Can a Physical 3 Dimensional Display Improve the Understanding of Topographic Maps for People with Low Spatial Ability?

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Abstract

With the recent developments of shape changing materials, possibilities arise to create a physical three dimensional representation of a topographic map. Our study investigates the differences in the understanding of a 2D and 3D view of a terrain compared with a physical representation of the same terrain. Furthermore, we correlate our findings with the spatial ability score, derived from a spatial visualization test executed by each participant. We have conducted an experiment to test the participant's understanding of terrains on different displays (2D, 3D and physical 3D). Although we did not find a significant increase for the low spatial ability group, we found a significant ($p=.013$) decrease for people with high spatial ability when using a physical 3D display compared to a 3D display. The Expertise Reversal Effect is suspected to be a key attribute for this.

Keywords: topographic map, relief map, physical three dimensional display, 2d, 3d, spatial ability, spatial visualization, 3D terrain models, terrain visualization, digital terrain model, Expertise Reversal Effect, Naïve Realism

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Topographic maps are highly detailed maps that shows both natural and man-made features. These maps are a valuable tool for hikers and campers. You can plan an entire trip with the help of a topographic map, and greatly decrease the chance of unpleasant surprises. These topographic maps contain contour lines, lines on the map that represent elevation. These lines explain the details about an area's elevation and by correctly reading the map, you can find the best way to ascend a peak or how to orient yourself using landmarks. For example, governments and military organizations use topographic maps to react to disasters, landscape design and plan military operations (Francica, 2004).

With contour lines it is also possible to create a raised relief map, a three dimensional representation of the area. The elevation of the terrain is physically represented facilitating the visual recognition of terrain features. Raised relief maps are a great visual and practical aid for gaining a better understanding of any geographical area. The digital equivalent of the raised relief map is a digital terrain model. The digital terrain model represents a surface without any objects like plants and buildings.

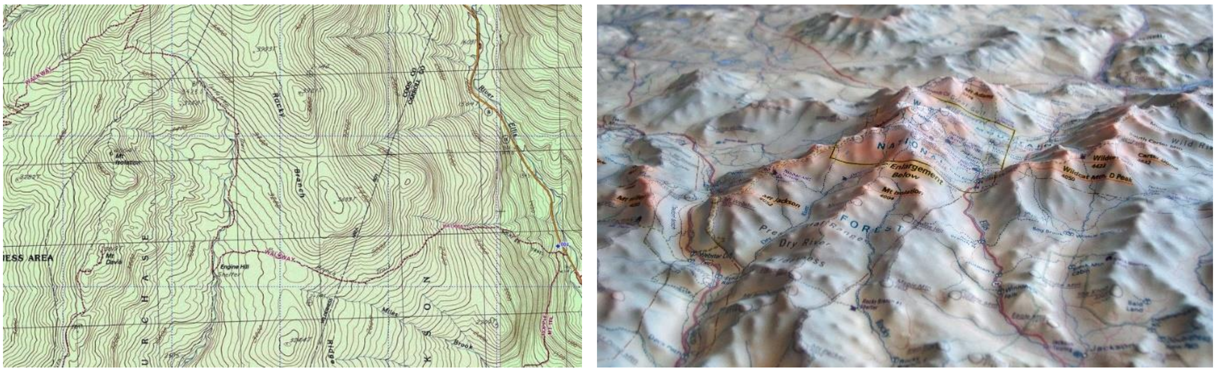

Figure 1. Left: Topographic map with contour lines. Right: Raised relief map.

With the availability of shape changing materials, new possibilities are rising, specifically to create a combination of the physical aspect of the raised relief map and the digital aspect of the digital terrain model producing a physical three dimensional version of a topographical map that can change shape (Coelho and Zigelbaum, 2010; Golla, Ginjupalli and Dave, 2014). With our research we investigate if it helps people understand a terrain's relief better than using a physical representation of an area. We expect to find a correlation between a person's spatial ability and the performance on different displays (2D, 3D and physical 3D). We hypothesize that the higher the spatial ability of a person is, the lower the difference in depth perception between different displays is.

Throughout our research a distinction is made between "view", "display", "2D", "3D" and "physical 3D". A view in our research is defined as a single projection of a two- or three-dimensional object or terrain. A 2D view shows one plane of a scene, for example a top or side view (Figure 2, a). A 3D view shows a perspective view of a scene with spatial structure (Figure 2, b). In our research the display describes the way a view is presented. A 2D display shows a single 2D or 3D view as a flat image, in this case a 3D view with perspective (Figure 2, c). A 3D display presents two slightly different images to the eyes of the viewer so that depth is perceived (Figure 2, d). A physical 3D display (P3D) consists of a tangible surface, sometimes it combines this surface with a visualization of images (for example a projection of spatial or geographical data) (Figure 2, e).

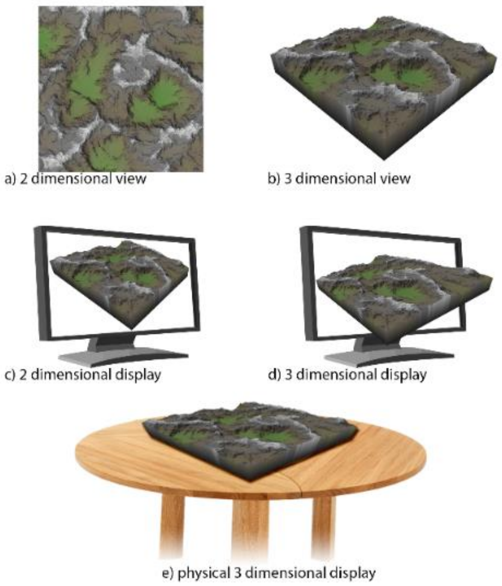

Figure 2. a) 2D view, b) 3D view, c) 3D view on 2D display, d) 3D view on 3D display and e) 3D view on physical 3D display.

Theoretical Background

John, Cowen, Smallman, and Oonk (2001) make a distinction between specific tasks and when to use 2D or 3D views. They say that for understanding shape and natural terrain a 3D view from a 45° angle is better than a 2D view. The views experimented with were a 3D rendered terrain from a 45° angle (Figure 3 left), a 3D rendered terrain from a 90° angle (Figure 3 middle) and a 2D topographic top view (Figure 3 right).

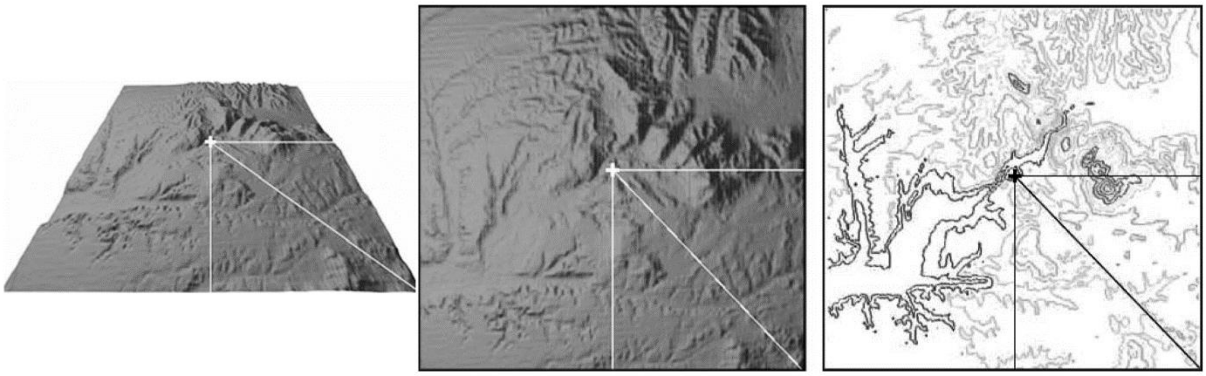

Figure 3. Views used in the experiments by John et al. (2001). Left: 3D 45°. Center: 3D 90°. Right: 2D topographic.

Hollands, Ivanovic, and Enomoto (2003) confirmed the findings of John et al. (2001). In both experiments two points on the terrain were marked with labels A and B. The participants were asked if the elevation of A was higher than that of B (A-High-B) or not. In another experiment participants were asked to determine if they would be able to see point B, were they standing at point A (A-See-B).

In the experiments by John et al. (2001) the proportion of correct scores did not differ between 3D from a 45° angle and 3D from a 90° angle. However, the A-See-B task was performed better on the 3D views compared to the 2D topographic view. The A-High-B task showed better results for the 2D topographic view. Results by Hollands et al. (2003) replicated the results from John et al. (2001), showing a 2D advantage for the A-High-B task, but a 3D advantage for the A-See-B task. However, for both findings one could argue that the 2D advantage for the A-High-B task could be because the elevation was explicitly color coded using contour lines. For the topographic view, participants could easily find the correct answer in an analytical way, they only needed to find the color of the nearest contour line at both points and analyze the line between them.

