

Chapter 3: Beyond the Bezel: Utilizing Multiple Monitor High-Resolution Displays for Viewing Geospatial Data*

* This chapter is a manuscript in preparation for submission to the journal *Cartography and Geographic Information Science*.

Luebbering, Candice R.; Carstensen, Laurence W.; Campbell, James B.; Grossman, Lawrence S.

Candice R. Luebbering*
Department of Geography
115 Major Williams Hall (0115)
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061
candice@vt.edu
Phone: (540) 230-8156
Fax: (540) 231-2089

Laurence W. Carstensen Jr.
Department of Geography
115 Major Williams Hall (0115)
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061
carstens@vt.edu
Phone: (540) 231-2600
Fax: (540) 231-2089

James B. Campbell
Department of Geography
115 Major Williams Hall (0115)
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061
jayhawk@vt.edu
Phone: (540) 231-5841
Fax: (540) 231-2089

Lawrence S. Grossman
Department of Geography
115 Major Williams Hall (0115)
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061
lgrossmn@vt.edu
Phone: (540) 231-5116
Fax: (540) 231-2089

* Corresponding author

Abstract:

Multiple monitor configurations provide attainable, low cost ways to create large, high-resolution desktop displays. Increased screen real estate is particularly useful for viewing and interpreting rich, complex geospatial datasets as both context and amount of detail can be simultaneously increased. To explore the utility of multiple monitor displays for viewing geospatial data, this experiment required 57 subjects to perform a variety of map and image reading tasks using raster and vector data on one of three different monitor configurations: one (1280 x 1024 pixels), four (2560 x 2048 pixels), and nine (3840 x 3072 pixels). A computer program captured each subject's performance by recording answers, mouse click locations,

viewing areas, tool usage, and elapsed time. A post-experiment questionnaire obtained additional qualitative feedback about subjects' testing experiences. Overall, subjects performed more efficiently on the larger display configurations as evidenced by a reduction in test completion time and in the amount of virtual navigation (mouse clicks) used to finish the test. Tool usage also differed among monitor conditions, with navigation tools dominating while using a single monitor and selecting tools (tools used to provide answers) predominating on the nine monitor display. Although overall results indicated the effectiveness of larger displays, task-level analyses showed that performance varied considerably from task to task.

3.1 Introduction

Geographic information systems (GIS) and high-resolution imagery have an increasingly prominent role in many research institutions, government organizations, and private sector businesses. This trend creates the need for new visualization formats that can make full use of high-resolution digital data. This research explores the utility of a low-cost solution of mounting multiple monitor displays to fulfill this need. By assigning experienced geospatial data users to perform map reading tasks on various display sizes and resolutions, this research investigates the possible task-completion benefits, usage strategies, and usability issues associated with using large, high-resolution multiple monitor displays for geospatial data.

Map layout parameters restrain cartographers and the amount of information they can usefully display on a map. When working in the traditional paper map medium, cartographers must consider the constant tradeoffs between the size, scale, and coverage of a map (Figure 3.1a). Specifying the parameters of one of these aspects restricts the available options for the other two. For example, once the physical size of a map is set, the cartographer must prioritize the importance of coverage area and scale, as an increase in one will result in a decrease in the other (Lloyd and Bunch 2003). Unfortunately the desired specifications for all three variables are not always attainable.

With the advent of geographic information systems (GIS), digital maps viewed on computer monitors have become at least as commonplace as their paper map counterparts. Computers have greatly aided cartography. The Internet provides rapid access to rich geographic data and imagery, and GIS tools allow for map design versatility. Despite these advantages, computer cartography faces the same cartographic limitations as paper cartography. Computer

screens are fixed in size and limited in resolution. The opposing requirements for greater map coverage area and scale of detail must compete because the physical size of the viewing area is fixed. Perceptually, users' needs for both greater context and visible detail are at odds (Figure 3.1b). If users need to see more detail, they lose the overall context; however, if they view the entire coverage area, they lose access to fine detail. Typical computer displays therefore limit the viewer's ability to utilize fully digital maps and data sources because the user is visually constrained by the bounding bezels of a single desktop monitor. To overcome the fixed size limitation of computer monitors, panning and zooming functions are essential for navigation (Slocum et al. 2005). These tools allow users to alternately capture desired coverage area and scale, providing the ability to quickly cycle back and forth between the two for comparison if one static view does not suffice. Frequent panning and zooming, however, have major implications on map perception. Panning at a large scale creates a loss of context as the entire map is not visible, while zooming out to obtain the full context alters the scale and results in a loss of detail (Brown 1993). High-resolution data and imagery can rarely be displayed to simultaneously view their full extent and quality.

