Does Effective Use of MaxWhere VR Relate to the Individual Spatial Memory and Mental Rotation Skills?

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Abstract: Desktop virtual realities are becoming increasingly widespread. Thus, it is important to measure if it can be really a next step in the evolution of computer science. This researched aimed to examine whether there is a relationship between the effectiveness of completing a task in MaxWhere VR and the users' cognitive characteristics: namely the spatial memory (measured by the Corsi-task) and the mental rotation ability. Thirty-one participants took part in this research and their results showed no relationship between the examined spatial abilities and work effectiveness. For navigating in the virtual space, the built-in CogiNav technology of MaxWhere was used. The participants rated their navigational experience in the virtual environment. There was no statistically significant relationship with the other measured variables. These results suggest that this VR can be used by anyone, independently from their spatial memory or mental rotation skill.

Keywords: desktop VR; virtual environments; spatial memory; mental rotation; MaxWhere

1 Introduction

This paper investigates the hypothesis whether there is a relationship between the effectiveness of completing a task in VR and the users' individual spatial abilities, namely the spatial memory (Corsi-span [1]) and the mental rotation ability [2].

The motivation behind this research is that virtual realities are increasingly popular. It is so widely used that in 2018 on the Gartner hype cycle it was considered as a mature technology [3]. It means the VR is already used to solve real problems in multiple fields and the real-world benefits are recognized. Virtual realities are already used in engineering and manufacturing technologies (Industry 4.0) such as digital twins. For instance, the VR augments virtual prototyping, which enables engineers to examine their design from any angle, in a 'real' context, without producing physical models. Education is another sector where virtual realities getting increasingly popular. From virtual field trips to virtual laboratories, a wide range of methods is used to spread different type of knowledge to the students. Initially the head-mounted displays (HMD) seemed to become the basis of the VR technology, but actually, the simulation sickness sets back the widespread use of this device. Beyond the games in offices or in education this VR is not so popular, because it requires a powerful PC, it is quite difficult to set up, and not so convenient to use for hours. Thus, among students, it cannot spread easily.

Desktop VR is another method to display virtual realities, it shows the 3D virtual space on a classic 2D display device. It is quite popular, as it does not require any specific hardware, works on a common PC and in most cases can be controlled by a classic mouse. It can seem that this kind of VR can spread very easily as it uses familiar devices to create a 3D visualization.

The transition from two dimensions to three dimensions is quite a big step. It corresponds to the transition from command-line operating systems (i.e.: DOS) to the graphical user interface (i.e.: Windows). The desktop metaphor provided a new user-friendly interface as it did not require the user to know all the commands of a specific programming language. Another new feature was the possibility of multitasking, the feature which enables to use more programs simultaneously. Now the technology moves toward to the 3D technologies, such as the MaxWhere VR, used in this study. The desktop virtual realities use the same devices and displays to show a 3D space (interface), instead of a classic 2D interface. The transition to 3D spaces seems like a big step, even if the devices remain the same.

Is this transition going to be an easy and natural transformation? Or is it a too sudden advancement and it would be better to find a smaller step before? A smaller step can be for example the appearance of a new apparatus. The computer mouse was such new control device, which helped the use of the 2D graphical interface. A new appliance does not solve all problems at once: first, the users have to learn how to use it properly. The computer mouse is a pointing device that detects the two-dimensional motion: the movements of the hand left and right and backward and forward. Then, it translates these movements into the motion of a pointer on a display. The movements are translated not in an absolute, but in a relative way, so the size of the table or mouse pad can’t be an impediment for the use of a large display. The first users had to learn this, and of course, there were people who despaired when they reached the end of the table with the mouse, but they wanted to go further on the display. Users had to learn that the computer mouse also detects acceleration, so if they move faster the mouse, the movement of the pointer also increases significantly. In like manner, the spread of the virtual reality also depends on the initial learning phase. This can predict if this will be an easy or tough entering. The transition from 2D to 3D can be realized if this change will be beneficial to all users. This evolution can be faster or slower, depending on different circumstances. To reach an overall prediction on this transition, it is important to examine the contributing factors not only from a technological but also from the human perspective. Such contributing human factor can be the users' previous experiences with new technologies, interests, motivation or the user's own cognitive characteristics. As cognitive characteristics, this paper will examine the spatial memory and mental rotation skills.

