THE ROLE OF HUE AND REALISM IN VIRTUAL REALITY

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Abstract
The use of Virtual Reality (VR) in general and virtual geographic environments (VGEs) in particular is becoming more and more common. However, the use and usability of traditional graphical variables within such environments is still rather unclear. Our research is based on a review of studies about the three-dimensional spatial visualization. We performed two empirical studies focusing on the role of colour hue and the level of realism within the VR environment on the task (wayfinding) performance of users. In the first pilot study we compare their wayfinding ability using colour hue markers (decision points) versus grey markers in the test virtual environment. In the second pilot study we compare their wayfinding within two environments with different levels of realism, realistic and symbolized, including points of interest (PoI) used for navigation. Our results showed that colour hue highly influences the participants' selection of points of interest and the level of realism affects their orientation ability, especially the number of PoIs they used. In general, participants perform wayfinding more effectively in the more realistic environment.

Keywords: *color hue, level of realism, navigation, virtual geographic environment, virtual reality, wayfinding*

INTRODUCTION

The main benefit of geoinformatics is undoubtedly to make life easier for people, to help them make better decisions in common life situations, and to bring some added value using spatial information (Řezník, 2013). Some of the latest technologies that could be used in real life are virtual geographic environments (VGEs) in combination with virtual reality - VR (Lin et al., 2015).

The factors influencing the usability of virtual 3D environments have been analysed from different viewpoints. Šašinka (2012) introduced a triarchic model identifying three different groups of key factors: spatial visualization (stimuli), user individual differences (spatial abilities, age, gender), and context (tasks to be solved, scenario). He emphasized the importance and interaction of all three of the above-mentioned categories when working with a traditional, two-dimensional representation. Recently, Lokka and Çöltekin (2016) presented an analytical study focused on navigation with virtual 3D geovisualizations and proposed similar categories (tasks, stimuli, and participants) as crucial inputs for testing the memorability of geovisualizations. They extended the original list of factors to include 3D geovisualization issues (e.g., level of realism, pseudo 3D versus stereoscopic 3D, interactivity of the visualization), and stressed the necessity of conducting further empirical studies.

The basic component of each visualization is color. There are many studies that explore the importance and impact of color in cartography. However, there are not many studies that use color for user orientation in a 3D environment. In their work, Raubal and Winter (2002) mention the role of color in orientation in space. The use of color as an element for signaling the correct walkthrough of a level is also mentioned by Shepherd and Bleasdale-Shepherd (2014), who combined GIS (Geographic Information System) and video games. Read (2003) notes that color can be used as a visual stimulus that focuses the individual's attention on a specific location.

The importance of color hue in orientation is also explored by other authors (e.g. Dalke, et al., 2005, Spence, et al., 2006, Osman and Wiedenbauer, 2004). An interesting concept is in the work of Helvacıoğlu (2007), which was the main inspiration for the first pilot study in this article. This study compared children's perception of color hue markers versus grey markers. Their results confirmed that the color hue markers are useful in decision-making and thus in wayfinding. Ranjbar et al. (2016) investigated the effect of color in a virtual environment, but the study did not find a connection between color use and finding the specified path, but the results were influenced by a specific VR environment (department store). Hidayetoglu et al. (2012) used a virtual environment instead of a real one for exploring a path using color. They confirmed that color improves the ability of people to find the right path.

A second important component of each VGE is its level of realism. We can distinguish between different types of realism. With varying levels of realism, we can see how people's behavior changes in a VGE compared with the real world (Chalmers and Ferko, 2010). User behavior across various levels of realism has been explored in many scientific research projects (e.g. Jahnke, Krisp and Meng, 2009; Zanola, Fabrikant and Çöltekin, 2009; Smallman and Cook, 2011; Wilkening and Fabrikant, 2011; Lokka and Çöltekin, 2017). However, none of these studies used interactive, stereoscopic visualizations as stimuli. Stereoscopic visualization was used by Zanola, Fabrikant and Çöltekin (2000), but the stimuli were only static views of selected geographic features.

