

# Performance of 2D versus 3D Topographic Representations for Different Task Types

Debra MacIvor Savage, Eric N. Wiebe and Hugh A. Devine  
 North Carolina State University  
 Raleigh, North Carolina

In this study, a performance comparison is made between 2D and 3D topographic representations for solving different tasks. The tasks involved answering questions that either did or did not require elevation information and were either focused or integrative. Integrative questions required understanding the relationship of three separate locations. 2D representations (i.e., contour maps) only showed a clear advantage for focused, non-elevation questions with 3D representations not showing a clear advantage for any other task condition. There were interactions between task type, dimensionality and elevation. In addition, the integrative, elevation questions were clearly more difficult regardless of dimension. In addition, participants' visualization ability, as measured by a paper-folding test, correlated with their task performance. Further work is proposed to look at how experience interacts with these tasks and topographic representations.

## INTRODUCTION

There are many types of problems that can be most effectively solved by visualizing geographic (spatial) relationships. Such applications as zoning and land use planning, natural resource planning, geographic education, park and recreation planning and maintenance, utility infrastructure maintenance and repair, mining, transportation planning and delivery route planning all require visualizing the relationship between terrain and objects located in geographic space. Typically, planar topographic contour maps are used in these applications, but would the integrated display of all three dimensions in a perspective view provide an advantage for spatial visualization over the traditional 2D topographic map?

Some evidence for 2D map superiority for both focused attention and integrated tasks has been found (Hollands, Pierce, & Magee, 1995). In fact, 3D perspective displays can introduce problems due to foreshortening of the depth (Y) of the map when it is tilted at an oblique angle (Smallman, St. John, & Cowen, 2002).

Other studies have found little or no advantage for 2D over 3D displays when scales and tick marks were used to facilitate data extraction (Bennett, Payne, Calcaterra, & Nittoli, 2000; Meserth & Hollands, 1999). (Haskell & Wickens, 1993) found that for integrated 3D spatial tasks, a 3D perspective (oblique) display may be preferable to a 2D display, and for tasks requiring focused attention, 2D separable or separate displays may be better.

### Topographic Maps

Topographic contour maps are (usually) static displays or hardcopy maps used as geographic visualization tools. They include rectangular grids of latitude and longitude, as well as contour lines. Contour lines are lines drawn through points of equal elevation at regular intervals such as 10 meters of elevation change. Contour maps may be shaded into different elevation zones (Muehrcke & Muehrcke, 1998).

The topographic contour map can be considered a separable display, which should facilitate focused attention

tasks (Garner, 1976). The elevation values are represented as elevation isolines, while the latitudes and longitudes are represented as a regular grid. Additionally, the elevation changes are enhanced visually by graduated shading; low areas are dark while higher elevations are light. Finally some of the contour lines have numeric elevation labels.

Although rich in detailed geographic information, contour maps have been found difficult to read by inexperienced users (Gilhooly, Wood, Kinnear, & Green, 1988). In addition, research has shown that 2D can be superior to topographic maps 3D representations for precise relative positioning tasks, but not for shape understanding. (St. John, Cowen, Smallman, & Oonk, 2001; St. John & Smallman, 2000).

The purpose of this research was to investigate whether the addition of shape (but no other 3D cues such as shadows) to the traditional 2D topographic maps is enough to gain the advantages of 3D for shape understanding, while retaining the relative positioning advantage of the 2D map. For this purpose, all of the traditional characteristics of the 2D topographic maps were retained: equally spaced latitude and longitude lines with numeric labels, elevation measured in isolines with numeric labels, and graduated shading from dark (low elevations) to light (high elevations). In addition, the 3D representations consisted of the 2D maps "draped" over the terrain. Tasks were of two types: Focused Tasks, which are similar to the relative position tasks in St. John (2001), experiments 5 and 6; and Integrated Tasks, similar to the shape understanding tasks used in St. John (2001), experiment 4 (See Table 1).

Table 1. Mapping of Focused and Integrated tasks to Relative Position (RP) and Shape Understanding (SU) Tasks (St. John et al., 2001).