This paper is structured as follows. Section 2 shows the current state of desktop virtual realities and provides an overview of the theoretical background of virtual reality and spatial abilities. Section 3 provides the methods of this experiment such as the used virtual reality, the spatial ability test, and all other measured variables. Section 4 presents the results of this experiment. Section 5 concludes the paper and discusses the results, shown in Section 4. The results of the paper are briefly summarized in the Conclusion section.

2 Preliminaries

2.1 When 2D Display Creates Immersion: Desktop Virtual Realities

The virtual reality term changes continuously from late 1960. It means a computer-generated three-dimensional world, where the user not just moves and acts in real-time but also experience a kind of presence [4]. Different technologies help to experience it. A CAVE system or a Head-Mounted Display (HMD) provides a so-called full immersive environment: more senses are involved in the experience than in a desktop virtual reality. The technology immerses the senses and body of the user into the virtual world. Then, different cognitive processes promote the creation of a mental model of the user's body in the virtual environment. Thus, the user can experience a sense of being in the simulated environment, which is called presence [5]. Presence is a psychological phenomenon, a state of consciousness, the sense of being in the virtual environment [6].

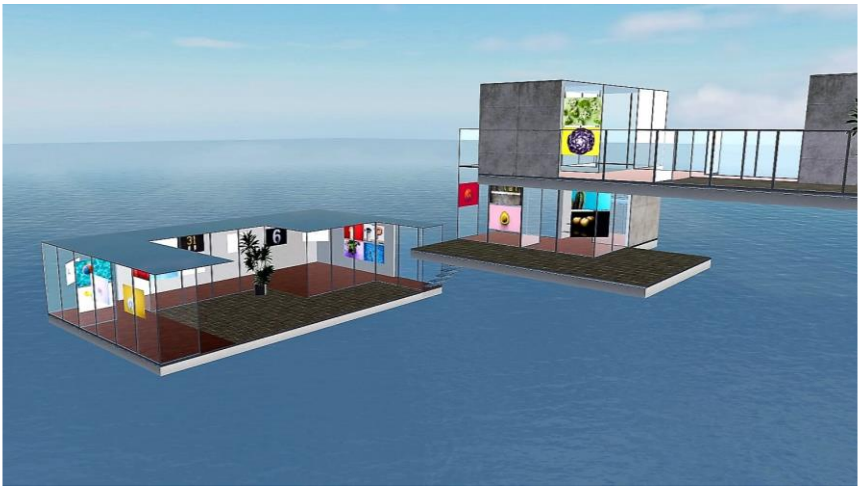

Figure 1
The desktop virtual reality, used in this study (screenshot was made in MaxWhere VR)

Desktop virtual realities are the simplest forms of virtual realities (VR[1]). A high-resolution 3D environment is displayed on a basic desktop computer. The three-dimensional space and the first-person view provide the basis of the feeling of immersion into the virtual world. To navigate in the virtual space, the users can use a computer mouse (or sometimes combined with keyboard). The virtual realities often contain different embedded interactive objects, which can be manipulated, rotated or moved. For this, different movement types are needed, which imitate the real-world movements of a person. For example, the physical movement of the head and body in VR is the rotation of the image. The zooming corresponds to the movements toward and away from objects. Furthermore, clickable "hotspots" are embedded to show video clips, documents in the VR or to provide a doorway to other virtual worlds [4, 7].

A great advantage of a desktop setup is that it requires only widely known devices, so it does not depend on an excessive training session. In some cases, more experienced gamers can have an advantage in navigation [8]. Gender differences are also examined in spatial orientation and navigation. In VRs with technical contents, which are navigationally and visually complex, male users are more confident and often outperform female participants [4, 8].

2.2 Virtual Reality and Spatial Abilities

Spatial ability is a group of cognitive functions and aptitudes that are crucial in solving problems that involve processing and manipulating visuospatial information [9]. With the spread of different new technologies, it is often asked

[1] From this part in this paper I use the general term VR to referI to non-immersive or desktop VR in which a classic 2D display is used

who will profit from this as the new method helps them be more productive; the already highly skilled experts in the field or the users with lower ability? Similar questions were asked in education when different new technologies such as multimedia animations [10, 11], 3D models [12, 13], or virtual learning environments [14, 15, 16] have appeared. Consequently, the question is still open; there is no final answer yet.