In the real world, people use different landmarks to navigate. However, we are not sure if this pattern persists in virtual environments. Lokka and Çöltekin (2017) compared realistic, abstract, and mixed visualizations in a VGE. All environments were based on a 3D model of fictitious city. The mixed environment had photo-textures only on selected buildings. Their participants preferred this mixed visualization VGE. Höffler's (2010) review argued that spatial ability plays an important role in learning from visualization, but he did not demonstrate that visualizations with a lower degree of realism are always more appropriate than visualizations with a higher degree of realism. A slightly different view of realism is given by Borkin et al. (2013). The authors come to the conclusion that visualization is always less memorable than the real world. They argue that the best solution is try to make the most accurate visualization accompanied by pictograms and other elements. However, they also assume that these added elements are attractive to people.

This paper describes two exploratory studies, one of which focuses on the role of color hue and the other on the role of realism in navigation tasks. Both studies were done in a VR constructed using the Unity graphic engine. The first pilot study used a HTC VIVE headset and the second used Oculus Rift. VR allows us to work with stereoscopic visualization, and because it offers a high degree of immersion, it produces a visualization closer to reality than many other visualization methods. VR created in the Unity engine allows us to change the appearance of individual objects, but due to relatively small number of studies that deal with this topic, we do not know exactly how these changes affect user behavior. A VR environment created with Unity also allows us to record the movement of the user in the virtual environment.

COLOR HUE WITHIN VIRTUAL REALITY

In the first pilot study (PS1), we focus on how the color designation of objects affects participants' wayfindg judgments. Specifically, we tested whether it is preferable to mark the route using color hue markers or gray markers.

Research question

The main goal of the research is to verify whether designating objects using color hue can significantly influence wayfinding behaviors. The work is focused only on finding the right path, which is marked with a certain color hue sequence. In this pilot study we also deal with the accuracy of participants' choices and the speed of their walkthrough. Because our study is based on the work of Helvacıoğlu (2007), the research questions were very similar. We focus on three aspects of wayfinding that are most crucial for this activity, including:

- the correctness of the walkthrough,
- the amount of time spent,
- the ability to properly reconstruct the walkthrough on the map.

We were interested in whether the color hue visualization would lead to a shorter walkthrough time, and to a smaller number of stops to look around. In the second part of the experiment, the participants completed a questionnaire survey that included giving a verbal description of the entire route. Using this procedure, we aimed to find out where the elements were oriented in the environment. We want to find out in both conditions whether participants used the color boxes as landmarks or preferred other points of interest (PoIs) such as important buildings, etc.

Research methods

Experiment materials

This pilot study used a 3D visualization of a small town that included many thematic symbols. The visualization included colored navigation markers and was modified so that the research route had six points where the participant had to turn, similar to what was done in Helvacıoğlu's (2007) experiment. At each of these six turnoffs, the navigation box indicated the direction of the route (Figure 1). There was also at least one landmark that was different from other buildings at each decision point. Specifically, these landmarks were two trees, a church, a well, a cross, and a mill.

In addition, we created two different environmental conditions. These differed from each other by the color of the navigation markers. In the first environment, all of the markers were the same grey color. In the second environment, the markers were colored in different hues: yellow, orange, red, purple, blue and green. In the first part of the research, both environments included a guideline. The guideline makes it possible for an experiment participant to follow the route by themselves. The second part of the experiment removed the guideline and thus the participant had to depend on his or her own navigational abilities. We modified the buildings in the town such that the participant could see only two markers at the same time.