	Elevation	Non-Elevation
<b>Task Type</b>	Focused	A-high-B (RP)
	Integrate	A-to-B (RP)
		A-see-B (SU)
		-----

The four hypotheses investigated in this study are:

1. For focused questions of a single value of Latitude or Longitude at a single location, we expected the flat 2D map and the 3D map would be equally effective, due to the grid marks available in both maps to aid individual value extraction. These tasks were similar to the St John (2001) Experiment 6 tasks with grid and topo, but only included tasks which did not require altitude judgments. The grid marks support the separability of the spatial dimensions of latitude and longitude, and should work equally well for 2D and 3D.

2. For focused questions of a single value of Elevation at a single location, we predicted that the 3D map would be more effective, due to the additional cognitive processing effort required to extract the third dimension of elevation from a 2D topographic map. This task is similar to the St. John (2001) Experiment 6 Grid and Topo condition, elevation (altitude) only. Although St. John (2001) found the 2D topo map better for these tasks, our representation has more exaggerated terrain, and so should facilitate relative elevation decisions.

3. For tasks requiring relative judgment of distance between several points in a plane (latitude/longitude), we predicted that the 2D map would be more effective than the 3D map. These tasks were similar to the St. John (2001) Experiment 6 latitude and longitude questions, except that our tasks involved choosing the nearest or farthest of several points from a single target point. This made these questions more integrated, requiring relative judgment of distances in latitude AND longitude among several points.

4. For integrated tasks to determine terrain shape, we predicted that the 3D map would be most effective, due to the additional information processing required in order to project a 2D map into a 3D mental image in order to solve the problem. Tasks were similar to St. John (2001) Experiment 4, but a variety of realistic problem scenarios were presented in addition to A-see-B type tasks.

## EXPERIMENT

### Method

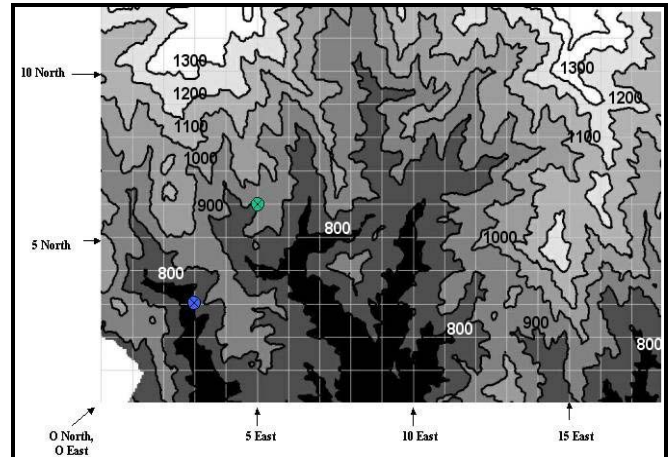
*Participants.* This study included 68 college freshman and sophomores, 34 were randomly assigned to 2D maps, and 34 received the 3D maps.

*Design.* The design was 2x2x2, with 2 types of displays (2D and 3D) between subjects, and 2 major types of tasks (focused and integrated) being within subjects (see Figure 1 for a focused task and Figure 2 for an integrated task). Each task type was further divided into those which required knowledge of elevation to perform the task, and those which did not. There were five questions in each cell, for a total of twenty questions per participant. All questions were displayed at 800X600 on a 19" color display.

*Stimuli.* Maps were created from USGS Digital Elevation Maps (DEMs) of Western North Carolina counties. Contour lines were created from elevation data, shaded,

labeled, and then "draped" over a terrain image derived from elevation (Z) values at regular intervals. Each 3D image was tilted to an angle which would allow the correct answer to be perceived. Five tasks of each type were created:

- 1) Focused, elevation (5 questions)
- 2) Focused, no elevation (5 questions)
- 3) Integrated, elevation (5 questions)
- 4) Integrated, no elevation (5 questions)



