CO-475

COMPARISON OF TOPOGRAPHIC MAP DESIGNS FOR OVERLAY ON ORTHOIMAGE BACKGROUNDS

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INTRODUCTION

This paper reports the findings of a recent pilot study conducted at Penn State University on the readability of diverse topographic map designs which include orthoimagery. The study involved eight map designs, drawn across eight locations in the United States, resulting in 64 map permutations. These were tested for readability on a non-cartographic-specialist audience. Results of the experiment have been surprising, and indicate that map location affects readability with much more pronounced influence than does map design, though design influence was detected when cross-examined with location. This paper describes the study, the map designs used, and the statistical analyses undertaken to assess differences in map readability. This research will lead to future readability studies with modified experimental designs which will examine differences introduced by map design in isolation.

BACKGROUND AND OBJECTIVES

US Topo, the new 1:24,000 topographic map series recently launched by the United States Geological Survey (USGS), incorporates the addition of orthoimagery as a standard map feature. Developed from an earlier beta version entitled "Digital Map - Beta" (USGS, 2009), these maps are publically distributed in GeoPDF format, permitting users to turn layers on and off, as well as take spatial measurements aided by the GeoPDF software. Users can print maps themselves for paper copies. The present US Topo cartographic “look and feel” of these maps echoes legacy topographic maps from the USGS, with modifications to symbols and text introduced to assure legibility atop highly variable imagery. However, cartographers at the USGS continue to explore alternate map designs that operate more effectively atop orthoimagery, and will consider implementing such a design if it is shown by research to be cartographically sound.

By introducing orthoimagery in their 1:24,000 topographic map series, the USGS joins a group of national mapping agencies (NMAs) who have incorporated orthoimagery into their maps, either in topographic map series products, or online in their digital map viewers, or both. Examples of such NMAs include the Institut Geographique National of France (viewer at http://www.geoportail.fr/), the Instituto Geográfico Nacional of Spain (viewer at http://www.ign.es/iberpix/visoriberpix/visorign.html), Ordnance Survey Ireland (viewer at http://maps.osi.ie/publicviewer/), and swisstopo (viewer at http://map.geo.admin.ch/). In addition to NMA orthoimagery use, popular cartographic services such as Google, Bing, MapQuest and recently ArcGIS Online, have been offering online maps with orthoimagery for some years. Online map viewers provided by NMAs vary in functionality, but often permit users to toggle map layers on and off, and sometimes allow users to adjust layer transparency. The USGS National Map online viewer features both of the mentioned functionalities, and serves as a user interface for finding and downloading topographic maps of interest, including those of the US Topo series; it is available online at http://viewer.nationalmap.gov/viewer/.

Including orthoimagery in topographic maps presents symbolization challenges peculiar to the overlay of vector symbols and labels on highly diverse image backgrounds. Vector graphic variables such as colors and transparencies need to be chosen with respect to how they visually interact with the imagery over which they are laid. Design decisions for U.S. topographic maps need to attend to maximum legibility and clarity, particularly since emergency response and natural resource management personnel rank among the most common users of topographic maps (Sugarbaker et al., 2009). Vector features over orthoimagery must be symbolized such that they are legible atop image pixels that may vary widely in color, even across small distances. Vector and orthoimage designs also introduce issues of vertical integration between the vector symbolization and the depiction of a given feature as it appears in the imagery. In addition to positional agreement issues (addressed elsewhere, such as Usery et al., 2005; Knoblock et al., 2006; Knoblock and Shahabi, 2007), visual redundancies and contrasts can exist between imagery and vector features as they appear differently between the orthoimage and vectors; these relationships should be actively used to reinforce and clarify map content. As examples, vector symbols such as water polygons can be made translucent, such that slight disagreements in location of shorelines between the orthoimagery and the vector water feature can appreciated, and the precise location of the shore can be judged by the map reader; also a view of the rooftops of buildings in dense areas can help to reinforce the urban-area tint applied in that area on the map. Different map designs will manage the relationships of feature representations between imagery and overlying vectors with varying effect.