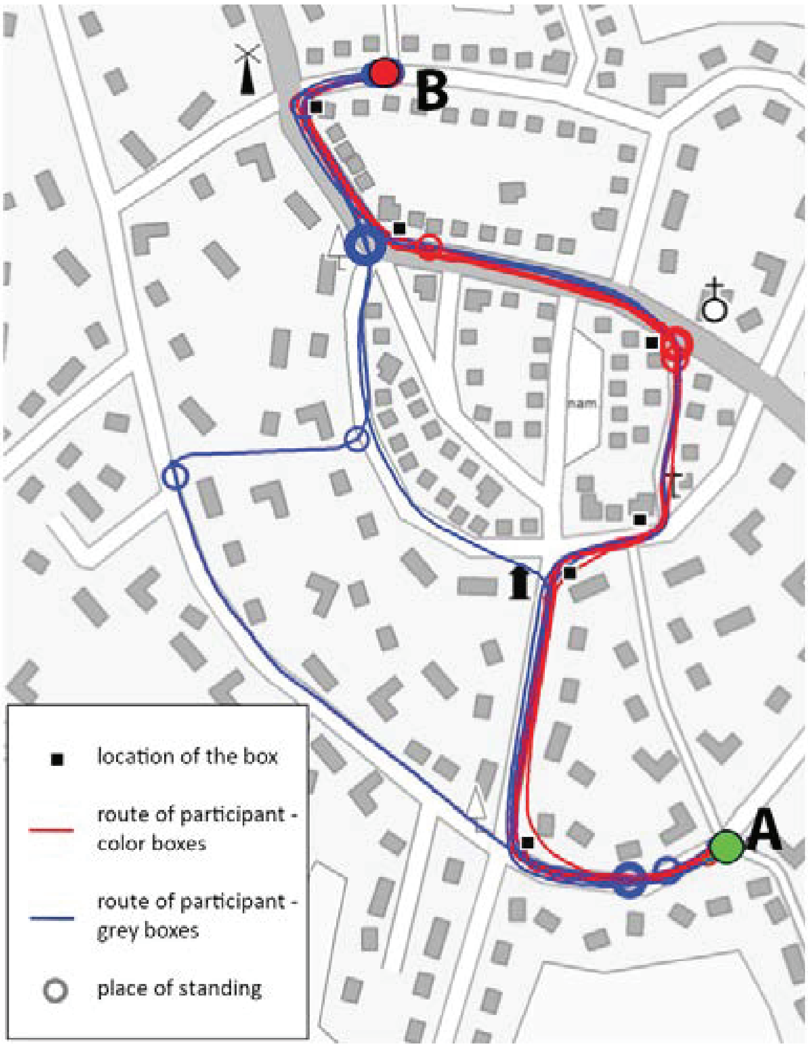

Figure 1. The individual routes with markers (A – starting point, B – finish point).

Experimental Procedure

The participants were first tested on their ability to distinguish colors, then they were introduced to the environment. In the third phase, the first part of task, which used the white guideline indicating the specified path was displayed, and then the participants were asked to follow the same path without the white guideline. The study used a between-subjects design. That is, each participant saw only one of the environmental conditions, either color hue or gray. Finally, participants completed a questionnaire survey (Figure 2).

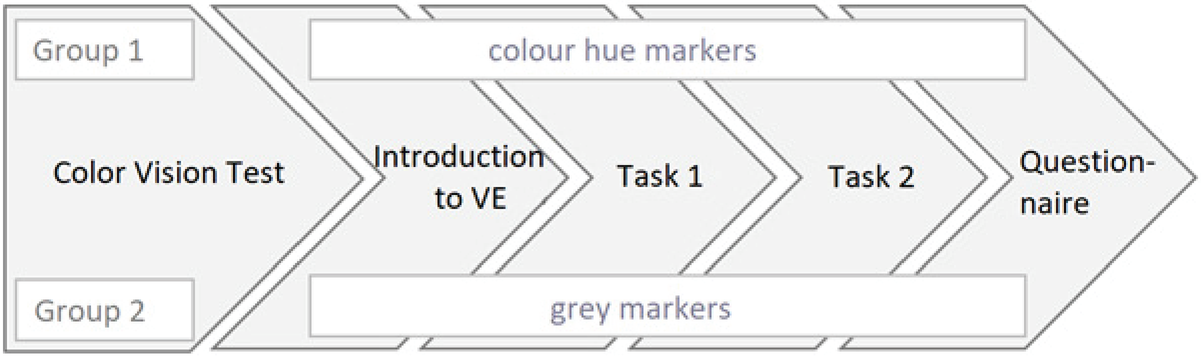

Figure 2. The design of PS1.