**Question: How much farther East is the green point than the blue point?**

- A) 1    B) 2    C) 3    D) 5    E) 6**

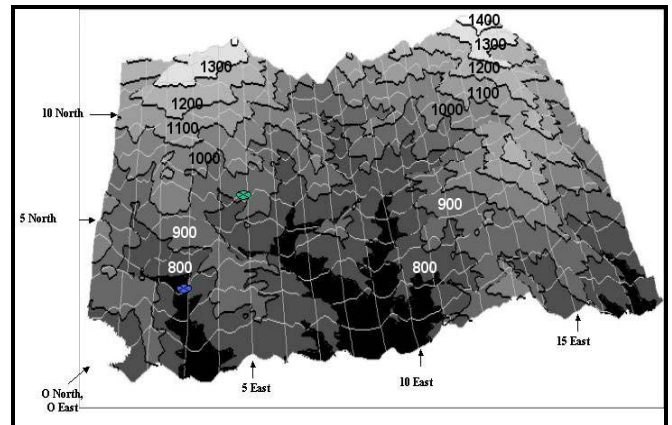
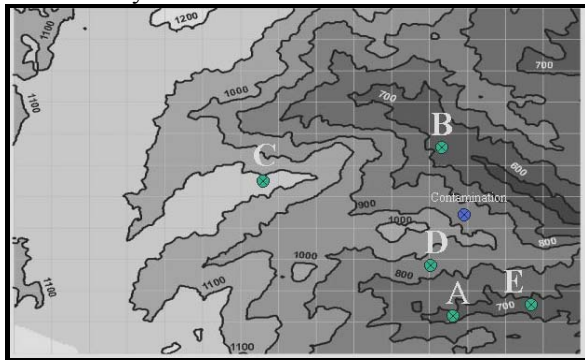


Figure 1. Example of a focused, no-elevation task. The upper version is 2D the bottom is the same map in 3D.

*Procedure.* Each participant was randomly assigned to the 2D or 3D condition. All tasks of each type were presented to participants in randomized order. Response time was measured as was correctness of response. Participants were instructed to answer as quickly and accurately as possible. The answers were multiple choice. Participants were given a survey regarding their previous experience with GIS or other visualization training, or geography (or hydrology, drafting, scientific visualization). Additionally, participants were tested for spatial ability using the Paper Folding Test (Ekstrom, French, Harman, & Dermen, 1976). Paper folding ability was

used as a covariate in this study in order to control for spatial visualization ability.



Well water pollution was found at the location labeled “Contamination”.

**Question: Given that water and water pollutants usually flow downhill, which point is the most likely source of the pollution (contamination)?**

A) B) C) D) E)

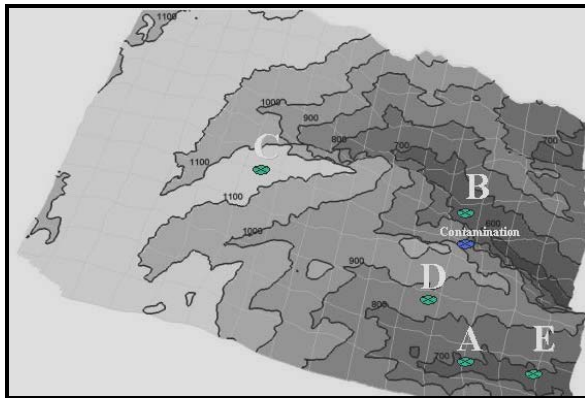


Figure 2. Example of an integrated, elevation-required task. The upper version is 2D and the bottom is the same map in 3D.

## RESULTS

### Accuracy

Accuracy results were analyzed using a three-way ANCOVA with repeated measures in two factors (Task type and Elevation). The main effect of the covariate (paper fold score) was significant,  $F(1,63) = 6.45, p = .014$ . The main effect of Dimension was also significant,  $F(1,63) = 4.47, p = .038$  (Figure 3). Additionally, the Task type x Elevation interaction was significant,  $F(1,63) = 5.08, p = .028$  (Table 2). The Task type x Elevation x Dimension interaction was not significant. For the focused, non-elevation task, post-hoc analysis showed a significant difference between the 2D and 3D groups in their mean accuracy scores (Mean 2D=.87, Mean 3D=.73,  $p = .023$ .) Figure 3 also shows significantly lower scores for the integrated elevation task in both 2D and 3D conditions ( $p < .001$ ) than for the other tasktype/elevation cells.

