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Investigating human cognitive abilities and emerging performance in desktop virtual reality

Doctoral Theses

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Contents

1 Motivation and research goals

Virtual reality is a dynamically evolving field that includes different technologies that create simulated 3D environments for various applications. In recent years, it has become widely popular outside of the entertainment industry. In 2018 on the well-known Gartner hype cycle, it was already considered a mature technology [2]. Mature technology means that virtual reality is already used to solve real problems in multiple fields, and also its real-world benefits are recognized. Virtual reality technology has moved beyond the entertainment sector, and it gained popularity in new fields, such as education, medical training, engineering, robotics, manufacturing, and industry 4.0.

Virtual realities are often considered as a technology product in which various innovations and developments determine the user experience. However, since humans use these devices, it is essential to take into consideration human characteristics. Such human characteristics could be the classic ergonomic aspects, such as physically comfortable handling of a device or some software ergonomic perspectives. Although in this dissertation, the focus will be on the relationship and connection between virtual reality and the human cognitive processes. When using virtual spaces, various cognitive functions help the user understand what the simulation is, what they see, and how they can use the space. Accurate perception and attention are essential to experience immersion into a virtual world. Navigation in virtual space is based on the proper functioning of perceptual-motor coordination. In addition, the

working memory and the existing knowledge base also play a role in the virtual reality experience [8].

Virtual reality is a heterogeneous technology both in terms of hardware and software. However, their common characteristic is the unique experience of its users, the so-called presence. Presence is the subjective feeling of being inside the virtual environment. The other common factor is the human cognitive and perceptual system, which has a significant role in the virtual reality experience. The human-centered scientific approach in virtual reality research should also be a priority along with technology, as human perception systems and cognition play a key role in perceiving the computer-generated illusion as space and behaving in it as in reality. Therefore, the systematic research of these characteristics in MaxWhere virtual reality is the paramount objective of the present dissertation.

Of the cognitive functions, the examination of spatial abilities is widespread in virtual realities, as the users of VRs can experience the spatial characteristics of the simulations thanks to them. *Spatial abilities* are a group of cognitive functions and skills that are determinants in processing spatial visual information that needs to be manipulated. I aim to explore the role of spatial abilities in the MaxWhere virtual reality. In particular, the relationship between the individual spatial abilities and the efficiency of task completion in the MaxWhere virtual environment. Another aim is to explore the users' navigational experience and analyze its connection with the measured spatial abilities.

The *sense of presence* is a unique characteristic of virtual realities from the human-centered perspective. Presence is the experience of "being" in virtual reality experienced by the users. It is a subjective variable, as it is the users' reaction to the immersion. In this dissertation, I aim to explore the sense of presence in the MaxWhere virtual reality. Moreover, I would like to investigate its relationship with individual spatial abilities. As MaxWhere virtual reality is widely used as a desktop VR, which is relatively less known than the HMD-based virtual realities, another aim is to compare the presence experiences of the novice and more experienced users.

Human memory performance is a significant aspect of the use of virtual reality, especially in educational context. The MaxWhere virtual reality allows placing 2D documents, figures, or even videos in the 3D space. I would like to measure the memory performance for these highlighted objects. Furthermore, I aim to compare it with a 2D browser display.

In addition, inside a virtual space, it is possible to display several figures and documents in an organized way. I aim to measure the memory performance for supplementary information that is not the focus of an experimental task. These research objectives have strong relevance in educational practice, as the most important information and figures could be memorized more easily if they are highlighted in the virtual environment.

The overall aim of this dissertation is to investigate human cognitive abilities and the emerging performance in desktop virtual reality.

2 Methods

The research area presented in the dissertation covers both computer and cognitive sciences: the topic is primarily related to information technology, but for examining the research questions, the application of cognitive psychology measurement methods was essential. In this way, the user's behavior, experience, individual cognitive characteristics, and performance could be measured.

During my research, I have performed cognitive psychological experiments and measurements in virtual reality. Using the control group research design, I have compared the results of two groups who solved the same task on different devices: one group in a browser and the other in virtual reality. I have analyzed the data with different statistical methods, corresponding to the given sample size, experimental design, and the research question (t-test, Spearman correlation, Pearson's correlation, ANOVA, Fisher-exact test).

Furthermore, I have used general psychological tools and tests to measure cognitive abilities and their online version (e.g., Corsi test, mental rotation test). I have also used different scales, including existing (e.g., Igroup Presence Questionnaire) and self-developed (navigational experience).

3 Theses

Thesis 1. I have examined by a cognitive psychological measurement the relationship of individual spatial abilities (spatial memory, mental rotation) with task performance and subjective navigational experience in desktop virtual reality, and there was no statistically significant correlation between the measured variables.

References: [13, 14]

Navigational experience: How natural and automatic the movement in virtual space is. A better navigation experience means more natural, automatic navigation.

Thesis 2. I have demonstrated by a cognitive psychological measurement that the sense of presence and spatial presence positively correlates with the subjective navigational experience in desktop virtual reality.

References: [15, 16, 18] ▪

Thesis 3. I have demonstrated by a cognitive psychological experiment that if an image is pulled out from its context and both the text and the image are pasted into a 3D digital environment, users reading text in the 3D environment will better remember the image's content. However, the same effect has not been demonstrated using a classic 2D browser.

References: [9, 10, 17] ▪

Thesis 4. I have demonstrated by a cognitive psychological experiment that users who perform a task on documents in a 3D environment can better

remember additional information about the current state of the task and have a better overview of the status of the project than users who perform the same task on a traditional 2D interface.
References: [11, 12] ▪

4 Applicability of results

The results presented in the dissertation can be used directly in the field of education. Research findings on the role of individual spatial ability suggest that measured spatial ability and task performance were not related in desktop virtual reality. Thus, it can be assumed that desktop VR environments can be used by users with different levels of spatial ability. In other words, the use of virtual reality in educational institutions does not disadvantage learners with lower spatial ability.

I have demonstrated that presence positively correlated with the subjective navigational experience. Thus, it is recommended to help the users of educational VRs to practice navigation, as with a smooth navigational experience, it is more likely that they experience a higher level of sense of presence, which could be also beneficial for their learning outcome [4, 5, 6].

Human memory, which is essentially connected to learning and education, was also the focus of my research. I have proved that an image is more likely to be remembered when it is separated from its original 2D context and inserted directly into the 3D space. This result can be easily applied in educational virtual spaces, as any visual information or figure can be saved as an image

file and inserted into a separate smartboard in the MaxWhere virtual reality. This highlighting method can help the students not just by highlighting the most important figures of the learning materials, but it directly helps them to memorize the figure. Furthermore, the results showed that even when these images are not in the focus of the task, virtual reality users are more likely to remember them than those who used a 2D interface for the same task.

In addition to education, the research results on information highlighting and the placement of 2D advertisements in virtual space can also be used in the advertising industry. The results showed that placing the 2D image-based advertisement on a different smartboard next to the content results in better memory performance. However, the same method in a 2D browser did not result in a higher rate of remembering participants. In the last year, some studies [1, 3, 7] cited this research from the field of media communication that focused directly on advertising, which shows the timeliness of this topic besides the possible application of the results in the advertising industry.

All the previously presented possible application closely relates to the design of virtual realities. Users of virtual reality environments can efficiently use the spaces if these are planned, designed, and realized in a manner that provides the possibilities to highlight images and smoothly navigate. Besides educational virtual realities, these principles can be applied in other types of VR spaces, such as virtual conference rooms, exhibitions, and trade shows.

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