Experiment Participants

PS1 involved ten people, five in each environmental condition (gray, colored). The participants' age range was between 21-31 years (M/F, 4/6), and all were non-geographers with minimal experience with VR. All participants passed the color vision impairment test without any problems.

Results - PS1

We observed differences between the accuracy and also the walk-through times in both groups (Table 1). The most observable difference is in their success in completing the task. All participants successfully followed the path with colored navigation markers, but only 2 participants out of 5 made no mistake when using the grey navigation markers. However, all participants reached the finish point. The total walk-through times and number of stops do not show any noticeable differences.

Table 1. Results of PS1.

ID	Environment (C - color, G – grey)	Successful task solving	Time (s)	Number of stops
P1	C	yes	147	3
P4	C	yes	139	0
P6	C	yes	133	0
P7	C	yes	137	0
P9	C	yes	132	1
P2	G	yes	133	0
P3	G	no	160	5
P5	G	yes	142	0
P8	G	yes	140	0
P10	G	no	129	3

All participants correctly described the route in the color navigation marker condition. The same two participants who made mistakes during walk-through, also described the route incorrectly in the grey marker condition. More interesting results can be seen when we focus on whether the participant used the marker for orientation, as the existence of these markers was neither explained nor emphasized in our instructions to them. In the color marker condition, the participants used the markers much more frequently than in the grey marker condition. Three people even used the markers for majority of the route. In contrast, only one participant used the grey markers in this way. The effect of the color hue is noticeable in this case. Significantly, color hue helped participants to register the presence of navigation markers and then use them for navigation. In the grey marker condition, participants more frequently mentioned buildings than the navigation markers in their description of their routes.

For the color marker condition, we also asked which color hue helped participants in their orientation within the environment. Most of the participants did not remember a specific hue that would help them. Instead, they talked about the "color contrast". They simply knew that each box had a different color and they were not interested in a particular hue. Only one participant could recall all of the colors. From this result, it is clear that none of the colors made it into the minds of the participants, they rather they focused on their contrast with the rest of the environment.

LEVEL OF REALISM WITHIN VIRTUAL REALITY

In the second pilot study (PS2), we focused on how the level of realism affect the users. The experimental condition, in this case, is the level of realism of in the virtual environment. The task is the same for each of the tested environments.

Research question

The main goal of this pilot study was to find out if and how the level of realism affects the participant in fulfilling the given wayfinding task. This task consists of memorizing and then correctly following the specified route in the VR environment. In the real world, there are many things that people use for orientatation such as, for example, the different elements of buildings, various important elements that are located in public places, etc. Therefore, we can hypothesise participants will better orientate themselves in a realistic environment, leading to better peformance on the task. So the research question were:

- Will participants achieve better results in realistic environments?
- Will they find a faster route and make fewer mistakes than participants in an abstract, symbolized environment?

Research methods

Experiment materials

For this pilot study, we created two 3D models of the same territory, namely, a small town with two portrayals, one realistic and the other symbolized (Figure 3). To preserve the real environment, the town is modeled according to the real town but a city was chosen that no participants would know. In addition to common town houses, several landmarks - church, cross, windmill, lookout tower, well, bus stops, rocks, trees, square, river, and other terrain elements - were placed in this town.

