 105]$$

RRD is the distribution of the recall rate differences of all participants. For our analysis we determined RRD as dependent variable. Furthermore RRD_j determinies the distribution of the recall rate differences of the participants under condition j. Table 1 shows the descriptive analysis of the variable RRD_j under the three conditions:

$j = 1$: CAVE and PM (physical motion)

$j = 2$: CAVE and VM (virtual motion)

$j = 3$: DVE (desktop virtual environment) and VM (virtual motion)

Fig. 8 illustrates the results of the descriptive statistical analysis of RRD_j in respect to arithmetical means and standard deviations.

In respect to the descriptive analysis of the study sample the results indicate that the value of the arithmetical mean of the RRD_j (recall rate difference) under condition $j = 2$ is greater than the one under condition $j = 1$ and the one under condition $j = 1$ is greater than the one under condition $j = 3$:

$$\overline{RRD_2} > \overline{RRD_1} > \overline{RRD_3} \tag{2}$$

In order to test our hypotheses we had to conduct an analysis of variance (ANOVA) on the distribution of the recall rate differences of all participants (RRD) at a prior defined significance level of $\alpha = 0.05$. The results of the ANOVA (see table 2) indicate that no significant differences between the three conditions can be identified neither regarding to the motion type ($p = 0.301$) nor to the immersion level ($p = 0.101$) in VEs. The normal distribution of the variable RRD was indicated by a Kolmogorov-Smirnov test.

We also used a post hoc Tukey test to compare the three examined between-subjects conditions pairwise with one another. The post hoc Tukey test (see table 3) reveals the pairwise differences and confirms that the found differences are not statistically significant.

B. Other factors

There were no significant differences among groups in respect to the participants prior VE experience, prior CAVE

TABLE III: Tukey test

	Mean difference	P-value
CAVE/PM - CAVE/VM	-0.6286	0.554
CAVE/PM - DVE/VM	0.3714	0.814
CAVE/VM - CAVE/PM	0.6286	0.554
CAVE/VM - DVE/VM	1.0000	0.228
DVE/VM - CAVE/PM	-0.3714	0.813
DVE/VM - CAVE/VM	-1.0000	0.228

TABLE IV: ANOVA among groups

	P-value
Prior VE experience	0.295
Prior CAVE experience	0.401
Evaluation of navigation	0.679
Self-estimated current ability to concentrate	0.839
Use of mnemonic techniques	0,014
General self-estimated memory performance	0,18

experience, evaluation of navigation, self-estimated current ability to concentrate and general self-estimated memory performance (see table 4). The use of mnemonic techniques was significant with $p = 0.014$ (see table 4 fifth row) at a prior defined significance level of $\alpha = 0.05$.

VI. Discussion

The results of the ANOVA indicate no statistical proof for our hypothesis that memorization performance varies with the motion type in VEs. Our sample showed minor differences among groups in respect to the motion types in CAVEs. Participants assigned to the condition CAVE and physical motion performed worse than the ones assigned to the condition CAVE and virtual motion. We assume that these differences derive from the following fact: Only 31.5% of the participants assigned to the condition CAVE and physical motion had prior experiences with using motion tracking systems, but 83% of the participants assigned to the condition CAVE and virtual motion were familiar with virtual navigation.
Further we hypothesized that memorization performance will depend on the level of immersion in VEs. The results of the ANOVA did not prove our hypothesis. At a prior defined significance level $\alpha = 0.05$ our results are not significant, but at a prior defined significance level $\alpha = 0.11$ our results become significant. Furthermore the majority of participants was not familiar with using CAVEs. Therefore we tend to assume that a difference exists. This needs to be investigated by follow-up studies.
Overall the results of the ANOVA indicate no statistical proof for our hypotheses, but they are consistent with the findings of Zanbaka et al. [6].
According to the analysis of confounding effects arising from the participants prior VE experience, prior CAVE experience, evaluation of navigation, self-estimated current ability to concentrate and self-estimated memory performance no significant differences among groups were found. In respect to the use of mnemonic techniques there was a significant difference between groups. Because all groups had an equal average memory score in the pretest, confounding effects can be neglected.