Savage, Wiebe, and Devine (2004) did not find a difference in accuracy and time between 2D and 3D views while using similar tasks, in contrast to John et al. (2001) and Hollands et al. (2003). The views Savage et al. (2004) used in their research were a 2D topographic view (Figure 4 left) and a 3D representation of this 2D view (Figure 4 right). In this research Savage et al. (2004) were interested if adding the 3D shape to a 2D topographic map was enough to have the advantages of a 3D view as described by John et al. (2001) and Hollands et al. (2003).

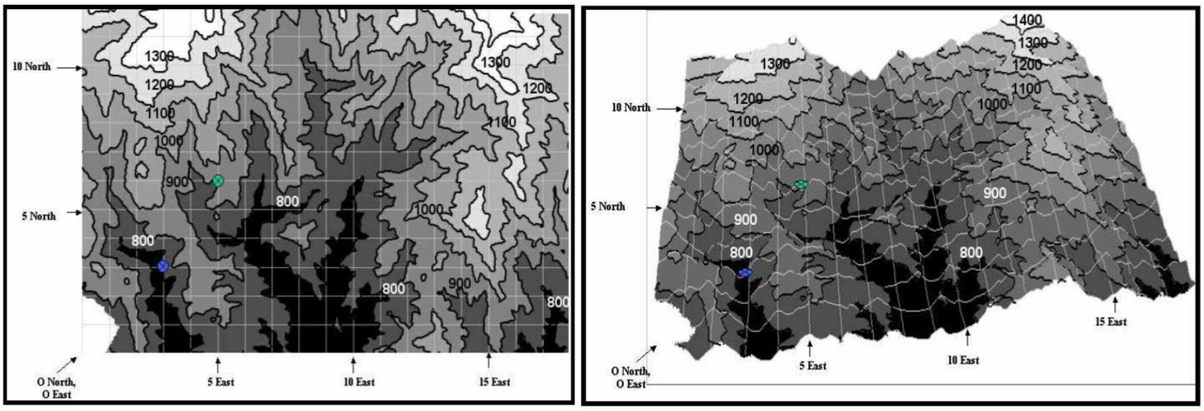

Figure 4. Views used in the experiments by Savage, Wiebe and Devine (2004). Left: 2D topographic. Right: 3D topographic.

Tory, Moller, Atkins, and Kirkpatrick (2004) compared a 2D/3D combination display to displays with only 2D and 3D views (Figure 5). They concluded that 3D displays (but only with appropriate depth cues) are effective for approximate navigation and relative positioning whereas 2D/3D combination displays are useful for precise orientation and position tasks.

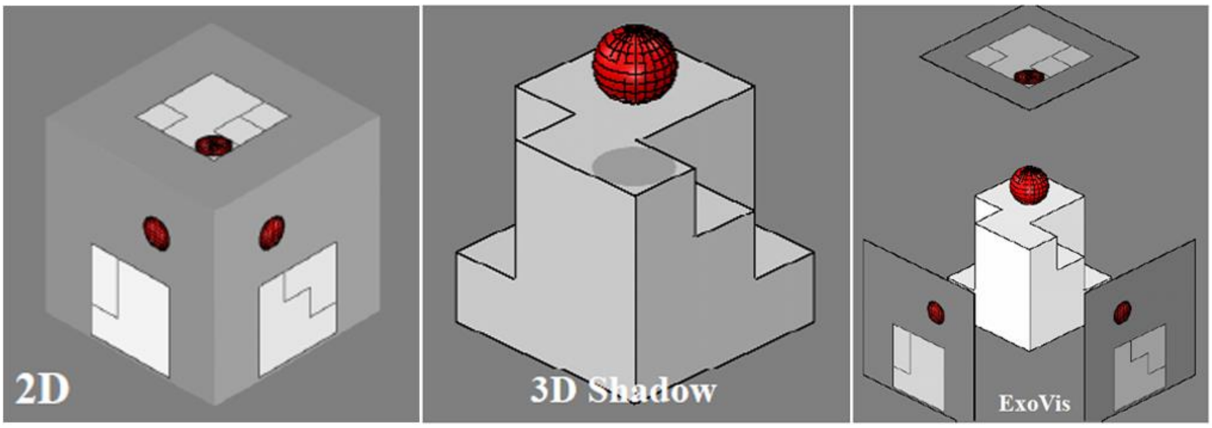

Figure 5. Views used in the experiments by Tory, Moller, Atkins, and Kirkpatrick (2004). Left: 2D. Center: 3D with depth cue. Right: 2D/3D combination.

Research by Cook, Smallman, Lacson, and Manes (2010) focused on replanning routes for an unmanned aerial vehicle over flat and mountainous terrain using 2D or 3D views. The 2D view performed better than the 3D view, Cook et al. (2010) explain that this could be because of the task being focused on the relative position rather than on understanding the shape of the terrain. Other reasons for the 3D view to perform worse could be found in the shortcomings of the 3D view, also described by John et al. (2001);

1. Projective ambiguity; Without other depth cues available in the 3D view, the location of objects is ambiguous along lines of sight into the viewing plane.

2. Distortion of distances and angles.

3. Foreshortening; The projection of objects tilted toward the line of sight in a 2D view is compressed.

When 3D knowledge is needed, the Proximity Compatibility Principle (PCP) suggests using a 3D view (Wickens, Merwin, & Lin, 1994). When specific information is needed on one of the dimensions, a 2D view should be used. 3D views can be most effective for tasks where 3D knowledge is required like shape and terrain understanding. When depth cues, such as shadows, are applied 3D views can be most effective when doing rough navigation and positioning tasks. A combination of 2 and 3 dimensional views is most effective for precise navigation and positioning tasks; people seem to need both an exocentric and egocentric view together giving a more realistic view of a terrain (Tory et al., 2004; Hollands & Lamb, 2011).

Depth is better perceived when using a 3D display to show a 3D view (Martins and Ventura, 2009; Slater, Linakis, Usoh, Kooper, & Street, 1996). Martins and Ventura (2009) used an experiment to evaluate the participant’s depth perception. Participants were shown a robot’s point of view on a 2D user interface and on a 3D head mounted display (HMD). In this view a set of objects was visible (Figure 6), the participants had to determine the relative distance between the objects. The participants had to draw a top view of the scenario using both the 2D interface and the HMD. Results showed participants performing much better when shown the robot's perspective in 3D using a head mounted display compared to an interface on a 2D display (Martins & Ventura, 2009). Tasks that required shape and terrain understanding were also performed better with a 3D display compared with a 2D display (Slater et al., 1996). In their experiment, participants were asked to reproduce a sequence of moves in a real game of chess, based on their observations from a virtual environment. The virtual environment was either screen based (exocentric) or on a head mounted display (egocentric) and was plain or realistic. Participants performed better when using the egocentric view in comparison to the head mounted display whereas the combination egocentric with the realistic environment yielded even better results.

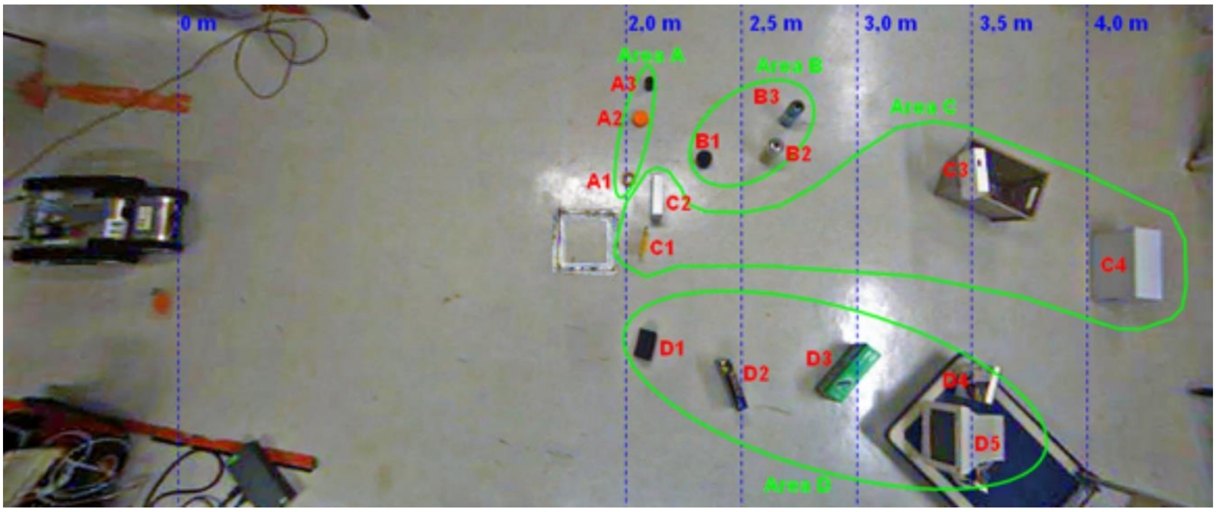

Figure 6. Top view of the experiment by Martins and Ventura (2009).