One display method for overcoming the conflict between context and scale are focus plus context screens. These interfaces combine a large low-resolution display with an embedded display area of high-resolution (Baudisch et al. 2002). While this is an improvement from single small displays, the interface still has a separation between context and scale. Both the desired context and scale of the entire view area are not visible at one time, instead only portions of the viewing area have both desired context and fine detail available. Moving beyond the focus plus context screens, thin, flat liquid crystal displays (LCDs) or plasma screen monitors are currently replacing bulky cathode-ray tube (CRT) monitors. In addition, many computers have the built-in capability to support multiple monitors. These coincident trends provide the means for making low cost, high-resolution displays by configuring multiple monitors to act as a single display (Hutchings et al. 2004a) (Figure 3.2). If image size were all that mattered, then projection of images could help solve the problem, but projectors only increase display area, not resolution, making high-quality imagery appear pixilated when viewed at close range. Multiple monitor displays, however, increase area and maintain high-resolution across the entire display so that imagery appears clearly even when users are close to the screen (Bezerianos & Balakrishnan 2005). Such displays are useful for a variety of computing tasks such as group collaboration,

viewing multiple applications simultaneously, or for enhancing video gaming experiences. In particular, maps displayed on multiple monitor configurations provide a new geospatial visualization opportunity by incorporating both larger coverage areas and greater amounts of detail into a single view. The previously fixed small size of the viewing area is expanded, providing less of a constraint to obtaining desired context and detail.

Researchers have not thoroughly studied the effectiveness of large, high-resolution displays, especially for viewing maps and imagery. Computer scientists specializing in human-computer interaction have largely conducted current research on multiple monitor displays. In most of these studies, typical office computing tasks (Ball and North 2005a; Grudin 2001; Simmons 2001; Tan & Czerwinski 2003), video game interfaces, virtual environments (Ni et al. 2006; Polys et al. 2005), or perception tasks (Czerwinski et al. 2003; Tan et al. 2003) were the focus of usability research and data collection. The few studies that have examined visualization of geospatial information used subjects who were not experienced in working with such data and visualizations (see Ball and North 2005b; Ball et al. 2005).

3.2 Related Work

While the quantity and quality of geospatial data and imagery have greatly increased, the viewing windows have remained relatively the same size with desktop monitors providing only a small view into an enormous virtual digital world (Czerwinski et al. 2006). Currently, display spaces for most desktop computer users occupy 10% or less of their physical workspace (Czerwinski, et al. 2006); Grudin (2001) estimated that desktop monitors cover only approximately 10% of our fixed field of vision. It is worthwhile to explore how users would function with displays that occupy larger proportions of their work areas and vision. Ware (2004) explored the efficiency of displays by comparing the ratio between brain pixels (retinal ganglion cells) and screen pixels, with the ideal being a one-to-one ratio. In foveal (central) vision with low-resolution displays, there are multiple brain pixels per screen pixel, so the brain is receiving redundant information. While a projector increases display size, the resolution of the display is unchanged so the larger image does not provide the brain with any new information. To enhance the effectiveness of larger displays, there should be a concurrent increase in the number of pixels so that more information is included on the display.

Although no cartographic research has handled multiple monitor designs yet, the field does provide complementary studies regarding visual search techniques and image size. These findings help to form hypotheses as to how readers might utilize maps and imagery on large, high-resolution displays. Lloyd and Hodgson (2002) speculated about the implications of geographic scale on visual search, hypothesizing that small photographs may produce longer reaction times due to the detailed information to process, while large photographs may also create longer reaction times due to the eye movement necessary to take in the entire image. Lloyd et al.'s (2002) subjects categorized land use using different sizes of aerial photographs with scale maintained for all images. In that study, when the display area was increased, the coverage area increased as well, providing more information to viewers. Both accuracy and confidence increased with the use of larger photographs, suggesting that a reduction in scale or the absence of neighboring information (context) increases task difficulty. Lloyd's findings pertain well to this research because, if users complete computer-based work at a certain scale, a larger display size and resolution should prove beneficial since it provides more information and context.

Enoch (1959) pursued the relationship between display (aerial map) size and map tasks, incorporating eye fixation measurements to gauge processing time and visual search movements. He found that eye fixations were centrally concentrated; users were less likely to discover objects located near the edge of a map. Subsequent research has supported this finding, confirming faster target acquisition when targets were located centrally on a map (Lloyd 1997). The study indicated a possible pitfall for larger displays because peripheral information may be overlooked and larger displays provide larger peripheral areas relative to smaller monitors. In a follow-up study to Enoch's work, Wood (1993) found that the number of eye fixations increased as image size increased. He also noted that the proportion of fixations falling within the image increased with image size, concluding that larger maps make better use of eye fixations since more fixations fall on the information presented. However, although the research of Enoch (1959) and Wood (1993) generated many implications for large map displays, they both focused on the smaller end of the map size spectrum, making recommendations for minimum map sizes to be used for presenting information, but not pursuing a maximum size recommendation.

