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When the display matters: A multifaceted perspective on 3D geovisualizations

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Abstract: This study explores the influence of stereoscopic (real) 3D and monoscopic (pseudo) 3D visualization on the human ability to reckon altitude information in non-interactive and interactive 3D geovisualizations. A two phased experiment was carried out to compare the performance of two groups of participants, one of them using the real 3D and the other one pseudo 3D visualization of geographical data. A homogeneous group of 61 psychology students, inexperienced in processing of geographical data, were tested with respect to their efficiency at identifying altitudes of the displayed landscape. The first phase of the experiment was designed as non-interactive, where static 3D visual displays were presented; the second phase was designed as interactive and the participants were allowed to explore the scene by adjusting the position of the virtual camera. The investigated variables included accuracy at altitude identification, time demands and the amount of the participant's motor activity performed during interaction with geovisualization. The interface was created using a Motion Capture system, Wii Remote Controller, widescreen projection and the passive Dolby 3D technology (for real 3D vision). The real 3D visual display was shown to significantly increase the accuracy of the landscape altitude identification in non-interactive tasks. As expected, in the interactive phase there were differences in accuracy flattened out between groups due to the possibility of interaction, with no other statistically significant differences in completion times or motor activity. The increased number of omitted objects in real 3D condition was further subjected to an exploratory analysis.

Keywords: 3D vision; geovisualization; real 3D visualization; pseudo 3D visualization; stereopsis, kinetic depth effect; human-computer interaction

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1 Introduction

With the growing use of 3D technologies in many areas such as, geology, geomorphology, hydrology, oceanography, meteorology, teaching geography, virtual tourism, documentation and preservation of cultural heritage, urban and transport planning, noise mapping, 3D cadastre [1–12] and others, the usability of 3D visualizations is increasingly discussed. The importance of 3D visualization increases also in other fields such as crisis management and air traffic control (ATC), which represent geoscientific areas highly motivated to secure user-friendly ergonomics [13, 14]. Creating a user-friendly interface preventing human errors should be the highest priority in user interface engineering; at the same time this type of information depiction is the key factor in influencing the processing of visual stimuli. Since the majority of 3D users in the mentioned areas are people with low-level experience working with geographical data, the investigation of 3D geovisualizations in non-expert populations is necessary.

Previous studies focused on the differences between real and pseudo 3D visualization of geographical data in relation to e.g. the estimation of distances [15], identification of similarities in 3D networks [16], spatial navigation [17] or military and disaster situations [18]. Based on the results of our previous exploratory study [19], we created a new experiment to clarify the benefits and limits of alternative 3D geographical visualizations at identifying

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the altitude. In this study we compare two types of 3D visualization - real 3D and pseudo 3D - in order to find out how non-expert people process and evaluate 3D geographical data; in addition, we analyze their task-solving strategies. To provide complex view on issue of 3D visualizations, we explore the static and interactive forms of 3D geovisualizations.

1.1 Real 3D and Pseudo 3D Visualization and Geovisualization

The monoscopic pseudo 3D visualization (also called weak 3D visualization; [15]), is displayed perspective-monoscopically on a flat media, e g. computer screen [20]. Pseudo-3D visualization offers only monocular depth cues for the identification of spatial features in the environment (e.g. linear perspective, relative size, interposition, texture gradient or kinetic depth effect). On the other hand, real (or "strong") 3D visualization [15] uses both the binocular and monocular depth cues and provides stereoscopy [20]. In the real environment, stereoscopic vision helps people to better discriminate distances and depths. In virtual reality, real 3D visualization simulates monocular visual depth cues as well as one of the binocular depth cues, namely binocular disparity [21]. The stereoscopy in real 3D is usually ensured by the use of a specific peripheral device such as 3D glasses. Due to stereoscopy, real 3D visualization offers more visual cues to detect the spatial features of the virtual display; the ability to better identify altitude is expected to be enhanced in real 3D [22, 23]. These two different types of 3D visualization are considered to be computationally non-equivalent [24], i.e. demanding different cognitive processing despite the fact they both depict the same content (information). The computational non-equivalency in virtual 3D viewing was supported also on the neuroscientific level, where extra visual cues included in the perceived scene aroused brain activity [25].

Studies on 3D visualization show enthusiasm on one hand and certain doubts on the other especially with respect to a user-friendly human-computer interaction. Some previous studies view interactive 3D visualization as an effective way of presenting geographic data and explaining the complex processes and various phenomena that occur in real environments [26]. Other studies consider 3D technologies as a promising tool for the future of advanced 3D cartographic products [13, 27]. Weber et al. [28] and Hirmas et al. [6] focus on the possibility of using 3D geovisualization when teaching geography; Bleisch and Dykes [29] describe the utilization of 3D geovisualization for planning mountain hikes and evaluation of 3D hiking maps. Zanola et al. [30] propose and evaluate the utilization of real 3D visualization in urban planning. On the other hand, the limitations of 3D visualization using motion and binocular visual depth cues have been reported, such as increased time needed for solving tasks, or visual discomfort [15, 31–33]. As highlighted by Plant and Stanton [34], the relevant features influencing the process of perception should always be considered in relation to the phenomenon of human error, which can be influenced by 3D visualization.