Relief by Leithinger, Lakatos, DeVincenzi, Blackshaw, and Ishii (2011) is an example of a P3D shape display. The table consists of 120 pins which can be actuated up and down individually. *Relief* has a geospatial application, best described as a tangible and interactive

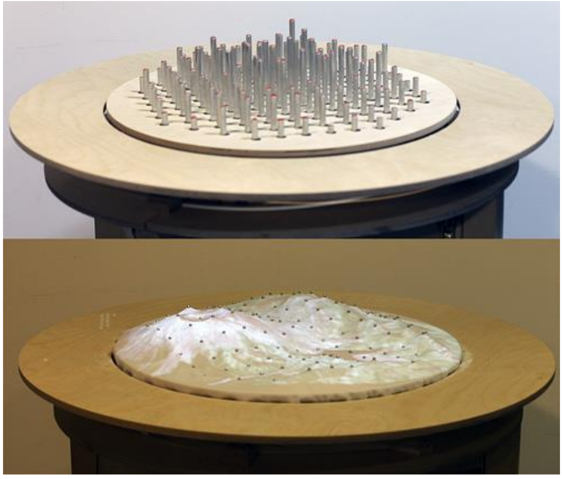

Figure 7. Relief is an example of an actuated tabletop display.

Google Maps (Figure 7). Apart from geospatial data, *Relief* can also show a physical shape from a 3D file. No formal experiments have been done but from the 300 users, many found it easier to understand the shape of a model when shown on this P3D display compared to a 2D display (Leithinger et al., 2011).

Research shows that spatial ability is an important factor in the understanding of 3D visualizations (Keehner, Montello, Hegarty, & Cohen, 2004). Spatial and other visual perceptual abilities have to do with someone's ability to create a mental representation of objects, shapes and locations in the environment they visually perceive. This ability also includes the manipulating of those representations mentally (Carroll, 1993). The two most important factors of spatial ability as identified by Carroll (1993) are spatial visualization and spatial relations. Where spatial visualization involves the ability to mentally transform (manipulate or twist for example) an object. Spatial visualization tasks often involve a series of mental manipulations to the object. Spatial relations also require mentally transforming an object, but generally the required mental manipulations (rotations) for spatial relation tasks are much easier. One example of a test for spatial relations is the card rotation test (Figure 8); the participant has to decide which cards are the same as a reference card. The cards that are the same are a rotated

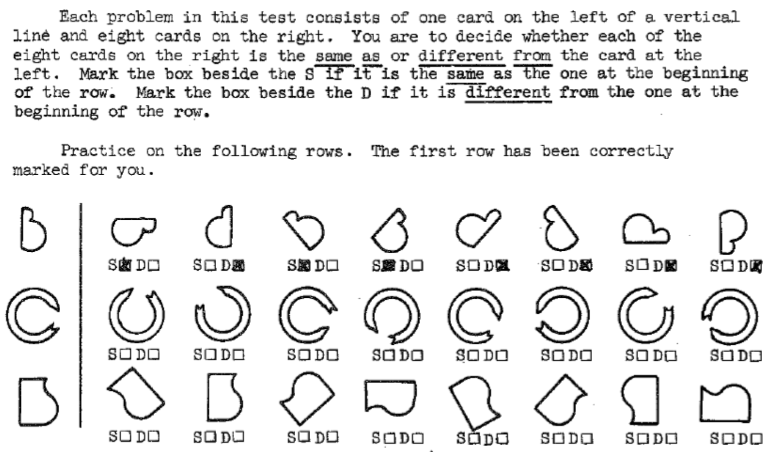

Figure 8. Card Rotation Test from: Ekstrom, French, Harman and Dermen (1976).

version of the reference card, the other cards are mirrored versions.

The way spatial visualization is measured is similar in most studies, they use (variances of) the paper folding test by Ekstrom, French, Harman, & Dermen (1976) or (variances of) the Vandenberg Mental Rotation Test (MRT) of spatial ability (Cook, 2010; Höffler, 2010; Shepard & Metzler, 1971). In the paper folding test, a piece of paper is folded and all steps are shown. After folding the paper, a hole is made in the paper. The participant is shown five different unfolded pieces of paper, each with different amounts and locations of holes. The participant has to decide which of those pieces of paper is the right one. In the mental rotation test, participants are presented two images of an object, but rotated or from a different angle, and asked if they are the same object (Cook, 2010; Shepard & Metzler, 1971). Harris, Hirsh-Pasek and Newcombe (2013) found that the two tests differ in two important ways. Mental rotation is a geometrically rigid transformation and although the objects are three dimensional, the test might assess spatial relations instead of visualizations. Also, the mental rotation test results show gender differences, in favor of males. Mental folding is a non-rigid transformation and its results do not show gender differences (Harris et al., 2013).

The specific role of spatial ability when dealing with 3D visualizations is unclear. Some research indicates that people with a high spatial ability find 3D visualizations more helpful than people with a lower spatial ability (Höffler, 2010). In a meta-analysis Höffler (2010) reviewed 19 studies focusing on the role of spatial ability when learning with visualization aids. Höffler (2010) concluded that people with a high spatial ability learn better when provided with static images that give them the opportunity to create their own mental model of the object. Hegarty and Kriz (2008) suggest that an external visualization such as an animation can act as a “cognitive prosthetic” for people with a low spatial ability. However, in another study Hegarty (2005) hypothesizes that people with a high spatial ability profit from dynamic visualizations when learning, while people with a low spatial ability do not.

Hypotheses

Our research starts with checking both Martins and Ventura (2009) and Slater et al. (2009) who say when showing a 3D view depth is better perceived when using a 3D display. When the understanding of a shape and terrain is required, a 3D display performs better than a 2D display. Leithinger et al. (2011) describes that users find it easier to understand a 3D model on a physical 3D display compared to a 2D display. This can be explained by research in spatial ability (Höffler, 2010), indicating that depth cues provided by a 3D visualization can help people to better understand the visualized by making it easier to construct a 3D mental model. Tangible 3D terrain models are most intuitive and interpretable for most people (Mitasova, Mitas, Ratti, Ishii, Alonso & Harmon, 2006). Research by Hollands et al. (2003) John et al. (2001), Tory et al. (2004) and Wickens et al. (1994) shows a 3D view is most effective for understanding shape and natural terrain when doing rough navigation and positioning tasks. Höffler (2010), Leithinger et al. (2011) and Mitasova (2006) already showed that people prefer a tangible 3D model over a 3D visualization or 2D model. In our research we will check if there is an advantage of using a 3D view over a 2D view. Because of the suggestions in the research above, we expect to find that a 3D view on a 3D display will yield even better results. In our opinion it makes sense humans are more capable of seeing depth in physical models in comparison to (virtual) images (on a screen); the human eyes and brain are built to conceive depth from the physical world around us.

Hypothesis 1 Terrain understanding and navigation tasks are performed with a lower error rate on a 3D display compared to a 2D display. Also these tasks are performed with a lower error rate on a physical 3D display compared to a 3D display.

Our research will test if depth perception on the different displays (2D, 3D and physical 3D display) is correlated to spatial ability. In our research we expect a correlation between spatial ability and how well participants perform the tasks on the different displays.

The higher the spatial ability of the participant, the lower the difference in depth perception between the displays is expected to be and vice versa. Because of the natural image of the physical 3D display, participants are expected to be more efficient using the physical 3D display when comparing to the 2D and 3D display. It is expected that the participants will need more time to complete the task when movement is permitted.

Hypothesis 2 For participants with a low spatial ability, a larger increase in performance between a 3D display and a physical 3D display is expected than for those with a high spatial ability.

Method

In our experiments a comparison was made between a 2D display, a 3D display and a P3D display. Participants were asked to perform a number of tasks in different experiments. The stimuli were presented on a physical 3D display and the view was always 3D. Three conditions were tested (Table 1);

1) Stationary stereo blindness; in which participants could only use one eye, head movement was prevented, and from a fixed distance from the stimuli. The participant saw the stimuli through one eye, this condition is comparable with looking at a 2D display.

2) Stereopsis stationary; in which the participants used two eyes but head movement was prevented as in condition 1. This condition is comparable with looking at a 3D display.