2.2.1 Ability-as-Compensator Hypothesis

In contrast to the ability-as-enhancer hypothesis, the ability-as-compensator hypothesis proposes that low spatial ability learners could gain particular benefit from the graphical representations, 3D models or virtual environments [11, 12, 17]. According to this hypothesis, the low spatial ability students gain benefit as otherwise, they have difficulty in mentally constructing their own visualization. Thus, the supplementary visual information saves them working memory and reduces cognitive load. Hays [11] used three types of presentation: only textual, static images and animated graphics. The low spatial ability learners who saw animation gained significantly contrasted to low spatial ability students who did not see the animation. On short-term comprehension, the spatial ability was a significant factor in the learning performance. However, in the long-term understanding, the type of presentation had a statistically significant effect on the subject's performance [11].

In a study with high school students, different spatial abilities and learning effectiveness were compared in two learning environments. With a pretest/post-test experimental design, a desktop virtual reality-based learning environment and a conventional classroom learning method with PowerPoint slides were compared. The results showed that low spatial ability learners were more positively affected by this special learning environment than high spatial ability learners [14].

Virtual realities provide the possibility of interaction beyond displaying 3D models. This direct manipulation provides benefits beyond passive viewing, especially for students with low spatial abilities. Direct manipulation of virtual environment facilitates the embodiment of the anatomical structure and helps maintain a clear frame of reference while interacting [16].

2.2.2 Ability-as-Enhancer Hypothesis

The ability-as-enhancer hypothesis proposes that the already skilled individuals could benefit as they have enough capacity left for mental model construction [10]. The 3D models which are designed to help the students to elaborate the spatial arrangement of a complex object. However, students with lower spatial ability became cognitively overloaded by them. Contrarily, the high spatial ability students benefited from the 3D models as their cognitive load did not cross the working memory limits [12]. The virtual realities differ from the classic 3D models as they are much more interactive: beyond watching the object from any viewpoint, the user can also manipulate it. Furthermore, a whole complex environment is displayed around the embedded model.

Anatomy is a great example of learning complex structures where spatial relations have a crucial role. The classic way of learning an anatomic structure involves 2D figures, sections from predefined planes. With this method, the student has to mentally create the 3D model, from the different sections. The number of different views are also important factors. A study [13] examined the effects of learner control and the number of views on the study of brain anatomy. They found the best learning performance when the students only see some key views and the control over the learning environment was low. The students with lower skills performed better when they saw only the key views (instead of multiple views). This can be explained by the higher cognitive load which was needed when they had to match the unfamiliar views with the more familiar key representations. In this research, the worst performance was measured when the students had no control over the presentation, and they saw multiple views [13].

Navigational tasks are also common in virtual reality studies. According to the ability-as-enhancer hypothesis, in virtual realities, better visualization or spatial skills help the user to build a better mental model of the space. As a result, these users can be more effective even in other related tasks, such as orientation, navigation in the virtual environment. Modjeska and Chignell [15] used a 2.5D map view and a 3D (fly-through view) in their study, but they did not find any significant difference between these two conditions. The spatial ability measures were in line with the ability-as-enhancer hypothesis. The users with the lowest quartile of spatial ability performed worse in the search task in the 3D condition. They found that for effective navigation, a minimum level of spatial ability was needed. The users who reached this level performed well in the experimental task. Thus, above this minimal level, presumably other factors account for the performance differences [15].

3 Methods

3.1 MaxWhere Desktop Virtual Reality

The whole experiment was conducted in the MaxWhere [18] desktop virtual reality, which was already used in several other studies [19, 20, 21, 22, 23, 24, 25]. This VR framework displays conventional web contents in a 3D virtual space. Webpages (or pdf documents, images, video files from the PC) are presented on the so-called smartboards, which are located within a virtual scene. These smartboards correspond to the tabs of a browser. When it is activated, an address bar appears on the top so the content can be changed quite easily to any other web content. Smartboards are in the standard 4:3 ratio or in A4 format for presenting documents.