1.2 Non-interactive and Interactive Level of Perception

In this study we distinguished between non-interactive and interactive levels of 3D perception. Non-interactive perception is represented by looking at static perspective views without the possibility to actively change the point of view. The interactive type integrates perception and manipulation with the geographical content to reach a given spatial objective; therefore, performance is more dependent on the participant's search strategy and on a motor activity when solving the task. The issue of interactive visualizations was explored in previous study [35] suggesting that interactivity does not necessarily enhance task performance if the needed information is immediately visible/available, no matter if obtained actively or passively. However, with respect to previous theories [36], the proximal visual cues we perceive to catch and understand reality is chosen from the wide spectrum of possibilities. Contextual issues such as visualization type or available control device matter in this choice.

2 Methods and Materials

2.1 Used Methods

In this study, the different types of 3D visualization with different number of visual cues are expected to induce participants' different motor activities. To explore separately both visual and motor aspects of interaction with 3D visualizations, we divided the experiment into two phases (Experiment 1 and Experiment 2). The aim is to compare the efficiency of alternative types of 3D visualization in static and in dynamic tasks (see Fig. 1). In the whole study participants' ability to identify the relative vertical position of objects in the scene was investigated. Participants were given the virtual geographical terrain with geometric objects of different colors placed in it and participants were asked to order them according to their altitude. All the primary test views of the geographical terrains were perspective (i.e. oblique) views. In both phases of the experiment (Exp. 1 and Exp. 2), participants dealt with ordering of the geometrical bodies in the terrain.

Experiment 1 was designed as a non-interactive variant where the stimuli were static perspective views. The aim of the non-interactive Experiment 1 was to explore the assumption that different types of 3D visualization of geographical data are perceived in different ways. The influence of 3D visualization type was explored, with focus on visual perception only. In the static, non-interactive virtual environment, the binocular disparity provided by 3D glasses was expected to increase the participants' ability to identify the altitude features of the terrain [22] in shorter time.

Experiment 2 was designed as an interactive experiment, with the participants being able to navigate the interactive 3D visualization by adjusting the position of a virtual camera. With such navigation, the missing cues of binocular disparity in pseudo 3D were expected to be compensated by the *kinetic depth effect* [37, 38] and therefore the accuracy in altitude identification was expected to be the same in both conditions. However, increased number of navigating actions (motor activity) were expected in pseudo 3D group as a compensation for missing binocular disparity. This increase of motor activity in pseudo 3D was expected to induce longer task-solving times. Crampton [39] suggested, that mental efforts should be enhanced in the pseudo 3D condition due to missing binocular depth cues and people would have to explore the scene more precisely to estimate objects altitude. Participants in real 3D would solve tasks more easily, but with the risk of omission (not finding) some important aspects in the scene, as suggested by Špriňarová et al. [19]. In Experiment 2, participants could have missed some objects in the scene, so we measured the number of omitted objects.

The two phased experimental design consisted of a series of tasks measuring the ability of participants to identify the correct altitude arrangement of objects in a three-dimensional geographical terrain. We alternated experimental tasks with filler tasks to prevent testing period from being monotonous and to keep participants focused and well-motivated for the experimental tasks (as seen in Fig. 1).

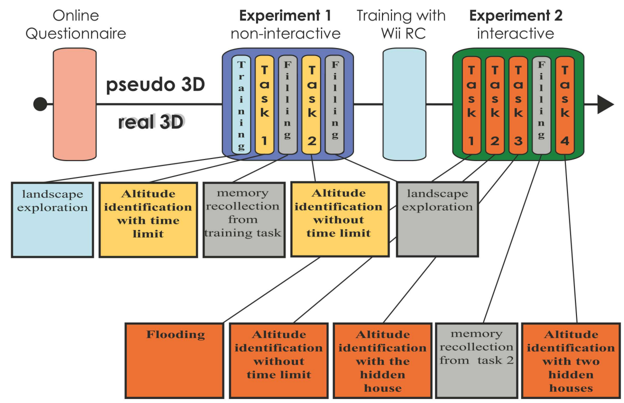

Figure 1: Schema of Design of Experiment.

2.2 Used Display Technologies and Geographical Data

The test arrangement was designed exclusively for the purpose of the present study. A real 3D display was created using Dolby 3D technology (wavelength-multiplexed stereo system utilizing a pair of projectors and a set of Dolby passive (filter) glasses). A pseudo 3D display was created with one of the projectors operating in the classic (2D) display mode. See Jorke et al. [40] for more details about display modes.