3) Stereopsis active; in which participants used both eyes and could move around the stimulus. This condition is comparable with looking at a physical 3D display.

Table 1

Conditions used.

Condition	Vision	State
1	Monocular	Stationary
2	Binocular	Stationary
3	Binocular	Active

This way there were three conditions available to look at the exact same stimuli, in contrast to using different stimuli and displays for 2D and 3D. Research by Martins and Ventura (2009) and Slater et al. (1996) compared a 2D display with a 3D representation but used different displays for the both conditions. Our research used the same display for all tasks and conditions, for instance technical differences (for example resolution) between displays did not interfere with the results.

The viewing angle for the first and second condition was 45° above the horizontal plane and the correct answer was always perceivable, other researchers used similar angles. For example, John et al. (2001) makes sure all prominent features are visible and uses an angle of 30°. The viewing angle used by Tory et al. (2004) was between 12° and 55°, because of the free movement in the experiment. Hollands et al. (2003) and Hollands and Lamb (2011) used a 45° angle in experiments and Savage et al. (2004) made sure the angle would always allow the answer to be visible.

To make sure unintentional head movement did not affect the experiment, participants in conditions 1 and 2 were asked to look through a viewing window. By using a viewing window all participants looked the same way at the object and head movement did not result in 3D perception by motion parallax (relative motion of the object against another). In the third condition the participants could move their head and body freely.

Experiment

The experiment is based on experiments by John et al. (2001) where participants were asked to perform terrain understanding and navigation tasks. In our experiment, participants were presented with a terrain layout. This terrain was created with cement; per terrain a digital model was created on which the terrain is based (Figure 9) (Appendix B). This digital model was generated in World Machine (Version 2.3.7; Schmitt, 2014), a tool for the creation of 3D terrain with a realistic geological effect.

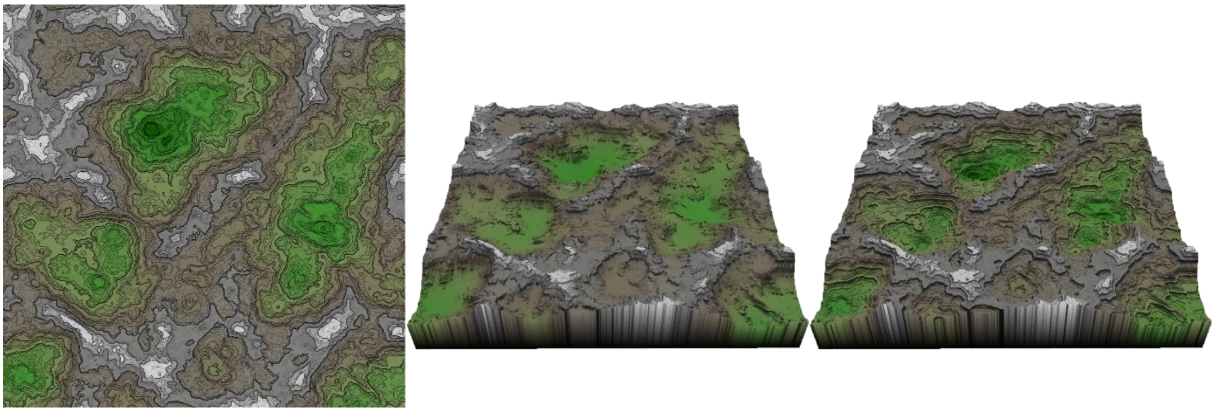

Figure 9. Images used as source for one physical 3D model, all source images in Appendix B.

The terrain generated is unique, there was no chance participants would be familiar with the terrain. The digital terrain was created with parameters to be similar to the terrains used by John et al. (2001) and real mountain terrain on earth. The “real” dimensions of each stimulus are 20 km x 20 km with a scale of 1:25 000 (one of the most commonly used map scales for bushwalking and in-car navigation). Hence, the measurements of the stimulus are 80 cm x 80 cm. The height of the models is at maximum around 15 cm which translates to 3800 meters in “real” dimensions. A negative of the digital model was dug in soil, the soil was covered in silver sand and a layer of cement was poured. Polyurethane foam and polystyrene was added to support the cement and kept the weight of the model relatively low. The model was than dug out and cleaned. The digital terrain models had color differences that indicated height, the physical models were not colored and had an almost plain sand color.

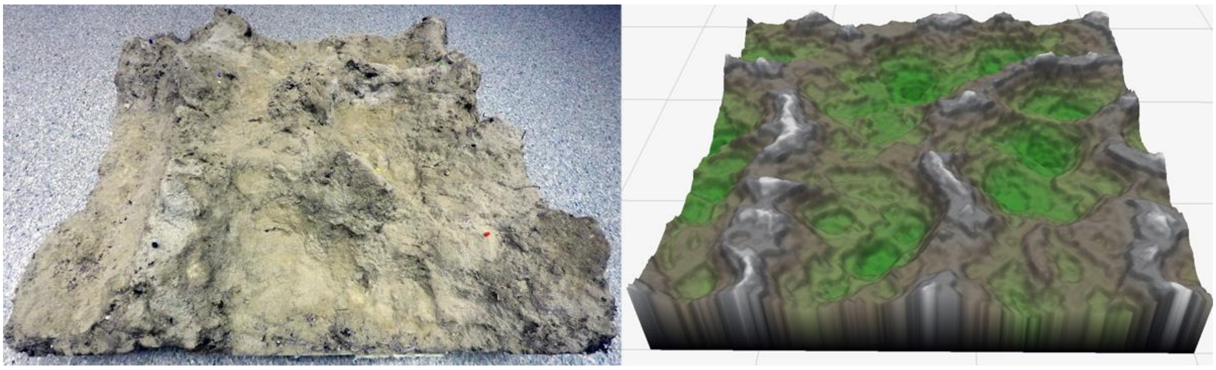

Figure 10. Left; The physical terrain model of the digital model that is showed on the right.

Two points on the terrain were marked with labels A and B. The participants were asked for 10 different stimuli to determine if they would be able to see point B, were they standing at point A (A-See-B). The A and B points were randomly selected for each stimulus, but with some constraints (Figure 11):

- A raster of 11x11 was laid over the stimuli (but not visible for participants), points could not be on the same row or column.
- The middle column, outer columns and outer rows were not used.
- There were always at least two squares between the two points.

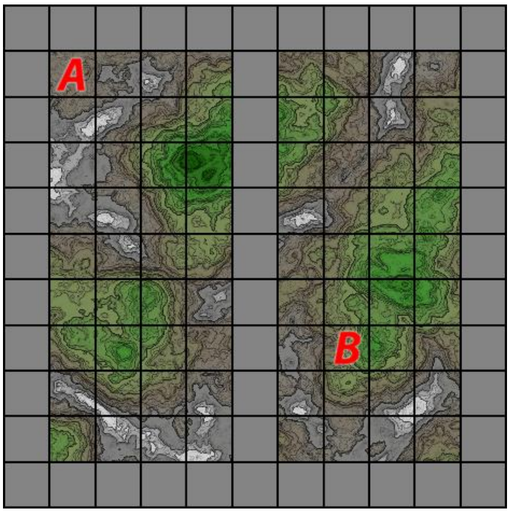

Figure 11. The raster overlay, grey area is not used.

For the A-See-B task, in half of the pairs point B could be seen from point A (Hollands and Lamb, 2011). The terrain models were evenly lid to eliminate shadows. The participants in condition 1 and 2 were positioned 1.1 meter away from the terrain model, participants in condition 3 started on the same location as in the other conditions but were asked to approach the terrain model and take whatever distance, angle and height they preferred to answer the question.

All participants would perform the tasks for all three conditions, in random order. Participants could answer *yes* or *no* for the tasks. For both tasks the responses and response times were recorded. There was one block of practice trials with a unique terrain model. After each exercise the participants were asked how confident they were on their answer.

We expected to confirm that condition 2 performed better than condition 1. Participants were expected to perform best when using condition 3, while needing more time to complete the tasks. For participants with a low spatial ability, a larger increase in performance between conditions 2 and 3 was expected than for those with a high spatial ability.

Procedure

The participants were recruited at the Leiden Institute of Advanced Computer Science. Before the experiments began, the participants signed an informed consent and did a binocular vision screening. Between 2.5% and 13% of the US population, have an anomaly of the binocular vision system. This number has been confirmed by an optometrist to be similar in the Netherlands. Our experiment depended heavily on the ability of the participants to use binocular vision to perceive depth (Heron and Lages, 2012). Using the binocular vision screening, data from participants that lacked this ability was rejected from the experiment when analyzing the results. For our experiment, of the thirty-five participants, five participants were removed from the dataset because they failed the stereovision screening.