This research has been undertaken with a grant from the USGS to develop new map designs for topographic maps with orthoimagery. The designs are meant to stimulate new symbolization ideas that may be incorporated into a new map design for future US Topo maps. The research has experimented with eight different map designs incorporating orthoimagery and vectors, across which graphical elements such as color and transparency are varied on both the orthoimagery and the vectors. Eight different test locations were chosen, taken from geomorphologically-distinct hydrological subbasins around the United States with a mixture of urban and rural settings; these eight were borrowed from previous research on multiscale topographic map design by Cynthia Brewer, Barbara Buttenfield and Lawrence Stanislawski for the Center of Excellence for Geospatial Information Science (CEGIS), USGS (details available at ScaleMaster.org). The designs were tested on members of the Penn State University community as a pilot study, and will be further tested on broader communities of users of United States topographic maps. This paper reports the development and user testing process thus far undertaken by the authors, discusses statistical test results obtained, and discusses implications the results may have on map design for orthoimagery.

This study regards topographic maps as documents which must communicate spatial information clearly (Robinson,1952), and focuses principally on the readability of various map designs. Readability is measured by three variables: user ratings, test question scores, and measures of response certainty obtained from test subjects, each collected across eight map designs and eight map locations. Findings thus far suggest that landscape variability (i.e., location) significantly impacts the readability of topographic maps with orthoimagery, whereas there is little impact on readability from map designs alone while landscape remains constant. Details on these findings are discussed in the Results section below.

MAP DESIGNS

Three map designs served as starting points from which to derive eight designs. Two of these were original designs developed by the authors, and the third is the existing US Topo.

The first original design developed by the authors took inspiration from multiple-color usage for human landscape features, seen in some European topographic maps, such as those of IGN France or England's Ordnance Survey. Effort was made to create a design with features depicted using many saturated colors which remained legible over a full-color orthoimage. Roads were cased and colored shades of purple, orange, yellow or grey according to class. Point symbols varied color according to feature type, with symbols relevant to emergency response (e.g., hospitals in blue, or police stations in red) figuring more prominently than others (e.g., points of interest in black). This map design incorporated translucent vector symbols for water polygons and roads, so as to allow features (e.g., roadways, shorelines) represented in both vector symbols and in the orthoimage to be reinforced by the dual representation. This was also done on the notion that translucent vector symbols allow for comparison of feature location against orthoimagery when vertical integration is imperfect. Labels for human landscape features were written in Myriad Pro font and with halos; different colors were used for halos in order to establish visual hierarchy between features (for example, such that local road labels receded while points of interest labels stood out). Dark, translucent hillshading, was used to both exaggerate topography and reinforce contour lines, as well as slightly dampen the orthoimagery. This design also incorporated tapered streams, to convey a sense of hydrographic hierarchy.

The second original design developed was originally intended for multiscale mapping, and so a subset of the design specifications which were in effect at 1:24,000 was used. This design was without orthoimagery, and was included in the study to explore whether presence or absence of orthoimagery significantly affected readability. This design was intended to serve as a topographic base map, having fairly muted colors that would easily accommodate operational data (including user-added notes, often by ink on paper). Color choices were determined with respect to divisions of the color wheel, with human landscape features in oranges, yellows and reds, boundaries in purple, water in blue, and environmental and landcover features in greens. The design incorporated a hillshade whose color ramp stretched across white, yellow and brown, with yellows landing on relatively flat portions of the terrain, emulating sunlight. Roads, in reds and oranges, were cased to ensure legibility on various backgrounds, and contours were gray to differentiate them from roads. Several text manipulations (character spacing, use of condensed typefaces, leading, bold and italic styles) were applied to achieve feature hierarchies, and text halos were very minimally used. This design also incorporated tapered streams.

The existing US Topo map design was recreated for the purpose of testing it against variations of the original designs. This design, described to some detail in Moore et al. (2009), seeks to provide symbolization that remains legible with and without orthoimagery. It has been developed in part from an earlier beta USGS topographic map series, "Digital Map - Beta" (USGS, 2009), which contained only a subset of feature types presently included (e.g. contours and hydrography have been added since Digital Map - Beta). The US Topo design seeks to remain close to the "look and feel" of legacy USGS 1:24,000 topographic maps, with the addition of orthoimagery. This design makes frequent use of halos for feature labels and cases some features such as roads to ensure legibility over the image.