Because the participant's motor activity (namely the types of actions used for navigating the terrain) in interactive Experiment 2 was measured, we avoided using the typical control devices such as computer mouse which could enhance a stereotypical behaviour in participants. A wireless handheld Wii Remote controller (RC), originally designed for a Nintendo game console, was used as a basis for the interaction. The Wii RC has motion tracking capabilities, but the precision and reliability of the movement detection is rather low and there is a risk of adverse effects on the users' performance. Therefore, we also used an optical Motion Capture system "OptiTrack" by NaturalPoint for tracking the position and orientation of the Wii RC. This solution provides significantly higher quality of tracking in terms of resolution, speed and reliability. The combination of Wii RC (providing active buttons for control actions such as zoom, orbiting and dragging) and an "OptiTrack" system enabled more natural 3D movement patterns, thus ensuring high user comfort. The above was possible due to more (namely three) degrees of freedom (DoF) available in comparison with the usual PC mouse, which provides 2 DoF [41]. With respect to embodied cognition approach where the cognition is considered to be body based activity as well as subjected to the situational contexts [42–44], the

3 DoF and free 3D movement enabled participants to carry out natural and interface-independent patterns of movements when controlling the visualizations.

Experiment 2 was displayed using the VRECKO software system. VRECKO is an open-source modular software which has been continuously developed by the Human-Computer Interaction (HCI) Laboratory at the Faculty of Informatics at the Masaryk University since 2003. VRECKO was programmed in C++ using the OpenSceneGraph library (see more details at http://vrecko.cz). A set of modules for the visualization of geographical data was developed and implemented by Tisovčík (2014) [45]. For Experiment 1 (non-interactive), a new, single-purpose and easy-to-use application was developed at the HCI Laboratory for the creation of experimental tasks, display of textual and graphical data, and recording of the answers and task solving times.

Digital terrain models (DTM) were used as a main input for creating 3D geovisualizations. A fourth-generation Digital Terrain Model of the Czech Republic (DTM 4G) was acquired by airborne laser scanning (ALS) and processed to ground resolution 5 × 5 metres. DTM 4G is now being distributed by ČÚZK (Czech Office for Surveying, Mapping and Cadastre). The collected point clouds were imported as text files directly into the VRECKO software where continuous terrains were created. DTMs represented different parts of the Czech Republic (mainly the Giant Mountains and Bohemian Paradise) and they were covered with a corresponding orthophoto. Some data (from the area of Bohemian Paradise) have been transformed by doubling the vertical values in order to highlight the relatively small variation in landscape altitude. The processing of data for interactive visualization in the VRECKO system is described in more detail in Tisovčík [45]. The terrain data used in Experiment 1 were also processed and exported using VRECKO system and then pre-rendered using Cinema 4D software. Stimuli used in the study were generated from geographical data that were similar to the data provided by the common applications with widespread use (e.g. Google Earth, Virtual Earth, Cesium and others).

2.3 Participants

The participants were 61 volunteers (students of psychology) recruited from the Department of Psychology at Masaryk University (42 women (W) and 19 men (M); age 19–31, m = 23.24, sd = 2.609). The data were collected in May/June 2015. The participants were recruited via e-mail, social networks and personal contact. Before testing, we questioned participants about their experience with 3D visualization and with geographical data. All of participants had some previous experience with 3D visualization applications, but none of them had an experience with the interaction with 3D geographical data as used in this study. Participants were not familiar with any of presented terrains. The research sample was chosen deliberately. The purpose of the study was to explore performance of inexperienced users with no geoscientific education, primarily on the perception level. Participants should have represented the general public, which is often the target group for 3D geovisualizations.

Participants were divided into two groups (real and pseudo 3D visualization) with an equal proportion of men and women in each group, in order to balance out the suggested differences between men and women in spatial orientation tasks [46]. The experimental conditions (including lighting conditions and other environmental factors) were identical for both conditions. Participants had normal or corrected to normal vision and had no motor/movement limitations. Participants agreed with the experimental procedure and participated voluntarily, with the open opportunity to withdraw from testing at any time. All of the participants were rewarded with small gifts after finishing the test battery. Before the testing, all the participants were told to pay attention to the spatial distribution of objects in the tasks. They were instructed that accuracy in answering was more important than speed, but also that their completion time would be recorded.

All collected data was analyzed with the use of IBM SPSS software. With respect to the distribution of scores, we used nonparametric methods for data analysis, namely, Mann-Whitney U Test for independent samples [47]. For a better illustration of the revealed effects, we displayed results by box-and-whiskers plots (Fig. 5 and Fig. 6). The boxes in these graphs represent the interquartile range and the black lines in boxes represent medians. The two whiskers (upright lines) visualize the data within a 1.5 interquartile range [48]. Furthermore, we visualized the individual representation of the participants' performance in the test by multiple circles (see participants' score in the graph legend).

2.4 Task and Stimuli - Non-interactive Experiment 1

To find out whether there is a general effect of 3D type on visual discrimination in altitude tasks designed in VRECKO, we prepared an experiment with non-interactive stimuli. The non-interactive Experiment 1 was fully computerized; participants answered with a conventional optical mouse. Experiment 1 consisted of 2 test tasks (the first containing 15 and the second 20 items; see Fig. 2). In addition to the two tasks, the testing procedure contained a training task and filler tasks (see Fig. 1). In every task there was a written instruction presented on the screen which preceded the given set of items.