Participants were seated and asked to do a small visual acuity test. After this the participant was provided with polarized glasses to conduct the binocular vision test. The Randot Stereo Test is aimed for adult stereo testing (Heron and Lages, 2012). Participants were shown the Randot Stereo Test booklet and asked, for eight areas, if it had a form in it or not (Appendix C). If after one minute no answer was given the next exercise was explained. The participant was pointed to ten rows of three circles. The participant was asked for each row, which one of the three circles seemed to float forward or appear different from the others; left, middle or right. Answers were recorded on the answer sheet (Appendix D).

To test the spatial ability, participants were asked to complete the paper folding test (PFT) by Ekstrom et al. (1976). The PFT was needed to score the spatial ability of the participants and gave the opportunity to draw conclusions whether spatial ability is linked to effectiveness of the participant on one of the conditions (Appendix A). In the PFT a piece of paper is folded and all steps are shown. After folding the paper, a hole is made in the paper.

The participant was shown five different unfolded pieces of paper, each with different patterns of holes. For twenty scenarios the participant had to indicate which of those pieces of paper was the right one. The participant had three minutes to complete the first ten exercises, after which he had to wait before continuing to the next ten. If the participant did not finish the first ten in the given time, he had to stop and continue to the next ten for which the participant also has three minutes. In total the test took less than 5 minutes and the outcome was a score, depending on the amount of correct answers, between 0 and 20.

The participant then continued the experiment and was asked to take a seat in front of the first terrain model. For every terrain model the participant was asked if point A was visible from point B, would the participant be standing on point A. This question was asked three times per terrain model, for each condition once. The order of the conditions was randomly selected, the points A and B were two of six randomly selected colored fusible beads. Hence the question to the participant could be for example;

"Answer the question as fast and correct possible with yes or no. Please look through the viewing hole (with one eye / with two eyes) and do not move your head and body. Imagine standing on the blue marker, and the scale of the model is irrelevant, could you see the red marker without the terrain blocking your view? Please state your final answer as *My final answer is Yes or No*"

When an answer was given, the participant was asked;

"How confident are you of your answer. On a scale of zero (not confident) to five (very confident), how confident are you that your answer is correct?"

The reaction time and answers were recorded with video, stopwatch and notebook to later process the data. All data was recorded on an answer sheet filled in by the surveyor. Terrain model 1 was used for a practice round. The whole procedure took an approximate of 20 – 35 minutes per participant.

Thirty-five participants were recruited, most of them at Leiden University and Delft University of Technology and consisted of (PhD) students, professors and MSc graduates. Age ranged from 19 to 48, with a mean of 28. Twenty-four males and eleven females participated in the experiment.

Results

We were interested to compare the performance (as measured by the correct answers given), within people, for each of the two spatial ability groups, low and high scoring. We wanted to compare the score on the first condition to those on the second and third. We had to use a non-parametric test because the distributions of scores for both groups were non-normal on one of the conditions, implying (because the sample was small) that the sampling distribution would be non-normal too. For each participant the amount of correct answers, the reaction time and the certainty score were recorded. This data was submitted to a Wilcoxon signed-rank test for the different groups and conditions. The results can be found in table 2.

Table 2

Results for all participants, results for the low spatial ability group and the results for the high spatial ability group.

All participants				*z*	*p*	*r*
Performance	Condition 2 (*Mdn* = 8)	>	Condition 1 (*Mdn = 7*)	*3.548*	*.000*	*.65*
	Condition 3 (*Mdn = 8)*	>	Condition 1 (*Mdn = 7*)	*2.785*	*.005*	*.51*
	Condition 3 (*Mdn = 8)*		Condition 2 (*Mdn* = 8)	*-1.583*	*.113*	*-.29*
Confidence	Condition 2 (*Mdn = 4.22*)	>	Condition 1 (*Mdn = 3.61*)	*4.557*	*.000*	*.83*
	Condition 3 (*Mdn = 4.67*)	>	Condition 1 (*Mdn = 3.61*)	*4.795*	*.000*	*.88*
	Condition 3 (*Mdn = 4.67*)	>	Condition 2 (*Mdn = 4.22*)	*4.553*	*.000*	*.83*

Low spatial ability				*z*	*p*	*R*
Performance	Condition 2 (*Mdn = 8*)	>	Condition 1 (*Mdn = 6*)	*2.204*	*.028*	*.40*
	Condition 3 (*Mdn = 7.5*)	>	Condition 1 (*Mdn = 6*)	*2.299*	*.022*	*.42*
	Condition 3 (*Mdn = 7.5*)		Condition 2 (*Mdn = 8*)	*-0.145*	*.884*	*.03*
Confidence	Condition 2 (*Mdn = 4.11*)	>	Condition 1 (*Mdn 3.67*)	*3.243*	*.001*	*.59*
	Condition 3 (*Mdn = 4.56*)	>	Condition 1 (*Mdn 3.67*)	*3.521*	*.000*	*.64*
	Condition 3 (*Mdn = 4.56*)	>	Condition 2 (*Mdn = 4.11*)	*3.419*	*.001*	*.62*

High spatial ability				*z*	*p*	*R*
Performance	Condition 2 (*Mdn = 9*)	>	Condition 1 (*Mdn = 7*)	*2.992*	*.003*	*.55*
	Condition 3 (*Mdn = 8*)		Condition 1 (*Mdn = 7*)	*1.632*	*.103*	*.30*
	Condition 3 (*Mdn = 8*)	<	Condition 2 (*Mdn = 9*)	*-2.486*	*.013*	*.45*
Confidence	Condition 2 (*Mdn = 4.28*)	>	Condition 1 (*Mdn = 3.61*)	*3.299*	*.001*	*.60*
	Condition 3 (*Mdn = 4.78*)	>	Condition 1 (*Mdn = 3.61*)	*3.314*	*.001*	*.61*
	Condition 3 (*Mdn = 4.78*)	>	Condition 2 (*Mdn = 4.28*)	*-2.486*	*.013*	*.56*

In total thirty-five participants participated in the experiment (Table 3), the scores of five participants were removed from the dataset because they failed the stereovision screening. Those participants scored a 2 (out of a possible 10), the mean was 7.4 (without those participants the mean was 8.5).

	All participants	Low SAS	High SAS
Male count	*24*	*12*	*8*
Female count	*11*	*4*	*6*
Age min	*19*	*19*	*22*
Age max	*48*	*46*	*48*
Age mean	*28*	*28*	*29*

The remaining thirty participants scored a mean of 14.2 on spatial ability, this was the cutoff score to create a low and high spatial ability scoring (SAS) group. This resulted in a group low SAS with N = 16, $\bar{X}$ = 12 and a group high SAS with N = 14, $\bar{X}$ = 16.7.

The amount of correct answers given was significantly higher ($p < .001$) for condition 2 than for condition 1. Likewise, for condition 3 the amount of correct answers given were more than for condition 1 ($p < .005$). However, there was no significant difference ($p = .113$) for the amount of correct answers given between condition 2 than for condition 3.

Other results (Table 2) show us that for people with a low spatial ability score, the amount of correct answers given was not significantly different for condition 3 (Mdn = 7.5) than for condition 2 (Mdn = 8), z = -.145, p = .884, r = .03. For people with a high spatial ability score, on the other hand, the amount of correct answers given was significantly lower for condition 3 (Mdn = 8) than for condition 2 (Mdn = 9), z = -2.486, p = .013, r = .45.

Table 4
Mean scores and Std. deviation for performance (as measured by the correct answers given) and certainty.

	Condition 1	Condition 2	Condition 3
All participants Performance	$\bar{X}$ 6.7, σ 1.4	$\bar{X}$ 7.9, σ 1.1	$\bar{X}$ 7.6, σ .6
All participants Certainty	$\bar{X}$ 3.5, σ .6	$\bar{X}$ 4.1, σ .5	$\bar{X}$ 4.6, σ .3
Low SAS Performance	$\bar{X}$ 6.5, σ 1.5	$\bar{X}$ 7.6, σ 1.2	$\bar{X}$ 7.5, σ .7
Low SAS Certainty	$\bar{X}$ 3.5, σ .7	$\bar{X}$ 4.1, σ .5	$\bar{X}$ 4.6, σ .2
High SAS Performance	$\bar{X}$ 6.9, σ 1.4	$\bar{X}$ 8.4, σ .8	$\bar{X}$ 7.7, σ .5
High SAS Certainty	$\bar{X}$ 3.5, σ .4	$\bar{X}$ 4.2, σ .4	$\bar{X}$ 4.6, σ .4

The table above (Table 4) suggests that even when the performance (as measured by the correct answers given) was worse in condition 3 compared to the performance in condition 2, the participants thought they performed better. The certainty score was always higher for condition 3 than it was for condition 2 ($p < 0.05$, Table 2).