From the three map designs described above, variations allowed for the development of eight different map designs. Designs were designated A through H, and a key to the coding of the eight designs is as follows:

A. first original design: full-color orthoimage, translucent hillshade, labels with halos, multi-colored vector features, translucency on water polygons and road features

B. same as A, with orthoimage in grayscale

C. same as A, without hillshade

D. existing US Topo design: full-color orthoimage, labels with halos, no hillshade, some cased (i.e., outlined) point and line features

E. same as H, with translucent orthoimage included under translucent hillshade but over contours

F. same as D with translucent hillshade instead of orthoimage

G. same as A, with orthoimage removed

H. second original design: translucent hillshade, no orthoimage, labels without halos

Thumbnails for each of these designs across a single map location (Missouri) are given in Figure 1, while larger versions of designs A and H are given in Figure 2. All map designs were developed and implemented entirely in ArcGIS (version 9.3.1) software.

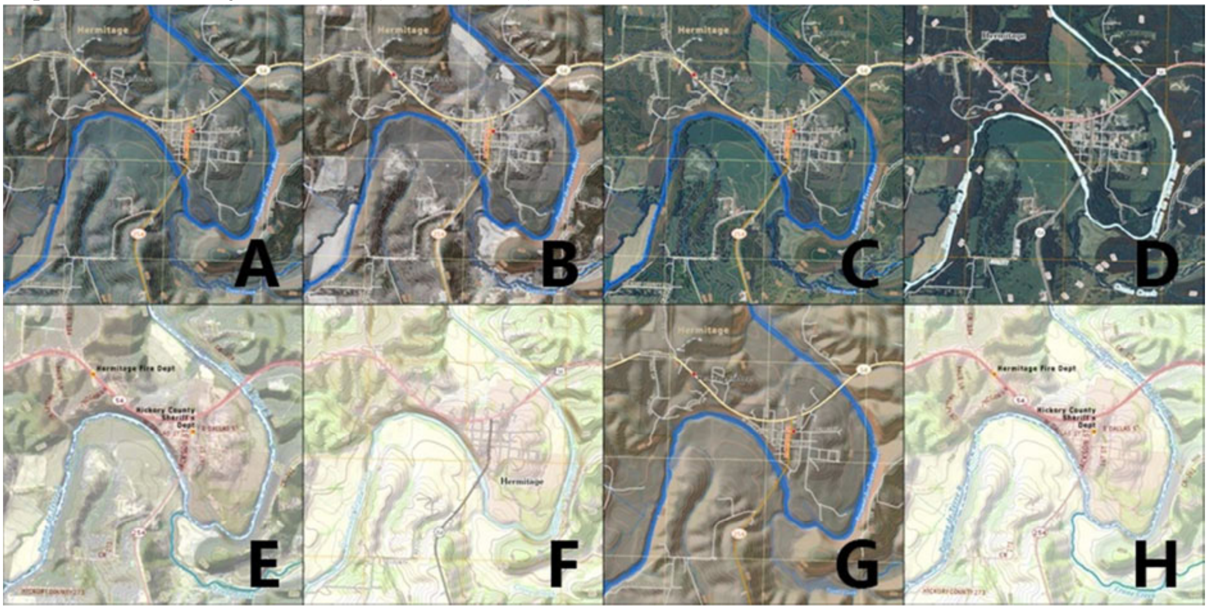

Figure 1. Eight map designs tested

Figure 2. Examples of map designs A and H.

APPROACH AND METHODS

Eight different locations from across the United States were chosen to reflect the diversity of the nation's landscape, ranging across characteristics such as urban/rural, flat/mountainous, and dense/sparse. Five-by-five-inch (12.6cm) sample squares were chosen at each location for implementation of the eight designs. The locations are each presented in thumbnails in Figure 3, all drawn in design D, and each identified by the code name given to them by the authors.