The MaxWhere VR environment has several "*Where*", that is the name of a predefined graphical and spatial design. The graphical design of these spaces is on a wide range from serene landscapes to modern offices or even spaceships. Similarly, the *wheres* are designed for different purposes: there are different virtual offices (individual or collaborative), educational spaces (lecture spaces, interactive laboratories) and spaces dedicated to presentations (exhibitions, conferences). In this study, the Glassy Where was used (artist: Students Széchenyi István University). This *where* is a three-floor, modern glass and concrete building that levitates above a serene sea. This space is designed for presentation and online exhibition, so it has a relatively high number of smartboards. The smartboards are located on the open walls of the building, also inside and outside.

For navigating in the virtual world, only an external mouse was used with two buttons and a scroll-wheel. The Cognitive Navigation Technology (CogiNav) [26] provides an intuitive way to move and perform operations with a simple external mouse.

3.2 Spatial Ability Tests

Both spatial ability test and the experimental tasks were presented by the Psytoolkit [27] software 2.5.2 version. Participants were instructed to use the full-screen mode of the smartboard during the spatial ability tests.

3.2.1 Spatial Memory: Corsi-Test

The online version of the classic Corsi-block tapping test [1] was administered. This test measures the short-term coding and retention of spatial information. On the display, nine squares were presented in the same color. Some blocks blink in a different color in a random sequence. The first sequence consists of two blocks. Then the participant has to click with the mouse on the block in the order or the blinking sequence. When they finished, they had to click on the "done" button. Then, they get feedback about their performance. If they did correctly, they received a higher number of blocks (longer sequence). If they did it wrong, they get one more chance. Therefore, if they did it wrong again, the test ended, and they received their score (the Corsi span): the number of correctly memorized blocks.

3.2.2 Mental Rotation Task

In the mental rotation task [2], the subjects have to imagine what a stimulus would look like if it would be rotated. In this online version, the participants see three figures. The top one is the target image, and they have to indicate which one of the two others in the bottom match the top one. The matching means that it is the rotated version of the stimulus. The participants have to mentally rotate the figures. Mental rotation time is the time needed to rotate one item in milliseconds. We used 2D stimuli in this implementation. Users first solved five practicing trials and then ten real ones.

3.3 Navigational Experience

Participants were required to rate their navigational experience after completing the task in VR. They had to indicate their agreement with five different statements related to their experience in the virtual space on a ten-point scale: “I moved confidently in the space”, “I felt that I was controlling my movements in space”, “I had difficulty navigating to where I wanted to” (reverse-scored item), “Navigation in virtual space was automatic for me”, “I felt the natural moving in the virtual space”. The Cronbach's Alpha of the five-item questionnaire was 0.883 that is considered optimal.

3.4 Experimental Task

The subjects had to complete different tasks in the virtual space which needed navigation. In the initial view, the users find themselves at the top floor of the virtual building. Where they found, the instructions and a webpage, which contained the spatial measures, the experimental tasks, and all other questions. On the other smartboards, images were displayed (source: unsplash.com). In the pictures, different object, numbers or titles were presented in front of a plain colored background. There were two smartboards with documents in pdf format.

To solve the tasks, the participants have to navigate in the space and answer several questions related to the digital contents and their arrangement (e.g.: How many images with yellow background are on the ground floor? How many pages are in a pdf?). Subjects have to indicate their answers on the webpage on the third floor. To get back to this main area they could also use the TAB key. Twelve points were the highest possible score in these tasks.

3.5 Procedure

The experimenter presented briefly the procedure and instructions for the experiment (the instructions were also visible in a smartboard in the VR. First, subjects were instructed to use a full-screen mode for the first two tasks: the Corsi-test and the mental rotation task. Then, they were informed that the full-screen mode is not obligatory. Then, they solved the experimental tasks (in the same virtual environment). Then, they rated their navigational experience, and they indicated if they knew this software before and how much time they spent already with it. Then, they filled the Igroup Presence Questionnaire (in this study these results are not included). They had to indicate if they use regularly other 3D software (games or designer programs). Finally, they answered basic demographic questions. The duration of the experiment on the average was 14 minutes (SD: 4.7). The whole experiment was conducted in Hungarian.