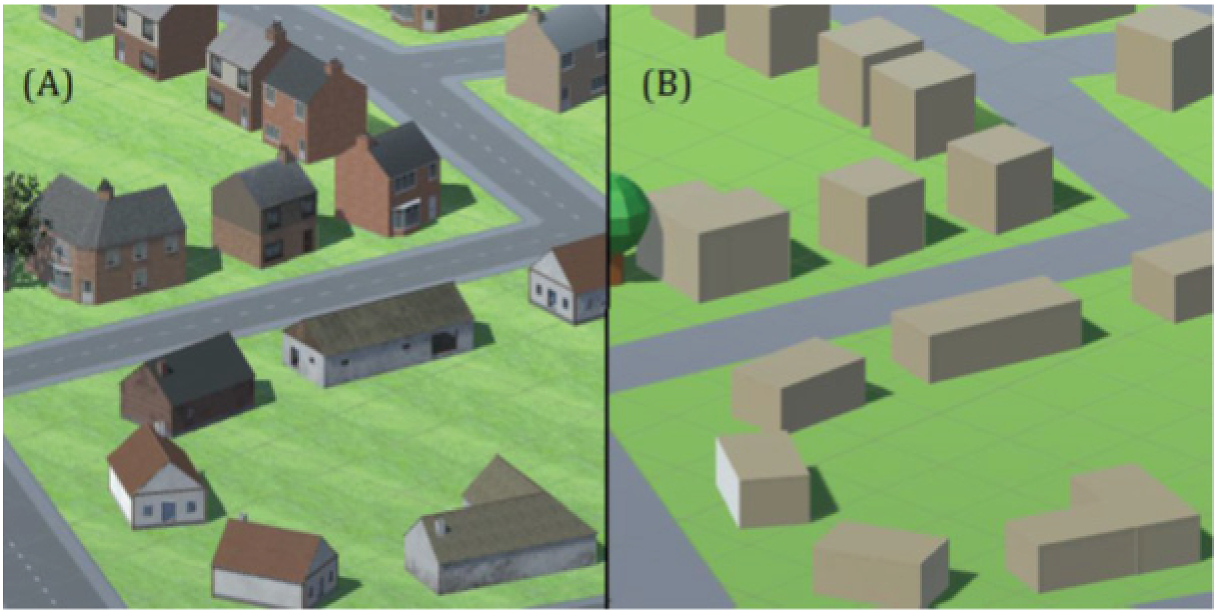

Figure 3. Comparison of designed environments (A - realistic, B - symbolized)

Experiment participants

PS2 involved 14 people who were evenly distributed across both experimental conditions (realistic, symbolized). Participants ranged in age from 20-35 years (M/F, 8/6), and were mostly students of geography. A few students from non-geographic fields were also tested for comparison, however no effect of disciplinary knowledge was detected. We used a between-subjects design. Participants were divided into two groups where the first group performed the task in the realistic environment while the other group performed a task in the symbolized environment. Each group had the same proportion of geography students and students studying other subjects.

Experiment Procedure

The participants first completed the Perspective Taking Test (PTT) and the Spatial Imagery Test. Subsequently, they were introduced to the VR environment when they put on the headset and tried to walk through the test environment. There, the controls and movement were explained and after each participant was ready, the task was begun. The experimental scheme can be seen in Figure 4.

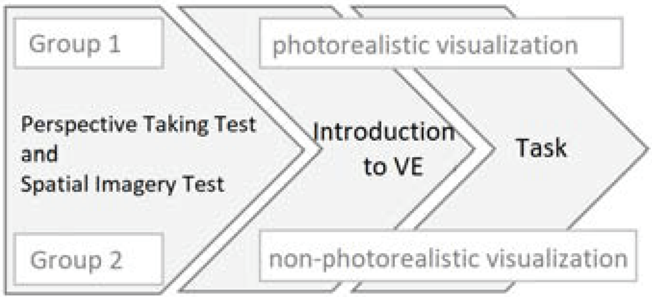

Figure 4. The experimental design of PS2.

The task was the wayfinding, namely finding the specified route in the VR environment. In this role, the participant fulfills the role of a tourist who is visiting the town and is interested in looking at the most interesting places. Before a participant started the route, they viewed a 2D map showing the walkthrough path. The participant had to remember this route and then proceed to the VR environment.

Results - PS2

In this task, the participant walked through the memorized path in the virtual environment. We made three measurements of participant performance:

- Task completion: has the participant reached the finish point;
- Task mistakes: the participant followed the memorized path, but made errors;
- Task correctness: the participant followed the memorized path without making any mistakes.

As shown in Table 2, all participants except one completed the task. More interesting is that all participants followed the correct route in the realistic environment, while three out of seven participants in the symbolized environment did not follow the correct route. When we focus on task correctness, we found the realistic environment more effective. Four participants out of seven accomplished the walkthrough without any mistakes in the realistic environment, while only two participants out of seven did not make any mistakes in the symbolized environment. If we focus on route length, standing time, and number of stops, participants who were in the realistic environment condition had a shorter route length, less standing time, and made fewer stops than those in the symbolized route, but the differences are not significant and are associated with making mistakes along the route.