Task 0 — Training

The training task was placed at the beginning of the test battery for the participants to get acquainted with the testing design and control devices. The training task required the participants to explore the presented landscape with geometric bodies randomly placed in it. Afterwards the participants were asked to answer questions using a computer mouse so they could learn how to answer. Participants were choosing correct answers by mouse click out of 6 options.

Task 1

The first task consisted of 15 items - 15 scenes showing 3 cubes of different colours placed onto the terrain models. We used different colours of cubes as convenient method for identification of specific cube. The first 5 scenes were shown for 5 seconds, the next five for 4 seconds and the last 5 were exposed for 3 seconds. Participants were instructed to estimate the order of the cubes according to their altitude. After scene preview an answer screen appeared and participants indicated the order of the cubes by matching the colored squares with appropriate boxes (see Fig. 2). Correct identification of all the three cubes was scored 2 points; one correct answer was scored 1 point and 0 points were given if no answer was correct.

Task 2

The second task comprised 20 items - 20 scenes showing 3 cubes of different colours placed on the terrain (see Fig. 3), but, contrary to Task 1, there was no time limit. The participants were asked to identify the order of the cubes according to their altitude. After being certain of their answer participants ended the scene preview so the answer screen appeared and they indicated the order of the cubes by matching the colours. Participants couldn't go back to the task and change their choice. Identifying the correct position of all the three cubes was scored 2 points; one correct answer was scored 1 point and 0 points were given if no answer was correct. We measured accuracy of answers and also the completion time (time period during which participants explored the scene).

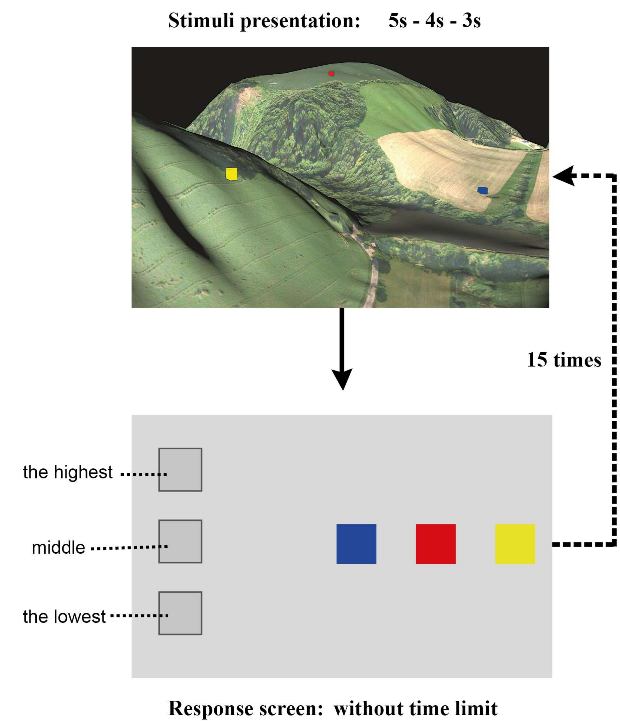

Figure 2: Schema of Task 1, Experiment 1.

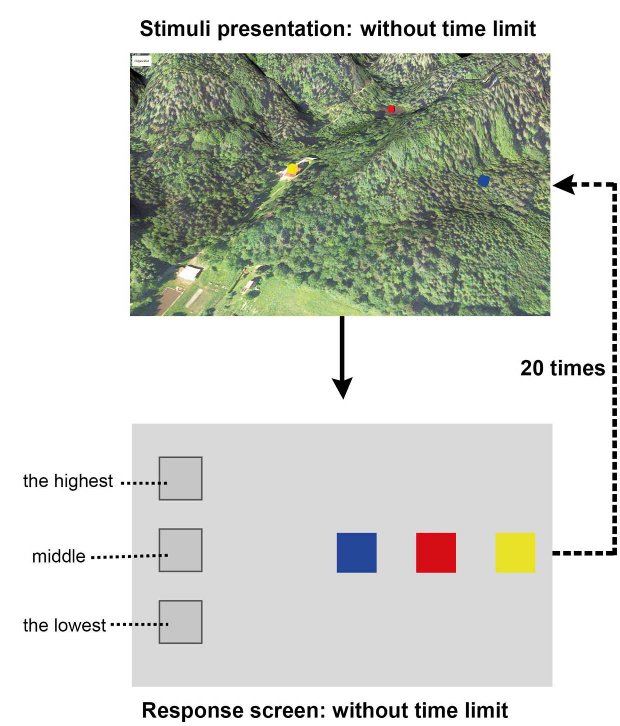

Figure 3: Schema of Task 2, Experiment 1.

2.5 Task and Stimuli – Interactive Experiment 2

Identification of the altitude of objects in a non-interactive display is different from active searching process in an interactive display. In the second experiment, participants were asked to identify the correct altitude order of several geometrical bodies in a scene during interaction with the 3D model. In order to thoroughly explore the information searching process, we made the experimental tasks more complex; the participants needed to interact with 3D visualization of geographical data to obtain more information and to be able to solve the tasks. The test battery consisted of four complex ordering tasks (schema of Experiment 2 is shown in Fig. 1). The number of tasks was limited by the long time needed to solve each of the tasks. There was no time limit imposed, therefore, participants could thoroughly explore the scene to find the correct answer. Each task was preceded by verbal instructions. The answers were during task solving verbally reported by the participant to the experimenter who noted them down for further analysis. Participants were asked to search the scene and once sure about the order, they offered their answers. The participants' motor activity was recorded by the VRECKO software.