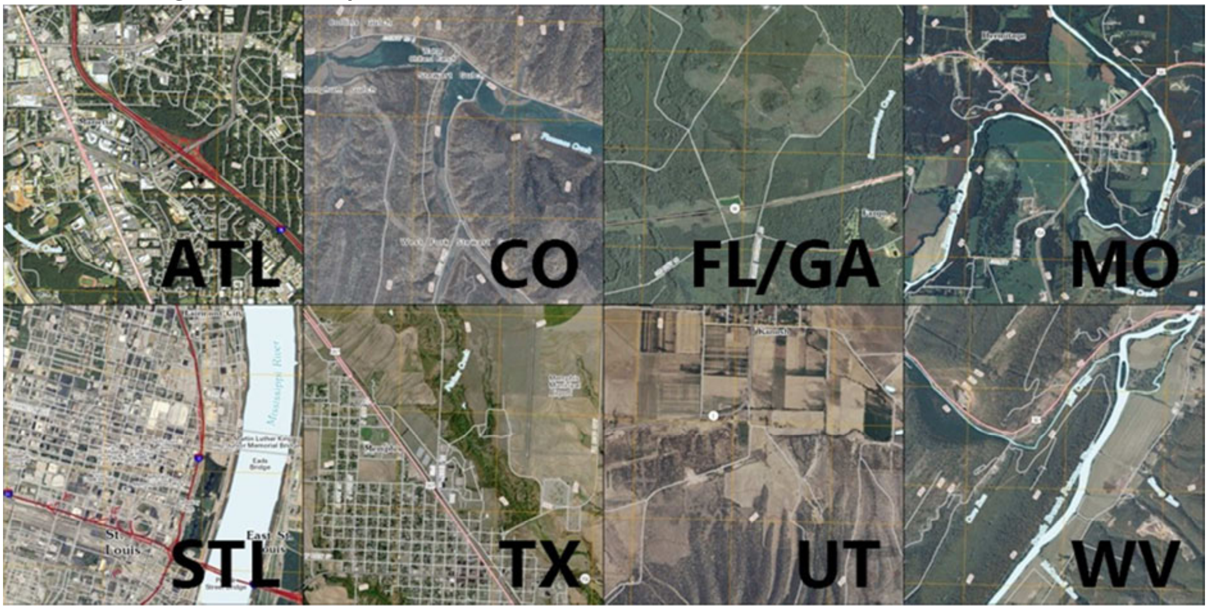

Figure 3. Eight map locations tested. Originals are 5-inches (12.6cm) square.

Thirty-two members of the Penn State University community were solicited to participate in our research study. Participants were explicitly chosen as adult non-specialists in maps or geography, so as to model the non-cartographic-specialist persons the USGS foresees as the most frequent users of topographic maps, particularly in emergency response and resource management scenarios. A digram-balanced Latin Squares experimental design was used to distribute participant responses. Rather than expose each participant to all 64 possible permutations between design and location, participants were distributed among eight groups, with four participants per group. The members of each group were shown a series of eight maps, the set of which represented all map designs and all locations, covering a total of eight map/design permutations; each group was shown a different set of eight maps, such that all 64 permutations were observed across all test participants. Figure 4 illustrates this scheme, with columns representing the set of eight maps each group observed. All participants observed all maps on paper, printed in full color at 600 dpi by a color laser printer from PDFs exported from ArcGIS.

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8
A	FL/GA	MO	WV	TX	CO	UT	ATL	STL
B	MO	TX	FL/GA	UT	WV	STL	CO	ATL
C	WV	FL/GA	CO	MO	ATL	TX	STL	UT
D	TX	UT	MO	STL	FL/GA	ATL	WV	CO
E	CO	WV	ATL	FL/GA	STL	MO	UT	TX
F	UT	STL	TX	ATL	MO	CO	FL/GA	WV
G	ATL	CO	STL	WV	UT	FL/GA	TX	MO
H	STL	ATL	UT	CO	TX	WV	MO	FL/GA

Figure 4. The test order by design (A to H) and location for each subject group.

Three questions were developed by the authors for each map location, tailored specifically to the landscape features visible at that location. Some questions made use of single-letter annotations placed on the maps, used to draw reader attention to specific places. In the case of design F, an emulation of legacy USGS topographic maps (without orthoimagery) with relatively sparse feature labels, certain landscape features referenced by the questions were added to the map with Segoe Print font, meant to simulate additions that map readers such as emergency response personnel might make by hand on paper. Questions were used in brief map-reading exercises each participant was asked to undertake for each map they observed. Questions were scenario-based and generally modeled around emergency response and resource management issues. The goal of the questions was to ensure that participants were required to read the maps to answer spatial inquiries. Each question had correct and incorrect possible answers. As participants answered each question, they were also asked to indicate whether they were sure or unsure of their answer. For each participant, a score (0 - 3) was obtained for correct answers, and sure responses. Example questions, chosen from the total of 24 used in the experiment, are:

• Where is there more tree canopy: to the west or east of Interstate 75?

• If a forest fire begins in the south-west corner, which is in more immediate danger: the ranch or the school?