Table 2. Mean Accuracy Scores for Task Type/Elevation Pairs

	Elevation	Non-Elevation
Focused	M=.83, SD=.24	M=.80, SD=.25
Integrate	M=.45, SD=.18	M=.71, SD=.20

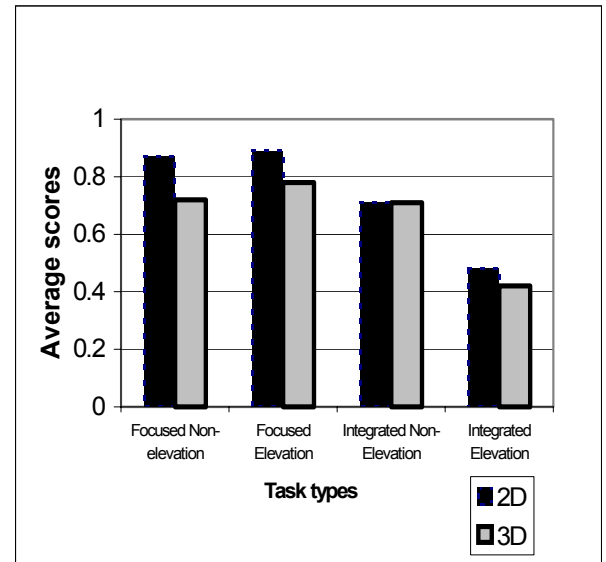


Figure 3. Accuracy Scores—Task type/Elevation by Dimension.

### Time

Time results were analyzed using a three-way ANCOVA with repeated measures in two factors (Tasktype and Elevation). The main effect of the covariate was significant,  $F(1,63) = 4.69, p = .034$ . The main effect of Dimension was not significant in this analysis,  $F(1,63) = .22, p = .64$  (Figure 2). The main effect for Elevation was significant,  $F(1,63) = 11.35, p = .0013$ . Additionally, the Tasktype x Dimension interaction was significant,  $F(1,63) = 5.05, p = .028$  (Table 3). The Tasktype x Elevation x Dimension interaction was not significant. For focused, non-elevation tasks, post-hoc analysis showed a significant difference between the 2D and 3D groups in their mean times (Mean 2D=13.6, Mean 3D=16.6),  $p = .012$ .

Table 3. Mean Times for Tasktype/Elevation Pairs

	2D	3D
Focused	M=19.7, SD=4.6	M=21.3, SD=6.0
Integrate	M=27.2, SD=6.4	M=25.2, SD=5.7

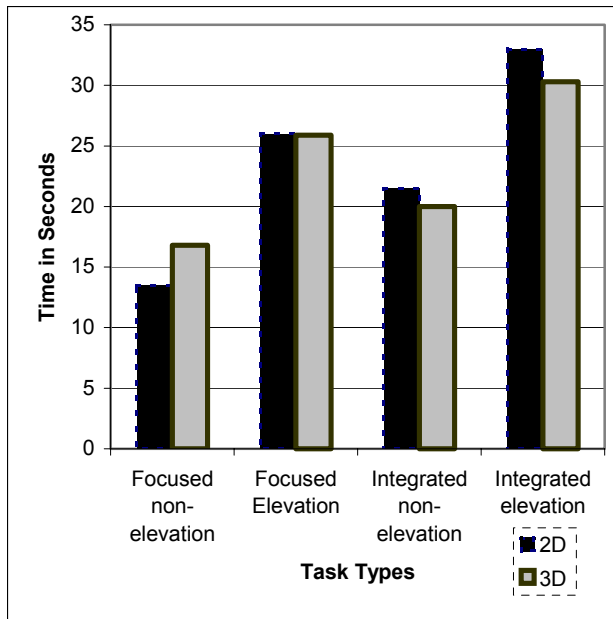


Figure 4. Reaction time—Task type/Elevation by Dimension.

## DISCUSSION

This analysis revealed a significant advantage in both accuracy and time for simple 2D tasks that do not require elevation data. This implies that for the 3D map representation used in this study may interfere with task performance, which is consistent with the research of others (Haskell & Wickens, 1993; St. John et al., 2001).

One might assume that for focused tasks requiring elevation (similar to St. John et al. 2001 A- high-B tasks), scores would be better and times would be reduced for those participants using the 3D maps, because the third dimension of elevation is added to the 3D maps as a redundant cue. However, we found that no significant difference in accuracy and time between 2D and 3D for this task type, in contrast to St. John et al. 2001 (who found a difference in accuracy but not time). Our result is puzzling, but could be due to the simplicity of the tasks: The elevation lines were clearly marked, there were redundant shading cues indicating high and low elevations, and the tasks were to compare elevations at two points or extract the elevation value at a single point.