While cartography provides pertinent research on visual search with maps and imagery, computer science has specifically explored display size and task performance. Initial studies in

the field did not involve multiple monitors. Simmons (2001) compared performance of office computing tasks on individual monitors ranging from 15" to 21" in size. Results revealed enhanced productivity on 21" monitors for tasks involving large database searches. Another study conducted by Tan et al. (2003) found that spatial orientation task performance using a wall display was 26% better than task performance on a smaller display desktop monitor. This improvement came solely from an increase in display size as resolution was unchanged. These findings provide extra motivation for exploring large, high-resolution display options since improvement already occurs both with small display increases (Simmons 2001) and with display area increases without resolution increases (Tan et al. 2003).

Computer design trends have provided a way around the expensive and difficult roadblock of acquiring a single, large, high-resolution monitor. First, several computer operating systems can support multiple displays and advancements in graphics cards support this ability as well (Czerwinski et al. 2003). In addition, thin, lightweight, flat screen LCD screens with small footprints are replacing bulky CRT monitors. Prices are predicted to drop continuously on LCD displays and already it is estimated that the average consumer can acquire 25% more pixels for the same price by buying two 17" LCDs instead of purchasing just one 21" LCD (Czerwinski et al. 2006). With this price trend and the fact that even laptop computers now also support multiple displays (Czerwinski et al. 2003), the use of multiple monitor displays will likely grow in the future. These displays are already enjoying more widespread use in homes, public places, and office spaces (Hutchings et al. 2004a).

Multiple monitor usage research in computer science provides insight as to the functionality and possible benefits of such configurations. Hutchings et al (2004b) conducted a longitudinal study that monitored users' typical computing activity, focusing on window visibility and use of display space. Over three weeks, these researchers found that users of large multiple monitor displays averaged 6.8 visible windows at a time while users of single monitors averaged only 3.5. Concerning the use of display space, single monitors had no available empty space 48% of the time, while large multiple monitors were entirely full only 14.3% of the time, suggesting that single monitor users are pressed for space while multiple monitor designs frequently provide free screen space more often. Large monitor display users took advantage of the additional screen space with less than one-fifth of the display space empty 80.8% of the time. Despite the obvious drawback of the effect of monitor bezels (frames surrounding individual

monitors) interrupting the display space (Figure 3.2), visual discontinuity does not always hinder results. Tan and Czerwinski (2003) found that central bezels did not distract subjects performing proofreading and monitoring tasks using a two monitor display. Half of the participants indicated a preference toward placing their tasks across the bezels. Ball & North (2005a) incorporated a larger 3 x 3 monitor configuration (17" monitors with 3840 x 3072 pixels) and argued that greater concentration is maintained with large, high-resolution displays because less virtual navigation is required. This finding is a key advantage in relation to the use of such displays for viewing maps because users can maintain a more stable sense of context, specifically if they are panning and zooming less. However, in additional work that also used a nine monitor display, Ball and North (2005b) noted that larger displays require more physical navigation, such as head turning, chair movement, or standing up to view the display. Researchers found high-resolution displays to be particularly effective in improving performance times in search and comparison tasks of relatively smaller targets (Ball and North 2005b) which may contribute to increased efficiency in analyzing digital imagery sources that involve fine detail.

Most relevant to the research described in this article, Ball et al. (2005) used a map-based experiment to evaluate navigational performance. Results showed that users of a 3 x 3 monitor configuration (17" monitors, 3840 x 3072 pixels) vastly outperformed those on a single monitor. On the multiple monitor display, subjects performed search and route tracing tasks twice as fast with 70% fewer mouse clicks and 90% less window management (Ball et al. 2005). While these most recent studies utilized maps, researchers designed the experiments from a human-computer interaction perspective and used subjects with little or no map reading experience.

3.3 Methods

3.3.1 Display

For this research, we arranged a multiple monitor display comprised of nine 17" flat screen LCD monitors in a 3 x 3 configuration mounted on a frame (Figure 3.2). The resolution of each monitor was 1280 x 1024 pixels, making the entire display's resolution 3840 x 3072 pixels. We could control how many and which monitors were functioning at any given time, allowing for any desired configuration. To research the effectiveness of different display sizes,

this experiment was performed using three monitor conditions: one monitor (1280 x 1024 pixels), four monitors (2560 x 2048 pixels), and nine monitors (3840 x 3072 pixels) (Figure 3.3).