• If you had to land a helicopter in this square, where is the firmest ground (amidst swamp) to do it on, A or B?

• Memphis gradually declines in elevation in which direction, northwest or southeast?

• Archeologists have defined two promising dig sites and need to chose one. Which offers the best location for all these factors: not tree covered, on relatively flat ground, and not disturbing farm fields, C or D?

• Would Hermitage be in danger of flooding if Pomme De Terre River rose 15 feet?

In addition to the map-use exercise, participants were asked to consider the effectiveness of the design of each map shown to them with respect to how well it communicated the information necessary to answer the questions. Participants were asked to sort their eight maps in order of decreasing effectiveness, and to assign to each a design grade out of ten, with 1 being very poor and 10 being very good.

Map readability was assessed using the three variables collected in the experiment: design grade, correctness score, and sureness score. All numerical data collected was compiled and analyzed using SPSS (version 19) statistical software. All statistical tests were evaluated to 95% confidence intervals. Statistical tests used were the following:

- two-way analysis of variance (ANOVA): a test for significant difference across populations in their mean values of a dependant variable, taking two predictor factors into account both singly, and in interaction;
- Tukey's Honestly Significant Difference (HSD): a post-ANOVA test for determining which population means are different from which, and by what relative quantities;
- ordinal regression: a test for dependence of an ordinal variable on one or more predictor variables.

RESULTS AND DISCUSSION

As mentioned in the introduction, it was generally found that significant impact on readability was attributed to location and the interaction of design with location, though design alone did not exert statistically significant influence. This pattern was expressed in each of the various analyses applied to the three measures of map readability in this study (design grades, correct answers, and sure answers).

Several descriptive statistics were calculated from tabulated participant responses. Means of design grade, irrespective of location, were calculated as follows, in order of highest to lowest (all grades out of 10): H (6.69), C (6.28), D (6.25), E (5.78), A (5.56), F (5.48), B (5.44), and G (5.34). As test respondents were explicitly asked to rate map designs for effectiveness of information communication, this sequence suggests that a map without orthoimagery (e.g. design H) may be clearest of all, but designs with orthoimagery (e.g. C and D) can closely compare. Mean grades were also seen to vary across map location: MO (7.31), WV (7.22), ATL (6.00), UT (5.80), STL (5.76), TX (5.47), CO (5.41), and FL/GA (4.19).

Design grades were observed to have a normal probability distribution, and were subjected to a two-way analysis of variance (ANOVA) test, with design and location as test factors. The output of this analysis is given in Figure 5. As the results indicate, differences between the means of grades given across the eight designs were not statistically significant, whereas such differences across location, and across design by location, were significant. The significance of the second term, design by location, indicates that design does in fact influence readers' evaluation of the clarity of a map, though the magnitude with which it does this may have been unobservable by this study or be quite different by location type such that design effect alone cancels out in the overall numbers.

Dependent Variable:Grade

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	667.069[a]	63	10.588	2.275	.000
Intercept	8771.493	1	8771.493	1884.469	.000
Design	54.233	7	7.748	1.665	.120
Location	234.046	7	33.435	7.183	.000
Design * Location	378.790	49	7.730	1.661	.008
Error	893.688	192	4.655		
Total	10332.250	256			
Corrected Total	1560.757	255			

a. R Squared = .427 (Adjusted R Squared = .240)

Figure 5. ANOVA results

To investigate differences in design grade predicted by location, the ANOVA test was followed by a Tukey HSD post-hoc analysis. Out of the 56 pairs of locations compared, 9 displayed statistically significant difference. These are presented in a truncated Tukey HSD output table in Figure 6 (without insignificant comparisons). These analyses indicate that a statistically-significant sequence with respect to design grades existed between at least seven of the eight map locations (in order of highest grades to lowest): ATL, MO, WV, CO, STL, TX and FL/GA. This means that ATL maps, for instance, were generally graded higher than others, regardless of which of eight map designs were seen.