3.6 Subjects

Thirty-six participants took part in the experiments. In the final analysis, 31 individuals' data were examined. The other five was excluded due to data loss or misunderstood of the experimental task. The mean age was 20.5 years (SD: 3.4). Twenty-five man and six women took part in the experiment.

4 Results

The goal of this study was to examine the relationship between the scores of the experimental task and the individual spatial abilities, such as, the Corsi span and the mental rotation skill. Furthermore, the navigational experience was measured. The result of the descriptive statistics is displayed in Table 1.

Table 1
Contains the mean and standard deviation of the examined variables

	Mean	Standard deviation
Corsi span	6.2	1
Mental rotation score	8.4	1.4
Reaction time of correct answers in the mental rotation task (ms)	6573.3	2087.9
Score of the experimental task	9.6	1.6
Navigational experience (1-10)	7.04	2.19

A Spearman's rank-order correlation was computed to assess the relationship between the Corsi span and the score of the experimental task. There was no significant correlation between the two variables, r_s (28) = 0.09, p = 0.635. There was no significant correlation between the score of the experimental task and the mental rotation score (r_s (29) = -0.174, p = 0.351) nor the reaction time of it (r_s (29) = 0.148, p = 0.426). Overall, there was no significant correlation between the examined variables which means that the obtained scores of the experimental tasks do not relate to either of the measured spatial abilities.

The navigational experience and the score of the experimental task were not related, according to the Spearman's rank-order correlation, r_s (29) = 0.068, p = 0.718. The navigational experience was not related significantly to any of the measured spatial abilities, such as Corsi span ($r_s(28) = -0.137$, $p = 0.471$), mental rotation score ($r_s(29) = 0.09$, $p = 0.63$) or the reaction time of the correct mental rotation answers ($r_s(29) = 0.133$, $p = 0.475$). Therefore, it means that the navigational experience does not relate to the individual spatial abilities or the performance of the experimental task.

5 Discussion

This paper investigated the hypothesis whether there is a relationship between the effectiveness of completing a task in VR and the user's individual spatial abilities, namely the spatial memory (Corsi span) and the mental rotation ability. According to our result, there is no significant relationship between these variables. Therefore, it means that using this type of desktop virtual reality is neutral to the individual spatial memory and mental rotation ability.

The relationship between virtual reality and spatial abilities is quite ambiguous. The ability-as-compensator hypothesis mostly appeared when students had to learn a complex 3D model, and the virtual reality helped them to reduce cognitive load and save working memory [11]. The ability-as-enhancer hypothesis was also present in researches where instead of a 3D model, a navigational task was the main interest. They found that a minimum level of spatial ability was needed for effective navigation [15]. The results of this paper show a similar pattern, as there was no significant relationship between the spatial ability measures and task performance. Measuring the threshold of minimal spatial ability for completing the task was not part of this research, but this could explain the results. Limitation of this study is the sampling was not random, as there were new users and more experienced VR users. Although in the analysis, this did not affect the results.

The aim of this study was to model an everyday usage of the MaxWhere virtual space and measure its relationship with individual spatial abilities. In the experiment, a relatively big virtual space was used. In educational settings, smaller spaces are more common, and these spaces are also more concentrated. The most important smartboards and information are placed in one central area. Thus, less navigation needed. It is also important to point out that in the MaxWhere VR the CogiNav technology is used, which is designed to make navigating seamless in 3D virtual spaces.

The results of this paper showed that there is no relationship between the measured spatial abilities and the experimental task requiring navigation. This means that a student with higher or lower spatial abilities can have the same benefits when using this kind of virtual reality.

The MaxWhere virtual reality uses general devices to immerse the users into a 3D space. As contributing human factors to the transition from 2D to 3D technology the spatial memory and mental rotation skills were hypothesized in this research. The results showed that these skills do not play a role in this transition (in the case of MaxWhere VR), as they are not related to the use of this virtual reality. This suggests that the MaxWhere VR can be used by anyone, independently from their spatial memory or mental rotation skill.

Conclusions

This research showed that there is no significant relationship between the effectiveness of completing a task in MaxWhere VR and the users' cognitive characteristics: namely the spatial memory and the mental rotation ability.

Acknowledgement

This work was supported by the ÚNKP-18-3 New National Excellence Program of the Ministry of Human Capacities.

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