3.3.2 Testing Software

A student-developed ESRI MapObjects program, which allowed easy test compilation and manipulation of maps and imagery based on simple text scripts, administered the test. The program supported four response formats: (1) select map features (with selected features stored as shapefiles), (2) type-in response, (3) multiple choice, and (4) on-screen digitizing (with digitized polygons stored as shapefiles). The program also recorded every mouse click during each test session, including the: (1) tool used, (2) location of the mouse cursor, (3) view area of the map or image, and (4) time of the click. These data permitted us to review a subject's entire session and examine how he or she navigated the maps and images to choose responses. The program prompted the questions and response types uniformly on all monitor configurations, removing the experimenter from providing any direct guidance during the experiment.

3.3.3 Test Content

The test consisted of a series of nine maps and images paired with 18 tasks (Table 3.1). Task types included visual search, size comparison, attribute comparison, data inference, route analysis, and digitizing. These tasks varied in complexity from simple single search tasks to more interpretive responses such as analyzing an aerial photograph or inferring a thematic trend from related information. Maps varied in number of layers and in format, raster or vector. Two reasons motivated the intentional inclusion of a wide spectrum of geographic visualizations and map reading tasks: 1) to emulate the workplace scenario of tackling many different types of tasks and 2) to allow a question-by-question breakdown to determine whether performance varies at the task and map level for different display sizes. To avoid biasing the test in favor of a particular display size, some tasks required subjects to zoom in to obtain the correct answer regardless of monitor configuration. Experiment designers selected topics so that subjects would not be familiar with them, assuring that the test evaluated their ability to use the map to extract information, rather than their familiarity with the topic at hand. Three versions of the test differed with respect to the order of presentation of maps and questions. The three versions were randomly utilized for subjects. We controlled any possible learning experienced as subjects became more comfortable with the format by altering the sequence of maps and questions.

3.3.4 Subjects

This focus of this experiment was the issue of display size for map reading tasks, not the subject's ability or inability to read a map; therefore, subjects were required to have completed or be enrolled in at least one map-reading or GIS-related course or have career-related experience with computer-displayed maps. Nineteen subjects participated for each monitor configuration (one, four, and nine) for a total of 57 subjects, all students of Virginia Tech. Volunteers were recruited using geography major and geography course listservs. Volunteers received extra credit in a map-reading course for their participation and monetary compensation if they were a top performer as gauged by correct answers and test completion time. Forty males and seventeen females participated. Subjects ranged from 18 to 52 years of age, with an average age of 22.77. Sixty-nine percent of the subjects were college juniors or above, including graduate students. The median number of college-level geography courses completed by subjects was five and 79% of subjects had used a GIS before. Eighty-four percent of subjects were geography majors.

3.3.5 Experiment Format

The format of the experiment included a tutorial, test, and post-experiment questionnaire. Subjects received documents reviewing the program's response types and toolbar (Appendices 1 and 2). Next, the researcher guided subjects through a brief tutorial on their specific monitor configuration. Once subjects were comfortable with the format and received responses to their questions, they completed the test independently. The researcher recorded additional anecdotal information and did not interfere with subject performance unless there were problems or questions to be addressed (e.g. computer froze, question clarification). Upon conclusion of the test, subjects completed a questionnaire to provide demographic information, level of map reading expertise, and perceptions of the display and experiment.

3.4 Results

With the data collected by the testing program, our results cover numerous aspects of subject behavior. Not only is the accuracy of question responses evaluated, but also usage efficiency including elapsed time, virtual navigation, and tool usage. The post-experiment questionnaire provided additional information regarding the subjects' experiment experience.

3.4.1 Accuracy

Fourteen questions had specific correct answers (not including two digitizing and two route tracing tasks). Users on the one monitor condition averaged 12.47 correct answers; users

on the four monitor display averaged 12.05; and those on the nine monitor display averaged 12.37 correct answers. Using a single-factor ANOVA analysis, these groups were not found to be significantly different ($p = 0.595$). Because correct answers were evenly distributed across monitor conditions, further analysis focuses on user behavior differences among monitor conditions using all subject data.