Grade
Tukey HSD

(I) Location	(J) Location	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
ATL	FL/GA	1.812	.5394	.021	.160	3.465
CO	MO	-1.906	.5394	.012	-3.559	-.253
	WV	-1.812	.5394	.021	-3.465	-.160
FL/GA	ATL	-1.812	.5394	.021	-3.465	-.160
	MO	-3.125	.5394	.000	-4.778	-1.472
	WV	-3.031	.5394	.000	-4.684	-1.378
MO	CO	1.906	.5394	.012	.253	3.559
	FL/GA	3.125	.5394	.000	1.472	4.778
	STL	1.875	.5394	.014	.222	3.528
	TX	1.844	.5394	.017	.191	3.497
STL	MO	-1.875	.5394	.014	-3.528	-.222
	WV	-1.781	.5394	.025	-3.434	-.128
TX	MO	-1.844	.5394	.017	-3.497	-.191
	WV	-1.75	.5394	.030	-3.403	-.097
WV	CO	1.812	.5394	.021	.160	3.465
	FL/GA	3.031	.5394	.000	1.378	4.684
	STL	1.781	.5394	.025	.128	3.434
	TX	1.75	.5394	.030	.097	3.403

Based on observed means.
The error term is Mean Square(Error) = 4.655.

Figure 6. Truncated Tukey HSD results for significant comparisons only (out of 56 comparisons total)

Interactions between design and location, seen as significant in the ANOVA analysis, were explored visually with a parallel coordinates plot (PCP) of grade means by design for each map location. Figure 7 provides the PCP, with designs sequenced from left to right in descending overall mean grade order. In addition to illustrating the various grades given to map designs at various locations, the PCP allows for the visualization of how much variance existed between grades given to any particular design across the eight locations. It is apparent, for example, that designs such as H and D were graded with less variance than were F and G, while D experienced a low outlier grade when mapping location FL/GA.

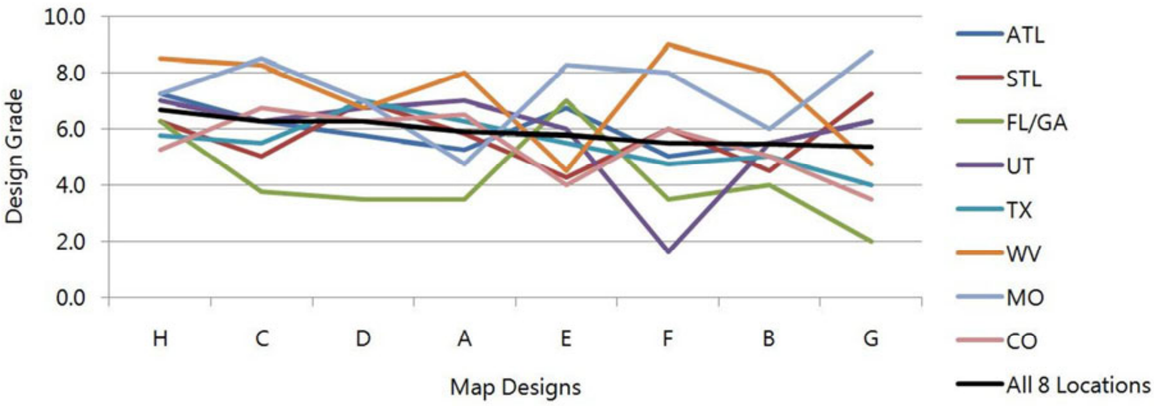

Figure 7. Parallel coordinates plot of grade means by design for each map location.

Numbers of correct answers and sure answers were each analyzed using ordinal regression logit models where map design and map location were factors. These analyses also generally supported the notion that location influenced readability with much greater power than did design.

Output for the logit model on the number of correct responses (Figure 8) indicated a significant likelihood that responses would be more correct (i.e., tending toward 3) for ATL, CO and MO (measured against the likelihood of correct responses for WV, taken by the model as a reference category). Interestingly, also, this model contained the only statistically-significant suggestion (at 95% confidence) that design affected readability (measured against reference category H), with design B bearing a likelihood that higher correct scores would occur more frequently.