VII. Conclusion and future work

Within this work we explored the impact of different motion types on memorization performance in virtual environments (VEs). Furthermore we investigated the influence of different levels of immersion in VEs on memorization performance. For our study design we chose a simple memory task as approximation of low-cognitive knowledge acquisition. The memorization task was conducted in a high-immersive Cave Automatic Virtual Environment (CAVE) and in a low-immersive desktop virtual environment. Physical walking and virtual walking were examined as motion types in VEs. In the CAVE physical walking was implemented by using head tracking and virtual walk by using the physical device "ART Flystick2^{TM}" for navigation.
The results indicate motion types and immersion levels in VEs do not influence memorization performance significantly. It cannot be ruled out that these results derive from the fact that the majority of participants were unfamiliar with CAVEs. Therefore follow-up studies examining participants who are familiar with CAVEs need to be conducted. For the design of follow-up studies the results generated by this work provide a good foundation in order to reach more mature results.
Furthermore in our future work we are going to examine higher-cognitive knowledge acquisition. We want to use our results for building up an interactive training tool in a smart factory virtual environment.

References

[1] H. Zhao, B. Sun, H. Wu, and X. Hu, "Study on building a 3D interactive virtual learning environment based on OpenSim platform," in *Audio Language and Image Processing (ICALIP), 2010 International Conference on*, pp. 1407–1411, 2010.

[2] D. A. Bowman, A. Sowndararajan, E. D. Ragan, and R. Kopper, "Higher levels of immersion improve procedure memorization performance," in *Joint Virtual Reality Conference of EGVE-ICAT-EuroVR*, pp. 121–128, The Eurographics Association, 2009.

[3] M. Roussou, M. Oliver, and M. Slater, "The virtual playground: An educational virtual reality environment for evaluating interactivity and conceptual learning," *Virtual reality*, vol. 10, no. 3–4, pp. 227–240, 2006.

[4] M. Slater, "A note on presence terminology." http://www0.cs.ucl.ac.uk/research/vr/Projects/Presencia/ConsortiumPublications/ucl_cs_papers/presence-terminology.htm, 2003. [Online; accessed 1-March-2013].

[5] E. D. Ragan, D. A. Bowman, and K. J. Huber, "Supporting cognitive processing with spatial information presentations in virtual environments," *Virtual Reality*, vol. 16, no. 4, pp. 301–314, 2012.

[6] C. Zanbaka, S. Babu, D. Xiao, A. Ulinski, L. F. Hodges, and B. Lok, "Effects of travel technique on cognition in virtual environments," in *Virtual Reality, 2004. Proceedings. IEEE*, pp. 149–286, IEEE, 2004.

[7] H. Järvinen, U. Bernardet, and P. F. J. Verschure, "Interaction mapping affects spatial memory and the sense of presence when navigating in a virtual environment," in *Proceedings of the fifth international conference on Tangible, embedded, and embodied interaction*, pp. 321–324, ACM, 2011.

[8] J. Rajsic and D. E. Wilson, "Remembering where: Estimated memory for visual objects is better when retrieving location with colour," *Visual Cognition*, vol. 20, no. 9, pp. 1036–1039, 2012.

[9] G. A. Alvarez and P. Cavanagh, "The capacity of visual short-term memory is set both by visual information load and by number of objects," *Psychological Science*, vol. 15, no. 2, pp. 106–111, 2004.

[10] L. F. Barrett, M. M. Tugade, and R. W. Engle, "Individual differences in working memory capacity and dual-process theories of the mind," *Psychological bulletin*, vol. 130, no. 4, pp. 553–573, 2004.

[11] D. F. Halpern and M. L. LaMay, "The smarter sex: A critical review of sex differences in intelligence," *Educational Psychology Review*, vol. 12, no. 2, pp. 229–246, 2000.

[12] D. Reiners, "Herausforderungen an moderne Szenengraphsysteme am Beispiel OpenSG," *Informatik-Spektrum*, vol. 27, no. 6, pp. 531–541, 2004.