Conclusion and Discussion

Our research was designed to see if there is an advantage of using a 3D display over a 2D display. We confirmed that people perform better when using a 3D display compared to using a 2D display of this terrain. Also we expected to find that the amount of correct answers given would increase when using a physical 3D display. Our results however, do not confirm this expectation, the participants in this study actually performed worse on the physical 3D display than they did on the 3D display.

Also this research focused on the relation of spatial ability and performance on the different displays. We expected a larger increase in performance for people with a lower spatial ability between the displays than the increase for people with a high spatial ability. However, we did not find a significant increase for the low spatial ability group, and we found a significant (*p=.013*) decrease for people with a high spatial ability when using a physical 3D display compared to a 3D display. Both our hypotheses are rejected, we expect the Expertise Reversal Effect to be a key attribute for this. We did however confirm part of our first hypothesis, the tasks were performed with a lower error rate in the second condition compared to the first (*p<.03)*.

The reason for the participants not to improve on the third condition in comparison to the second condition may be attributed to the Expertise Reversal Effect. The Expertise Reversal Effect describes that someone more advanced at for example, relative position tasks, can be hindered by the information that is presented to better explain the relative position to someone who is a novice to relative position tasks. Or as Paas, Renkl and Sweller (2004) explain it; "A cognitive load that is germane for a novice may be extraneous for an expert. In other words, information that is relevant to the process of schema construction for a beginning learner may hinder this process for a more advanced learner". If our results can be attributed to the Expertise Reversal Effect, the low spatial ability participants would benefit from the physical representation, while high spatial ability participants are overwhelmed by the amount of non-relevant information caused by the possibility to walk around the model (Huk, 2006).

Almost all participants were recruited at The Leiden Institute of Advanced Computer Science (LIACS) and Delft University of Technology. Almost all participants had a higher education degree or were attending one. Spatial ability is a predictor of the performance and devotion to science, technology, engineering, and mathematics (Wai, Lubinski and Benbow, 2009). We think this is also the reason the spatial ability scores in our experiment were generally very high. The mean of the spatial ability score of all participants was 14.2 where the mean scores presented by Ekstrom et al. (1976) are between 10.4 and 13.8 (Figure 12). Our low SAS group have a mean SAS of 12, which we think is too high to represent a low SAS group, looking at the mean scores of Ekstrom et al. (1976) whose mean scores, for the

Data on Tests from 1963 Kit

	Source: Unpublished study of cognition & personality (Suburban 11th & 12th graders; 288-300 males, 317-329 females)				Source: Other studies			
Factor & Tests	Mean	S.D.	Rel.	Sample	Mean	S.D.	Rel.	Sample
VZ								
1 Form Board					124.8	38.3	.81	46 college students
2 Paper Folding	11.5	3.7	.75	males	13.8	4.5	.84	46 college students
	10.4	3.7	.77	females	10.4	---	.84	82 Army enlistees
3 Surface Development					43.6	15.1	.90	46 college students
					37.8	---	.92	86 Army enlistees

Figure 12 Mean score of the Paper Folding Test. Ekstrom, R. B., French, J. W., Harman, H. H., & Dermen, D. (1976).

whole population, were around that same score.

We suspect that if our low spatial ability group had an actual low spatial ability they might have performed better in the third condition compared to the performance in the second condition and confirm the Expertise Reversal Effect.

In our experiment we also found a clear example of Naïve Realism. Naïve Realism describes the misalignment of intuition or the preference of people and their performance on for example the way information is shown (Cook, 2010). Smallman and St. John (2005) found that a person’s intuitions and preferences are closely related, but the actual performance is absolutely not aligned. In our research participants were very certain their answer was correct in the third condition (Table 4), more than in the second (even though they performed worse in the third condition compared to the second). Participants were most likely convinced the apparent benefit of walking around the model in condition 3 should as a consequence result in a better answer than in condition 2.

A last comment we need to make regarding the experiment is that participants may have moved their head a little bit in condition 1 and 2. Although we asked all participants to loop through the viewing hole in condition 1 and 2 and keep their head from moving, we suspect participants to have moved their head, unwillingly and just slightly. This movement could have given the participants a perception of depth through motion parallax (the movement of the objects against each other and the background).

Future Work

In future research the following changes and additions would be interesting to implement in the experiment:

- Sample Size; because of the small sample size and the relatively high spatial ability score mean, we would like to see the results of a bigger sample size with a more evenly distributed spatial ability score. With the results of lower scoring participants than in our study, we expect to confirm the Expertise Reversal Effect with more confidence.

- Experiment setup; although the current experiment was designed to assess the general shape and layout of a terrain and showed an improvement for the 3D conditions (2 and 3 in our research) over the 2D condition (condition 1 in our research). It may have been too easy a task to show a difference between conditions 2 and 3.
- Conditions 1 and 2; participants were asked to look through the viewing hole and not move their head. Participants might unintentionally slightly have moved their heads while looking though the viewing hole. In a future research this head movement should be prevented to exclude perception of depth through motion parallax.

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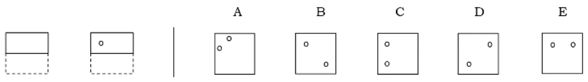
Appendix A – Paper folding test

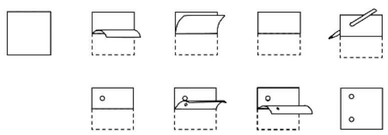
Paper Folding Test—Vz-2-BRACE

In this test you are to imagine the folding and unfolding of pieces of paper. In each problem in the test there are some figures drawn at the left of a vertical line and there are others drawn at the right of the line. The figures at the left represent a square piece of paper being folded, and the last of these figures has one or two small circles drawn on it to show where the paper has been punched. Each hole is punched through all the thicknesses of paper at that point. One of the five figures on the right of the vertical line shows where the holes will be when the paper is completely unfolded. You are to decide which one of these figures is correct and draw an X through that figure.

Now try the sample problem below. (In this problem only one hole was punched in the folded paper).



The correct answer to the sample problem above is C and so it should have been marked with an X. The figures below show how the paper was folded and why C is the correct answer.



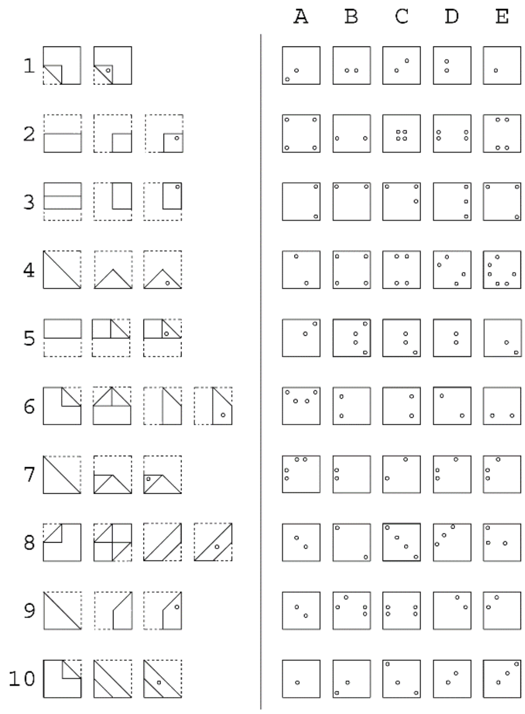
In these problems all of the folds that are made are shown in the figures at the left of the line, and the paper is not turned or moved in any way except to make the folds shown in the figures. Remember, the answer is the figure that shows the positions of the holes when the paper is completely unfolded.

Some of the problems on this sheet are more difficult than others. If you are unable to do one of the problems, simply skip over it and go on to the next one.

You will have three minutes for each of the two parts of this test. Each part has one page. When you have finished Part One, STOP. Please do not go on to Part Two until you are asked to do so.