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Threshold	[NumCorr = 0]	-2.952	.577	26.155	1	.000	-4.084	-1.821
	[NumCorr = 1]	-.741	.462	2.578	1	.108	-1.646	.164
	[NumCorr = 2]	1.141	.464	6.053	1	.014	.232	2.051
Location	[Design=A]	.296	.473	.390	1	.532	-.632	1.223
	[Design=B]	1.344	.507	7.027	1	.008	.350	2.337
	[Design=C]	.882	.488	3.271	1	.071	-.074	1.838
	[Design=D]	.948	.490	3.741	1	.053	-.013	1.908
	[Design=E]	.022	.470	.002	1	.963	-.899	.942
	[Design=F]	.163	.471	.120	1	.729	-.761	1.087
	[Design=G]	.324	.474	.469	1	.494	-.604	1.253
	[Design=H]	0[a]	.	.	0	.	.	.
	[Location=ATL]	1.519	.512	8.789	1	.003	.515	2.522
	[Location=CO]	.984	.486	4.093	1	.043	.031	1.937
	[Location=FL/GA]	.464	.472	.964	1	.326	-.462	1.390
	[Location=MO]	1.287	.499	6.646	1	.010	.309	2.265
	[Location=STL]	-.523	.465	1.261	1	.262	-1.435	.390
	[Location=TX]	-.529	.465	1.290	1	.256	-1.441	.384
	[Location=UT]	.497	.473	1.105	1	.293	-.430	1.425
	[Location=WV]	0[a]	.	.	0	.	.	.

Link function: Logit.

a. This parameter is set to zero because it is redundant.

Figure 8. Logit model results for the number of correct responses.

Several likelihoods that counts of sure answers would be higher were significant across various map locations (ATL, CO, FL/GA, STL, TX), while none were significant across map designs (Figure 9). This is not a finding from which to draw generalizations, since question sets were customized to the particular landscape seen at each location, and varied in difficulty by location.

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Threshold	[NumSure = 0]	-4.352	.543	64.339	1	.000	-5.415	-3.288
	[NumSure = 1]	-2.346	.493	22.682	1	.000	-3.311	-1.380
	[NumSure = 2]	-.079	.462	.029	1	.864	-.986	.827
Location	[Design=A]	-.801	.473	2.868	1	.090	-1.728	.126
	[Design=B]	-.578	.473	1.495	1	.222	-1.504	.348
	[Design=C]	-.380	.473	.645	1	.422	-1.306	.547
	[Design=D]	-.214	.473	.205	1	.651	-1.142	.713
	[Design=E]	-.386	.473	.668	1	.414	-1.313	.540
	[Design=F]	-.192	.473	.164	1	.686	-1.119	.736
	[Design=G]	-.203	.473	.185	1	.667	-1.131	.724
	[Design=H]	0[a]	.	.	0	.	.	.
	[Location=ATL]	-1.007	.479	4.422	1	.035	-1.945	-.068
	[Location=CO]	-1.413	.482	8.594	1	.003	-2.358	-.468
	[Location=FL/GA]	-1.993	.488	16.693	1	.000	-2.949	-1.037
	[Location=MO]	.447	.484	.853	1	.356	-.502	1.397
	[Location=STL]	-2.522	.495	25.946	1	.000	-3.492	-1.551
	[Location=TX]	-2.556	.496	26.590	1	.000	-3.527	-1.584
	[Location=UT]	-.846	.477	3.136	1	.077	-1.781	.090
	[Location=WV]	0[a]	.	.	0	.	.	.

Link function: Logit.

a. This parameter is set to zero because it is redundant.

Figure 9. Results for sureness of answers.

CONCLUSIONS AND FUTURE PLANS

Statistical analyses of test results have almost unilaterally indicated a significant influence of map location on map readability, while any such significant influence exerted by map design alone remained unobservable. While this study set out to examine differences in readability introduced by various map designs, the general interpretation of the authors is that readability differences introduced between the map designs tested were not comparable to those introduced by the various landscapes mapped, even though all locations were seen with all designs. Differences in map design alone were not observed to significantly affect map reader impressions (grades), performance (correctness) or certainty (sureness). All eight map designs used in this study were designed to be as clear as possible; findings from our analyses suggest that a choice between differing map designs, so long as all designs considered are legible and clear, does not seem to pose a potential risk to the accuracy with which the resulting maps can be used. Instead, with any given design, certain locations across the country may be harder or easier to interpret from a topographic map because of landscape differences.

As mentioned before, this research has been a pilot study into various map designs for orthoimagery overlay for the USGS. Plans for the near future include follow-up experiments, particularly wherein location will be controlled, and participant feedback will be sought across designs with all other variables kept constant. Future experimentation will also involve larger populations of topographic map users in the United States, and be drawn from broader user communities than within a single university. It is expected that experimentation of the sort just described, by excluding location effects, will make readability differences between map designs with orthoimagery more pronounced.

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