The investigated variables included the correctness, completion time, the number of omitted objects and the amount of motor activity participants performed. The motor activity included navigating in interactive 3D visualization through adjusting the position of a virtual camera (the virtual point of view). Changes in the position and orbiting (i.e. rotating of the 3D world around a fixed point in the space) of this virtual camera were recorded at 60 fps (*frames per second*). From these raw data, a file including all motor actions of all the users was created. Data about each motor action include: type of action (dragging, orbiting or zooming with a virtual camera), starting time of the action, duration in milliseconds, total sum of movement of the camera and total sum of camera orbiting. Any change in the virtual camera position was considered, no matter the duration. Four variables were measured: (1) correctness rate; (2) searching activity during task-solving; "motor activity" which was calculated as the sum of all motor actions of a user for a particular task; (3) task-solving times and (4) the number of omitted objects in the scene.

Task 0 — Training

The training task was placed at the beginning of the test procedure to flatten out the possible differences in Wii RC skills between the participants. The participants were instructed about how to control their actions with the Wii RC and then asked to practice control of a training map for 5 minutes.

Task 1

In Task 1 the participants were asked to rank the presented buildings (located near a lake) based on the level of risk of their flooding. The buildings were marked by colours and there were 6 of them. Every correctly identified position was scored 1 point.

Task 2

The second task required the participants to order 7 geometric bodies according to altitude. The participants were asked to rank the geometric bodies from the lowest-placed one to the highest-placed. Every correctly identified position was scored 1 point.

Task 3

In the third task, the visual display contained 4 houses standing near the lake. Three of them were visible at first sight and the fourth was not. Again, the participants had to order them according to altitude. Every correctly identified position was scored 1 point.

Task 4

In the last task, the participants were asked to order the objects in the scene according the altitude, but this time two of the objects were hidden in the terrain – not visible on the first sight. The total number of objects was 6; see Fig 6, bottom right. Every correctly identified position was scored 1 point.

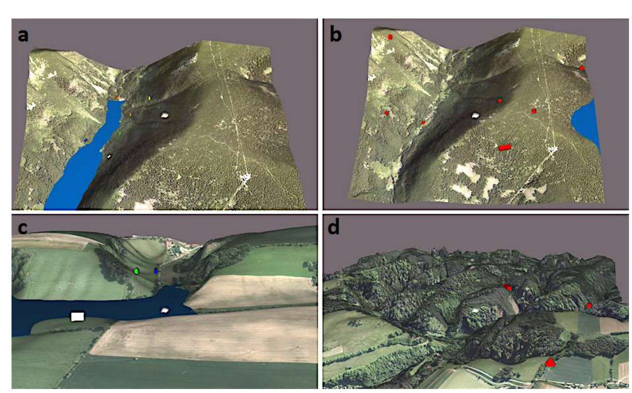

Figure 4: Experiment 2 - Examples of Tasks Initial Views (Task 1 – a; Task 2 — b; Task 3 — c; Task 4 — d)

3 Results

3.1 Experiment 1

The total number of participants was 61 (42W/19M). There were 28 participants in the pseudo 3D condition and 33 in the real 3D. Due to the relatively small number of participants we used non-parametric methods to analyze the data.

Task 1 — Altitude Identification With Time Limit

Accuracy Real 3D users (cumulative score; m = 20.38; med = 21.00; sd = 1.90) were not found to be significantly better than the pseudo 3D group (cumulative score: m = 19.75; med = 20.00; sd = 2.23) at identifying the altitude in the set time limit (U = 525.5, p > 0.05). See the similar cumulative accuracy scores for real and pseudo 3D groups on box-and-whiskers plots (Fig. 5).

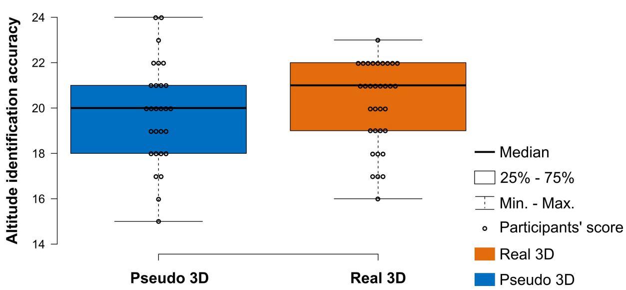

Figure 5: Accuracy in Altitude Identification with Time Limit in Real 3D and Pseudo 3D Groups (cumulative score; max 30 points), Experiment 1, Task 1.