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO

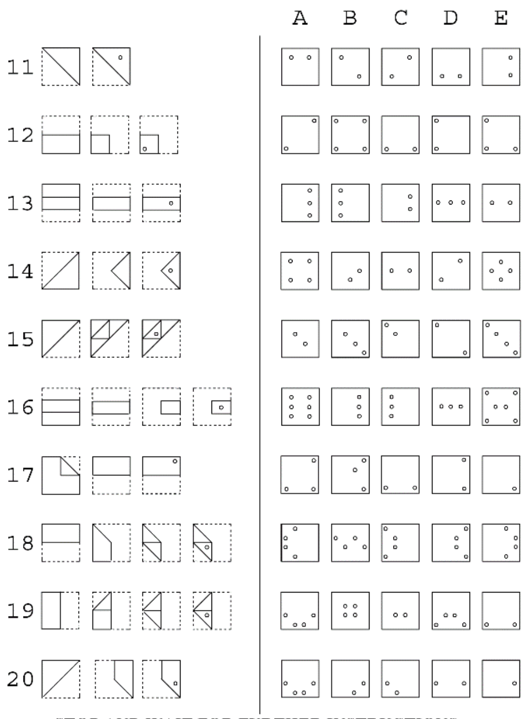
PART ONE (3 MINUTES)



STOP

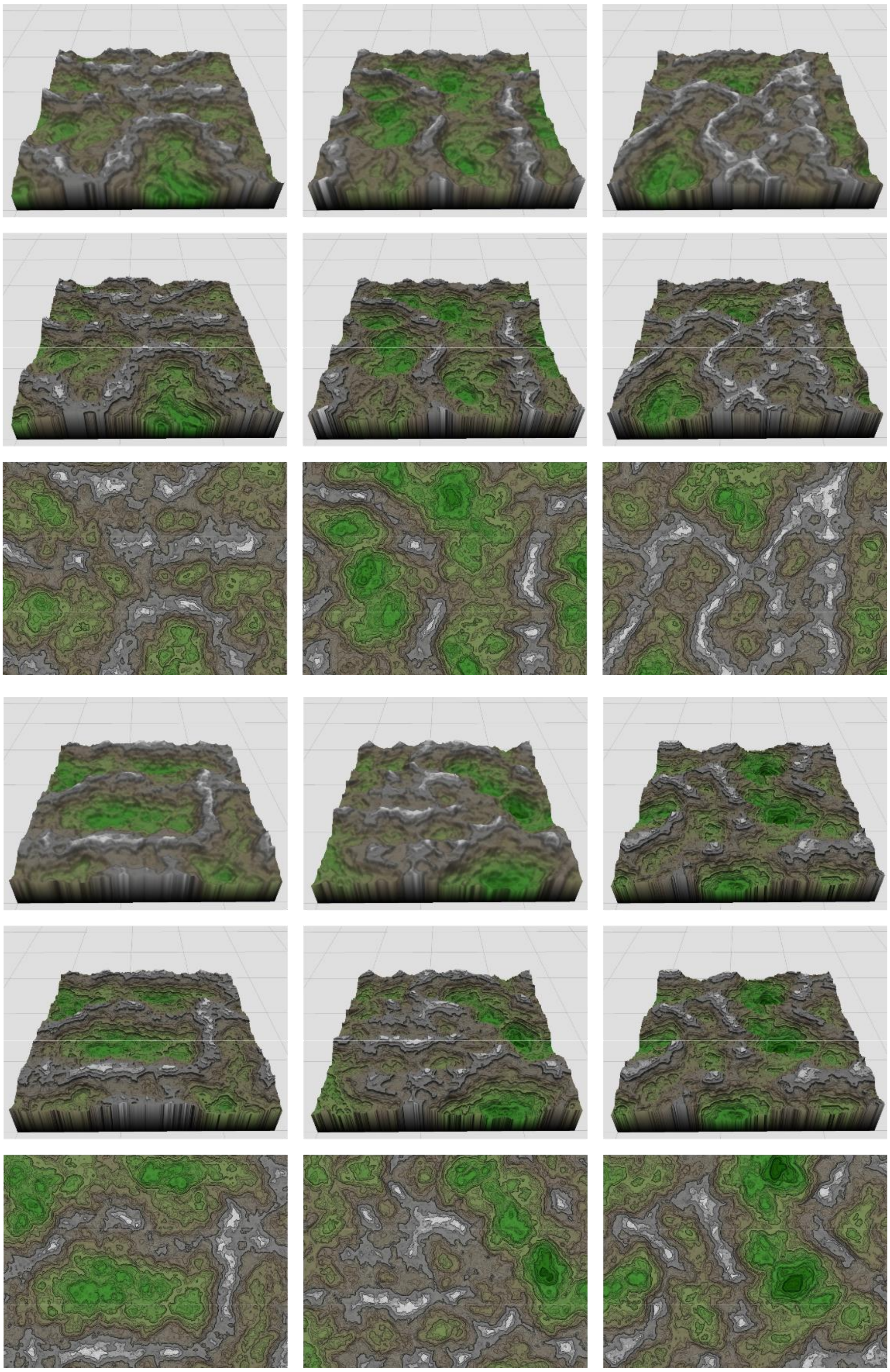
DO NOT PROCEED TO THE NEXT PAGE UNTIL ASKED TO DO SO

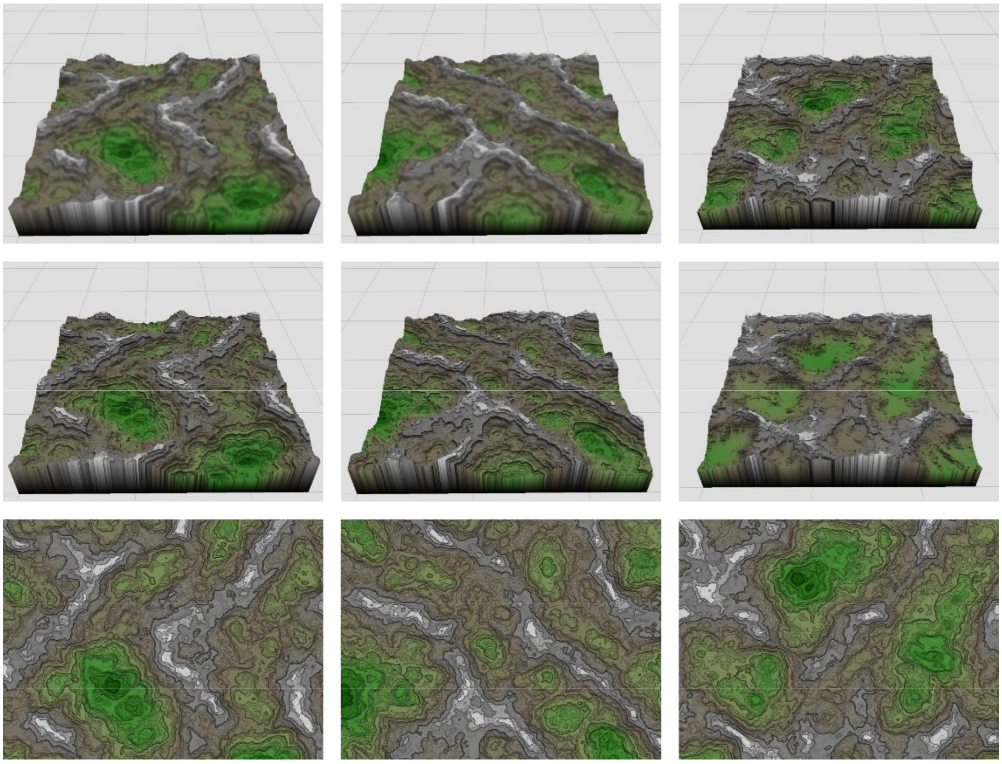
PART TWO (3 MINUTES)

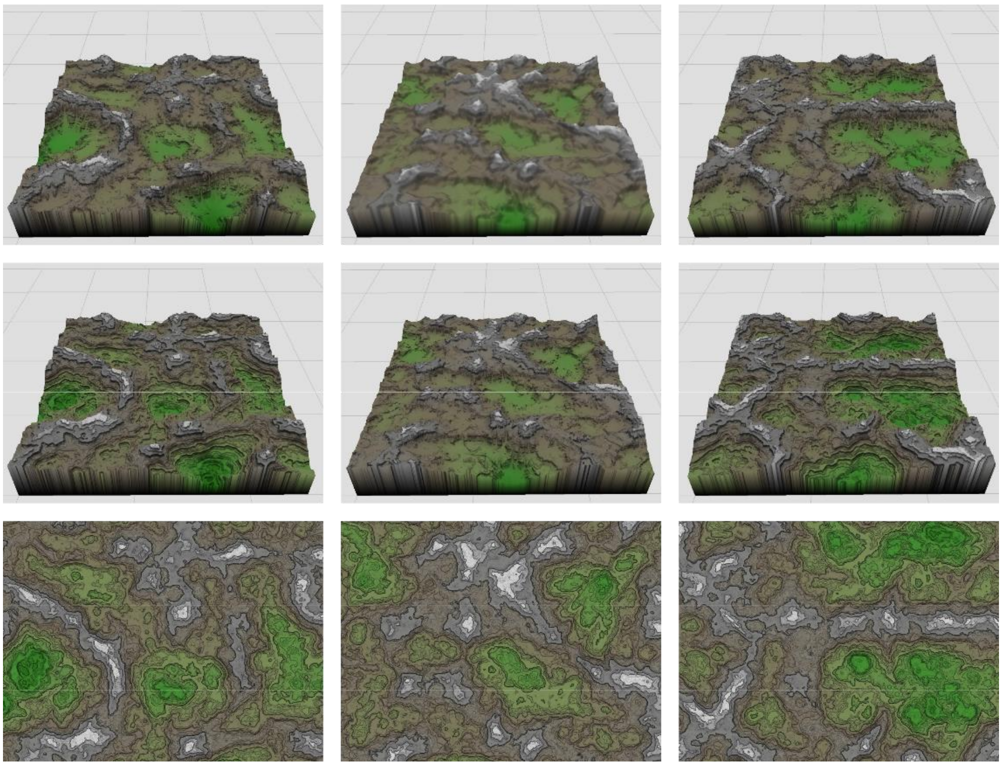


STOP AND WAIT FOR FURTHER INSTRUCTIONS
DO NOT GO BACK TO PART ONE

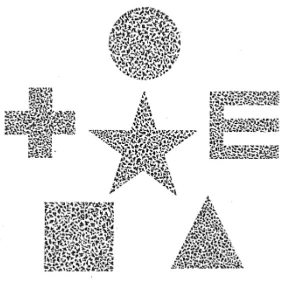
Appendix B – Computer models of the terrain models