We predicted that for integrated tasks not requiring elevation data, scores would be better and times would be less for those using 2D maps, due to the misunderstanding of the effects of foreshortening in 3D maps (Smallman et al., 2002). We found that there was no significant difference in accuracy and time between 2D and 3D for this task type.

Finally, we predicted that for integrating tasks requiring elevation data (shape understanding tasks), there would be an advantage to using 3D maps (Haskell & Wickens, 1993; St. John, Cowen, Smallman, & Oonk, 2001). However, we found that there was no significant difference between 2D and 3D in either accuracy or time for this task type.

It is worth noting that spatial visualization ability, as measured by the Paper Folding Test seemed to be a strong indicator as to how individuals would perform on these types of tasks. In addition, shape understanding tasks showed themselves to be the most difficult—whether they were paired with 2D or 3D maps. On the other hand, focused, non-elevation questions were the easiest, with an advantage going to the 2D maps, as predicted by St. John et al., 2001.

## CONCLUSIONS

Tasks which were essentially 2D and required simple focused data extraction were best supported by 2D maps, even when tic marks and mesh were included on the 3D maps. There was no apparent advantage of 3D maps for those tasks requiring elevation information, nor was there a disadvantage for integrated tasks which did not require elevation information. Although more research needs to be done, there is little support in these results using for using this style of 3D topographic maps in problem solving and data extraction tasks. Future research is planned to include analysis of experience level with topographic maps as a separate factor, as well as inclusion of additional questions of each type.

## References

- Bennett, K. B., Payne, M., Calcaterra, J., & Nittoli, B. (2000). An empirical comparison of alternative methodologies for the evaluation of configural displays. *Human Factors*, 42(2), 287-298.
- Garner, W. R. (1976). Interaction of Stimulus Dimensions in Concept and Choice Processes. *Cognitive Psychology*, 8(1), 98-123.
- Gilhooly, K. J., Wood, M., Kinneer, P. R., & Green, C. (1988). Skill in Map Reading and Memory for Maps. *Quarterly Journal of Experimental Psychology Section a-Human Experimental Psychology*, 40(1), 87-107.
- Haskell, I. D., & Wickens, C. D. (1993). Two- and three-dimensional displays for aviation: A theoretical and empirical comparison. *International-Journal-of-Aviation-Psychology*, 3(2), 87-109.
- Hollands, J. G., Pierce, B. J., & Magee, L. E. (1995). *Displaying quantitative information in two and three dimensions*. Paper presented at the Human Factors and Ergonomics Society 39th Annual Meeting, San Diego, CA.
- Meserth, T. A., & Hollands, J. G. (1999). Comparing 2D and 3D Displays for Trend Estimation: The Effects of Display Augmentation. In *Proceedings of the Human Factors and Ergonomics Society 43rd Annual Meeting, Houston, Texas, September 27-October 1, 1999*. (Vol. 2, pp. 1308-1312). Santa Monica, California: The Human Factors and Ergonomics Society.

- Muehrcke, P. C., & Muehrcke, J. O. (1998). *Map Use: Reading, Analysis and Interpretation* (Fourth ed.). Madison, WI: JP Publications.
- Smallman, H. S., St. John, M., & Cowen, M. B. (2002). Use and Misuse of Linear Perspective in the Perceptual Reconstruction of 3-D Perspective View Displays. In *Proceedings of the 46th Annual Meeting of the Human Factors and Ergonomics Society* (pp. 1560-1564). Santa Monica, California: Human Factors and Ergonomics Society.
- St. John, M., Cowen, M. B., Smallman, H. S., & Oonk, H. M. (2001). The Use of 2D and 3D Displays for Shape-Understanding versus Relative-Position. *Human Factors*, 43(1), 79-98.
- St. John, M., & Smallman, H. S. (2000). Designing for the Task: Sometimes 2-D Is Just Plane Better. In *Ergonomics for the New Millennium. Proceedings of the XIVth Triennial Congress of the International Ergonomics Association and 44th Annual Meeting of the Human Factors and Ergonomics Society, San Diego, California, USA, July 29-August 4, 2000* (Vol. 3, pp. 407-410). Santa Monica, California: Human Factors and Ergonomics Society.
- St. John, M., Cowen, M. B., Smallman, H. S., & Oonk, H. M. (2001). The Use of 2D and 3D Displays for Shape-Understanding versus Relative-Position. *Human Factors*, 43(1), 79-98.