Task 2 — Altitude Identification Without Time Limit

Accuracy Real 3D participants (cumulative score: m = 30.54; med = 31; sd = 3.04) performed significantly better than the pseudo 3D group (cumulative score: m = 27.11, med = 27.5, sd = 3.57) at identifying the altitude without a time limit. The results were found to differ significantly (U = 690.5, p = 0.001). A comparison of both groups with respect to their accuracy is shown in Fig. 6, where real 3D group significantly outperformed pseudo 3D group.

Completion Time There were found no significant differences in total completion times (U = 391; p > 0.05) between the pseudo 3D group (cumulative score: m = 339.96 s; med = 327.97 s; sd = 113.90 s) and the real 3D group (cumulative score: m = 310.86 s; med = 306.05 s; sd = 88.70 s).

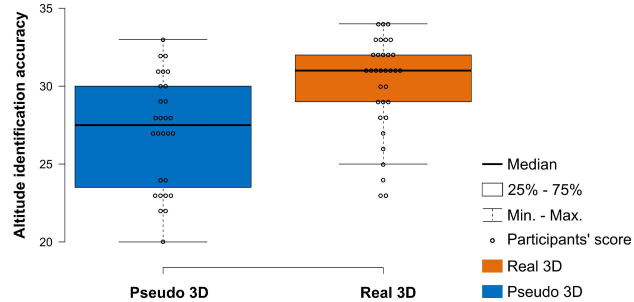

Figure 6: Accuracy in Altitude Identification without Time Limit in Real 3D and Pseudo 3D Groups (cumulative score; max 40 points), Experiment 1, Task 2.

3.2 Experiment 2

Only 56 (37W/19M) of the total number of 61 participants were included in data analysis; 4 participants had to be excluded due to technical reasons (4 participants from the real 3D group got lost in the 3D virtual space, they were not able to finish the task and gave up, so their data had to be excluded from the data analysis); 1 participant withdrew from the experiment. There were 27 participants in the pseudo 3D group and 29 participants in the group working with the real 3D. Due to the relatively small number of participants, non-parametric methods were used to analyze the data.

Tasks 1 – 4

With respect to the interactive tasks 1–4 (flooding, altitude identification, flooding with the hidden house, altitude identification with two hidden objects), no significant differences were found in completion time, accuracy, motor activity or omission rate between the pseudo 3D and real 3D conditions. All the features of interaction with the virtual 3D geographical context were similar for both groups (see Table 1).

Exploratory Analysis

Although there were no statistically significant differences between the real and pseudo 3D groups with respect to omissions, total number of omissions was consistently higher for the real 3D condition (see Fig. 7). The above was true despite the fact that all objects in Task 1 and Task 2 were visible at first sight. The real 3D users were more prone to omit important aspects of the scene. These results are in accordance with a previous study by Špriňarová et al. (2015). In Task 3 we encountered floor effect and no differences were found. However, as seen in Fig. 7, the omission rate was considerably higher among the real 3D

Table 1: The Experiment 2 – Interactive Altitude Identification - Summary of the Results (m = mean; med = median; sd = standard deviation, U = Mann-Whitney U test value; p = level of significance).

		Task 1		Task 2		Task 3		Task 4	
		Pseudo 3D	Real 3D	Pseudo 3D	Real 3D	Pseudo 3D	Real 3D	Pseudo 3D	Real 3D
Response time (s)	m	70.00	72.24	135.22	102.38	91.44	93.31	171.85	153.59
	med	68	60	92	95	78	81	142	150
	sd	35.28	38.62	92.97	52.03	52.83	46.97	102.26	79.86
	U	393.5		477.5		408.0		464.0	
	p	0.974		0.471		0.787		0.652	
Accuracy	m	4.33	3.83	3.48	3.76	2.63	2.69	3.85	3.93
	med	6	4	3	4	2	2	4	4
	sd	1.96	1.67	1.19	1.75	1.47	1.29	1.88	1.41
	U	323.0		430.5		396.0		400.5	
	p	0.242		0.507		0.937		0.879	
Error Rate	m	0.04	0.07	0.07	0.14	0.00	0.00	0.26	0.52
	med	0	0	0	0	0	0	0	0
	sd	0.190	0.258	0.267	0.351	0.000	0.000	0.526	0.790
	U	404.0		416.5		391.5		449.5	
	p	0.599		0.444		1.000		0.230	
Motor Activity	m	227.44	251.86	346.41	231.48	349.56	453.38	497.48	292.17
	med	139	248	220	119	200	279	263	201
	sd	256.34	180.26	391.69	250.15	365.11	515.043	567.94	264.32
	U	454		331		450.5		313	
	p	0.305		0.321		0.333		0.198	

group. Although the differences in the omission rate between Tasks 1, 2 and 4 were not statistically significant, the propensity of the real 3D participants to ignore some aspects presented in the scene remains an issue for further research as it could be considered from the human factors point of view [49].