Appendix C – Randot Stereo Test



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RANDOT STEREOTESTS

Stereopsis, as a discrete test of the ability to binocularly discern a difference in the distance from the observer of two static objects, has been attended by many variables that have made it difficult to correlate various tests by the measure of binocular parallax. Form (both figure and ground), size, contrast, and distance between objects also influence judgment, and some figure-ground configurations include monocular clues that may invalidate the test.

The RANDOT Stereotests now provide the opportunity to achieve excellent validity and reliability. Binocularly devised random dot patterns, made popular by computer technology, require the individual to extract a form figure from ground without the help of any monocularly visible contours. As disparity is reduced, however, the young child needs additional help to separate the form of figure from ground, so monocular contour is added. But whether homogenous or diverse, figure and ground are contiguous with no lateral or vertical distance between them to influence judgment. Although the homogenous RANDOT test prescribes a "form" response, it is valid if there is perceived only "something" or "nothing" at the proper locations.

The RANDOT Stereotests provide three variations to facilitate testing of individuals at different levels—of comprehension as well as a gradient of disparity:

1. Large homogenous areas containing simple forms at two levels of gross disparity, with each set having one blank to act as control.

2. Cartoon animals to attract the interest of young children are arranged at three gross levels of disparity.

3. Contoured circles at ten levels of disparity provide a finely graded sequence for critical testing.

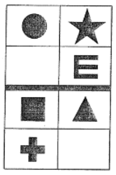
TO ADMINISTER, hold the test upright before the subject to maintain the proper axis of polarization; also, do not permit the head to tilt to the side. Provide adequate light, but avoid reflections from the surface of the test—a dark area or curtain behind the subject helps. Although the tests are graded for 16 inches, some variation in distance should have little effect on the score. Polarizing viewers must always be worn—over prescription glasses, if used. For the bifocal wearer, position the test properly for near-point viewing. Impaired acuity itself may blur the random dot pattern to a point where an otherwise normal person cannot separate a disparate form from the background.

RANDOT Forms

Simple geometric forms and the familiar E are central in each area except one, which acts as a control. A direct procedure is to ask which area does **not** appear to have any form in it. The mature child may be able to identify the forms, but an acceptable response is that there is "something" or "nothing" in the proper areas. If there is not a quick response with the forms, do not conclude too rapidly that there is no stereoscopic fusion. Some binocular individuals rely heavily on monocular clues of depth such as motion parallax, overlap, size, perspective, shading, and when binocular disparity is the only one present, as in this test, the perceptual response may develop slowly. So let the subject study it for a while, giving him encouragement and suggestions. Poor response from some children may be because of communication difficulties and not visual inadequacy. Be simple and direct to assist understanding. Encourage the child to point rather than relying solely on verbal responses.

Presenting the test upside down will reverse the polarity of the images, making the form appear behind ground instead of forward, but it is usually easier to perceive the form if it is forward of ground.

Use the front page of these instructions to help the non-verbal person match the form he sees.



ANIMALS
(with random dot ground)

In each of the three tests only one of the animals should appear forward from the others or "different." It will help the children if you move your finger across the animals in the line being tested and ask, "does one of these seem to come out closer to you than the others?" Then have the child point to the one sslected.

SCORING—Refer to the chart below. Take each line in order. When one is missed, go back and test the preceding line again to determine whether subject can achieve this level or is just guessing.

SCORING KEY		Seconds of arc at 16 in.	Shepard Percentage	Verhoff Distance
A	Cat	400	15%	.1
B	Rabbit	200	30%	.2
C	Monkey	100	50%	.3

CIRCLES
(with random dot ground)

This multiple-choice series tests fine depth discrimination. Within each of ten targets are three circles. Only one of the circles has crossed disparity, which, when seen binocularly, should appear to stand forward from the other two. Ask which one seems to float forward or appears "different" from the others—left, middle or right. Always assist the child by running your finger across all three circles and then have him point to the one selected.

SCORING—Refer to the chart. Record the level of stereopsis of the last one chosen correctly. If one is missed, go back and test the preceding line again to determine whether subject can achieve this or is just guessing.

SCORING KEY		Seconds of arc at 16 in.
1	L	400
2	R	200
3	L	140
4	M	100
5	R	70
6	M	50
7	L	40
8	R	30
9	M	25
10	R	20

The suppression check is useful in analyzing the visual balance of the two eyes. The right eye sees the R and a vertical line—the left eye the L and a horizontal line, which in normal binocular vision combines with the vertical line to form a cross. The relative stability of these can give clues of eye dominance, and of course gross fading or absence indicates a failure of that eye to function properly under binocular conditions. A change manifest in the appearance of the forms when covering the opposite eye may help to indicate the nature and degree of malfusion present.

NOTE: Please store your Stereo Tests in a cool, dry place when not in use. High heat and humidity may cause fading.

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P/N 70021

Appendix D – Answer Sheet

ANSWER SHEET

Participant # _____

Filled in by surveyor		Filled in by participant	
Date	___ - ___ - 201 _	**Gender**	o Male | o Female
Start time	___ : ___ h	**Age**	___
End time	___ : ___ h	**Color blind**	o Yes | o No

We will not be sharing information about you to anyone outside of the research team. The information that we collect from this research project will be kept private. Any information about you will have a number on it instead of your name. Only the researchers will know what your number is. The research is filmed for later analyses.

You do not have to take part in this research if you do not wish to do so. You may stop participating at any time that you wish without stating a reason.

I have read the foregoing information, or it has been read to me. I have had the opportunity to ask questions about it and any questions I have been asked have been answered to my satisfaction. I consent voluntarily to be a participant in this study.

Name ______________________

Signature ______________________

Date ___ - ___ - 201 _

Filled in by the surveyor

Screening results			
Visual Acuity	Score	___	
Stereo test result			
Forms	Top correct	o Yes | o No	
	Bottom correct	o Yes | o No	
Circles answers			
1	o Left	o Middle	o Right
2	o Left	o Middle	o Right
3	o Left	o Middle	o Right
4	o Left	o Middle	o Right
5	o Left	o Middle	o Right
6	o Left	o Middle	o Right
7	o Left	o Middle	o Right
8	o Left	o Middle	o Right
9	o Left	o Middle	o Right
10	o Left	o Middle	o Right
Spatial ability score	___		

Experiment Stimulus	Condition	Point markers	Time	Answered	Scale confidence
8	3	Green Blue	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5
	1	Black Purple	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5
	2	Blue Yellow	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5
1	3	Green Blue	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5
	2	Black Pink	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5
	1	Green Yellow	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5
2	1	Red Black	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5
	3	Green Pink	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5
	2	Red Blue	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5
3	3	Red Black	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5
	2	Green Pink	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5
	1	Blue Yellow	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5
4	2	Red Green	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5
	3	Green Pink	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5
	1	Pink Yellow	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5
5	3	Black Yellow	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5
	2	Red Yellow	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5
	1	Red Pink	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5
6	3	Green Blue	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5
	1	Red Purple	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5
	2	Purple Yellow	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5
7	1	Red Black	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5
	2	Green Pink	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5
	3	Black Blue	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5
9	2	Black Yellow	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5
	1	Purple Blue	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5
	3	Green Yellow	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5
10	1	Green Pink	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5
	2	Pink Yellow	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5
	3	Green Black	___ sec	o Yes | o No	o 0 | o 1 | o 2 | o 3 | o 4 | o 5

Condition	Vision	State
1	Monocular	Stationary
2	Binocular	Stationary
3	Binocular	Active