Table 2. Results of PS2.

ID	Environment (R - realistic, S - symbolized)	Completed the task	Passed the specified route	Without mistake	Length of route (m)	Time of standings (s)	Number of stops
P1	R	yes	yes	yes	984	23	7
P3	R	yes	yes	yes	968	3	3
P5	R	yes	yes	yes	979	27	4

P7	R	yes	yes	yes	974	0	0
P9	R	yes	yes	no	1158	26	7
P11	R	yes	no	no	1111	49	8
P13	R	yes	yes	no	2377	42	15
P2	S	yes	no	no	2652	251	39
P4	S	yes	no	no	1088	16	7
P6	S	yes	yes	no	1012	25	8
P8	S	no	no	no	1159	15	4
P10	S	yes	yes	yes	980	3	3
P12	S	yes	yes	no	1355	3	2
P14	S	yes	yes	yes	962	2	1
Success rate	R	100%	85,70%	57,10%	1222	24,3	6,3
	S	85,70%	57,10%	28,60%	1315	45	9,1

GENERAL DISCUSSION AND FUTURE DEVELOPMENT

Since the first pilot study was methodologically inspired by Helvacioğlu (2007), the results we obtained should be compared with that study. Regardless of the difference between the experiment environments (real buildings versus VR), we confirmed that color (color hue) has a significant effect on the success of the walkthrough. We also achieved similar results related to color memorability, with no distinct difference between colors. Participants remembered all the colors regardless of the hue. It was also possible to confirm the effect of color on the use of the markers. On the other hand, it was not possible to confirm that color led to faster times. The reasons may be varied, but probably one of the most important is the way of walking. A VR that is controlled by the keyboard loses the nuance of movement, while in reality, it is possible to slow or accelerate according to our confidence in the direction we are heading.

When we focus on how the level of realism influences the given task, it is clear that people perform better with a realistic environment than a symbolized one. The results of the second study show that participants who used the realistic following the route through. This may be due to the fact that the realistic environment is more obvious to people, so they are better oriented. The symbolized environment can be more monotonous and because of it, people more easily become lost there.

There are several limitations of the pilot studies. Probably the most important constraint lies in the low number of participants. In this small group of people, one single person with an unusually poor or excellent performance can greatly influence the results as a whole. Therefore, the results presented should be considered preliminary, an exploratory study that rather points to existing issues.

Similar results have been published by Liao et al. (2016) and Schmidt and Delazari (2013) who compared a 2D map and 3D visualization and came to the conclusion that people are better and faster using realistic 3D visualizations than a 2D map that is more symbolized. Bandrova (2001) and Bandrova and Bonchev (2013) have also come to the conclusion that realistic visualizations are preferred and considered to be more natural to people.

Although we can now easily use applications like Google Earth VR, user behaviour with VR environments is still underexplored. Thus, this paper, as well as other similar studies (e.g. Špriňarová, et al. 2015; Juřík, et al. 2016; Liao, et al. 2016; or Kubíček, et al. 2017) shows where research should be focused. Cartography, in general, can play a major role in creating digital models tailored to the needs of VR. The advantage of our research is the implementation of the VR, which can be used in later user testing.

The results show that 3D visualization with a high level of immersion can be more beneficial to humans in the future than the classic 2D visualization we know, for example, from classic maps. However, VR is a technology that is still hitting the limitations of computer technology as well as other practical problems (cable connection, heavy weight of headsets, etc.). In addition, motion in VR environments is often controlled using a keyboard and mouse, which is not a completely intuitive control method (this topic is more discussed by Juřík et al., 2016). While new controls for movement in VR have been developed, there are still some limitations with space, etc.

It would be interesting extend this study for example by using eyetracking (pilot studies on the interaction of interactive 3D geovisualizations with eye-tracking have already been done - see Herman, Popelka and Hejlová, 2017). Using this method, we could better find out which POIs and landmarks are more useful in orientation and wayfinding. Eye-tracking would also make it easier to recognize how much the participants observe other elements of the environment.

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