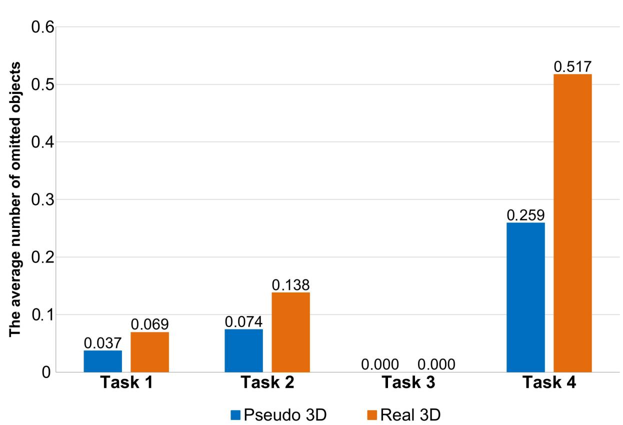

Figure 7: Average Number of Objects Omitted by Real 3D and Pseudo 3D Users in Tasks 1- 4, Experiment 2.

The increase in total motor activity invested into searching among the pseudo 3D group (Task 4, see Fig. 8) might have been surprise-related; during the testing, we observed that more participants in the pseudo 3D condition noticed during manipulation with the 3D visualization that there were hidden objects in the scene and were not noticed at first sight. The pseudo 3D participants were surprised that the scene contained more objects than what was initially at first sight and they searched for other possibly hidden objects, just to be sure. An analytical search process (i.e. the systematic sequential searching) was activated by non-standard situation while the real 3D participants contented themselves with the first available answer.

In order to gain a better insight into participants' motor interaction with the UI, we analyzed the interaction with respect to the three specific types of action performed in the virtual interface (dragging, orbiting, and zooming), see Fig. 9. There is almost identical movement pattern for both groups of participants in training task (Task 0), which was preceded by exact instructions. For the testing period, however, the strategies of the real 3D and the pseudo 3D groups differed, although in general the patterns of actions in both conditions were similar. Although more research is

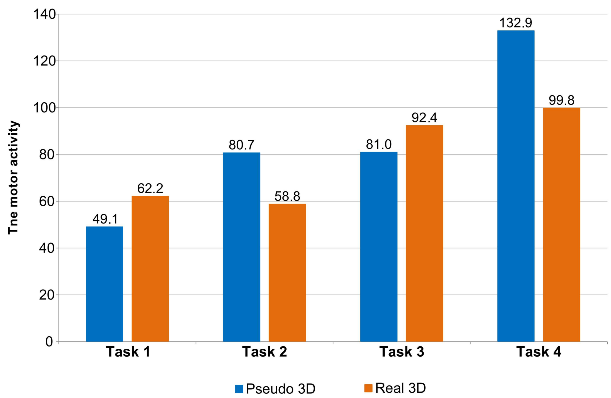

Figure 8: Total Motor Activity of Real 3D and Pseudo 3D Users in Tasks 1–4, Experiment 2.

needed on motor interaction with interactive geovisualizations, in this study we found no relation between specific type of 3D visualization and general pattern of navigating motor activity (see in Fig. 9).

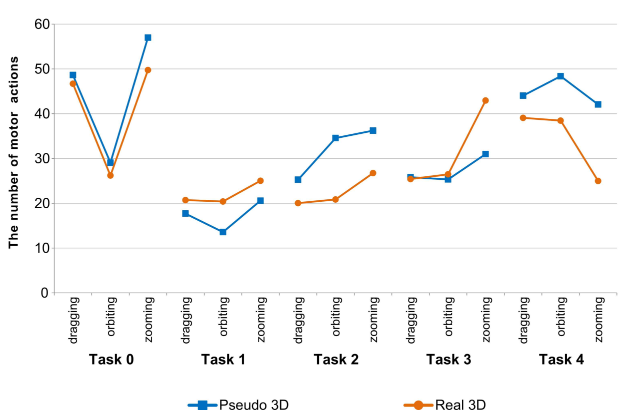

Figure 9: Detailed Analysis of Motor Activity of Real 3D and Pseudo 3D Users in Tasks 1–4, Experiment 2.

4 Discussion

Based on results of the data analysis, we found strong evidence that real 3D condition enriched with stereoscopic binocular depth cues resulted in better spatial identification in non-interactive (i.e. static) 3D geographical visualizations (Experiment 1). The importance of binocular disparity in visual perception was emphasized e.g. by Landy et al. [23] and Qian [22]. The above effect was present in altitude-identification in non-interactive tasks without time limit, where the real 3D participants significantly outperformed the pseudo 3D group. We can assume that in Task 1 the above mentioned effect was cut off by the effect of time pressure. The completion times in Task 2 were found to be the same for both conditions. This evidence opposes the previous suggestion about the operator's general tendency to spend more time evaluating the spatial features of pseudo 3D visualizations [19]. The suggestion was based on Crampton's claim [39] that two-dimensional content must be mentally transformed into a three-dimensional form and thus is bound to require more mental operations. We can summarize that our expectation about better identification of heights in the scene due to binocular disparity included in real 3D visualization was verified. We assume that this effect occurred due to the presence of binocular depth cues in real 3D visualization tasks. In real 3D geovisualizations were more visual cues available for participants to help them with the detection of altitude data. Binocular disparity can thus be viewed as enhancing the perception of vertical distribution of objects in static geovisualizations.

In interactive 3D geovisualizations as we used them in Experiment 2, the missing binocular cue in the pseudo 3D condition was expected to be compensated by the interaction with 3D geovisualization. According to the results, the interactive nature of the scene can offer enough compensation for the missing binocular depth cue thanks to the kinetic depth effect [37] provided by manipulation the visual display, as earlier discussed by Bingham and Lind [50] or Rogers and Graham [51]. A pseudo 3D user who interacts with dynamic geovisualization can reach the same information about the spatial distribution of the scene as the real 3D user, but with the use of different visual cues. However, due to differences in number and quality of visual cues included in these alternative ways of 3D visualization, the real 3D group and the pseudo 3D group were expected to differ in the way participants handled the geovisualizations to reach the correct solution (e.g. time responses or motor activity performed when navigating the scene). In this matter our results showed no differences between the two groups. The comparable amount of motor activity performed by the participants from both groups can be explained by the concept of affordance [52], which is an intrinsic property of an interactive 3D visualization; thus, navigating of the visual display occurred spontaneously in both conditions and the tasks were solved with approximately the same amount of motor activity, because participants navigated (moved) the 3D visualizations spontaneously in both conditions.

The increased tendency to omit target objects in the relatively simple tasks, which was observed in real 3D group (Experiment 2), should be mentioned. As participants were asked to order bodies in the interactive 3D visualizations according to their altitude (Experiment 2), the real 3D users persistently omitted (didn't notice) some of those bodies, although without statistical significance (tasks 1, 2 and 4). Such omissions speak for computational non-equivalency as discussed by Larkin and Simon [24] and can be explained from more than one point of view. The influence of such phenomena as fidelity of the display [53], immersion and presence as the "feeling of being in VR" [54], which could affect the choice of visual cues [36] included in the scene, should be considered in further research.

Since various types of geovisualizations are frequently used in many applied areas, general tendency to omit some of the important aspects of the scene in real 3D interactive tasks should be highlight of this study, especially with regards to the applied field. Omission observed in real 3D condition could be in general classified as human error [47]. To reveal this effect in interactive 3D geovisualizations, we chose a group of inexperienced participants without any geoscientific knowledge. Regarding this, the demonstrated effect can be related to the non-expert population, which is increasingly aspiring on using various geoscientific products. The mentioned findings are particularly relevant for such geoscientific areas, where there are 3D data presented to users who have only partial geoscientific knowledge (teaching geography and other geosciences [6, 55], virtual tourism [12, 29] or urban, landscape and architectonic plans for the public [4, 11]).

Taking into account the presented results, the specific nature of virtual 3D scene which was created with the use of DTM and corresponding orthophoto should be kept in mind. Deeper insight into how can be human performance influenced by particular UI setting in cartographic tasks was discussed by Lokka and Coltekin [56]. Our results would refer specifically to altitude identification tasks in analogical interactive geovisualizations with particular focus on human perception issues. Although interactive 3D geovisualizations were previously explored by Wilkening and Fabrikant [9] or Bleisch, Dykes and Nebiker [26], in the majority of studies on this topic were used only static stimuli [7, 15, 17, 29, 30]. In our study, we present a comparison of different types of 3D geovisualizations in non-interactive and interactive tasks. Such a comparison brought clear evidence, that the use of stereoscopic 3D technologies does not necessarily provide exclusively advantages when working with 3D geovisualizations. Exactly opposite, it can cause decreased awareness about the geographical content resulting in human errors.

Our study is unique especially with respect to the analysis of motor activity which reveals new perspectives on phenomena occurring in interactive 3D geovisualizations. Also, it suggests direct implications for practical use of interactive 3D geovisualizations in non-expert populations such as redundancy of real 3D geovisualizations in interactive virtual environments. The above mentioned issues are a challenge for further visualization tools and GIS software optimization. Their importance should be reflected also within upcoming research in related areas.

5 Conclusion

In this study, we explored the influence of real (stereoscopic) 3D and pseudo (monoscopic) 3D visualization on the human ability to identify altitude information in non-interactive and interactive virtual 3D geovisualizations. We designed a two phased experiment to compare the performance of two groups of participants, one of them using the real 3D and the other one pseudo 3D visualization of similar geographical data (DTM covered by orthophoto). The interface consisted of a Motion Capture system, Wii Remote Controller, widescreen projection, and the passive Dolby 3D technology (for real 3D vision). The first phase of the experiment was designed as non-interactive; the second phase was designed as interactive. We measured and analyzed participants' accuracy at altitude identification of the objects placed in virtual geovisualization, time responses, and amount of the participants' motor activity during interaction with 3D geovisualizations. Results suggested that the real 3D technology can enhance the ability to detect the altitude dimension in static 3D geovisualizations. However, as expected, differences between groups in altitude identification were flattened in the interactive phase due to the possibility of interaction with geovisualizations. No other statistically significant differences in response times or motor activity were found. Further analysis of the results shown that there was increased tendency to omit task-related objects in interactive real 3D geovisualizations. These findings can negatively influence the spread of the real 3D geovisualizations into various fields of human activities.

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