3.4.2 Elapsed Time

With the computing system used for this research, maps and images took longer to render on the four and nine monitor configurations than on the single monitor. Users could not request tools or type input while the images were rendering, thus their recorded times were exaggerated. This technical issue will likely be overcome in the near future with computer processing improvements; thus, as in Polys et al. (2005), a rendering time handicap was accounted for to set the playing field level for all monitor arrangements. Subjects were told to disregard time on digitizing tasks since digitizing accuracy and speed provide conflicting motivations; therefore, digitizing tasks were not considered in the elapsed time results

The corrected overall elapsed time results by monitor condition are in Table 3.2. The range, minimum, and maximum times all declined from the one monitor display to the nine monitor display. A single-factor ANOVA test revealed a significant difference among the three monitor conditions ($p < 0.001$). ANOVA, however, does not indicate exactly which groups are significantly different from each other. To establish this, we used Tukey's studentized range (HSD) test, a multiple comparisons test that tests the significance of each pair wise comparison. At $\alpha = 0.05$, the one monitor group was significantly different from both the four and nine monitor groups, but the larger display groups were not significantly different from each other. At the individual question-level, analysis revealed greater variability in elapsed time per task. While overall test session elapsed time decreased, individually only six of the 16 non-digitizing questions had significantly different times among monitor conditions (Table 3.3). The six tasks with significantly different results all showed a decrease in average elapsed time spent on the task from the one monitor condition to the larger configurations, with the nine monitor display having the lowest average on four tasks, and the four monitor display the lowest average on the remaining two.

3.4.3 Virtual Navigation

Virtual navigation was quantified by tabulating the number of mouse clicks used to accomplish a task (all tools included). Table 3.4 shows the overall test results for the three monitor conditions. Digitizing tasks were not included because digitizing accurately involves more vertices, which increases virtual navigation and could disguise trends on non-digitizing tasks. The average, minimum, maximum, and range of the number of mouse clicks used to complete the entire test decreased as display size increased. The results by display size were significantly different ($p < .001$) as shown by a single-factor ANOVA test. According to Tukey's studentized range test with $\alpha = .05$, the one monitor group was significantly different from the four and nine monitor groups, which, again, were grouped together by the test. At the question level, seven of 16 questions were significantly different in virtual navigation among monitor conditions (Table 3.5).

Figure 3.4 provides a visual of the difference in the frequency of virtual navigation and also the location of mouse clicks in reference to the information needed to complete a task. The program recorded the location of each mouse click along with the zoom window of the map in view when the subject made each click. Since individual clicks could represent simply a corner of a zoom box dragged over a large area, this figure depicts the centroids of each zoom window visible when a subject submitted a mouse click.

Corresponding to the decrease in virtual navigation, the researcher directly observed more physical navigation by subjects as they used the four and nine monitor displays. Physical movements included leaning forward to examine portions of the screen, leaning back to look upwards, head turning to search the entire screen, and standing up to search the top of the display.

3.4.4 Tool Usage

The testing program recorded the tool used with every mouse click, allowing the ability to track the distribution of tool usage. Different display sizes alter the frequency of use for different tools. The types of tools fall into two general categories: 1) searching: zooming and panning (zoom in, zoom in fixed, zoom out, zoom out fixed, zoom to previous extent, zoom to next extent, zoom to full extent, and pan) and 2) question answering: selecting and digitizing (select features, clear select features, and digitize). This dichotomy provides a simple breakdown to view tool usage change (Figure 3.5). Over all questions, the clear trend shifts from the majority of tool usage being zooming and panning on one monitor (58% zoom/pan, 42%

select/digitize), to a majority of tool usage selecting and digitizing an answer on nine monitors (25% zoom/pan, 75% select/digitize). To evaluate this change statistically, each subject's tool usage was standardized into the percentage of their tool usage that was zooming and panning. A single-factor ANOVA test showed that the percentage of zooming and panning tool usage was significantly different among the monitor groups ($p < .0001$). Further, Tukey's studentized range test ($\alpha = .05$) reported each monitor condition as significantly different from the others (Table 3.6). At the question level of analysis, tool usage did not consistently hold to the overall trend. Some tasks reflected the same pattern (Figure 3.6a), others showed a reversal (Figure 3.6b), and many exhibited unique distributions somewhere in between.

3.4.5 Subject Responses about Displays

The post-experiment questionnaire, in addition to collecting demographics, asked subjects about their previous map display experiences and the configuration used in the experiment. Fifty-four percent of subjects cited computers as the map display medium used most often, while 28% had used a multiple monitor configuration before, with most of those having used two monitors. Subjects rated the suitability of the display size they used for the experiment from a rating of "1: much too small" to "5: much too large". Responses shifted from the small end of the spectrum for one monitor subjects to the too large end for nine monitor subjects, while 84% of four monitor display users cited that setup as neither small nor large (Table 3.7). The average rating for the display sizes was 2.28 for one monitor users, 3.16 for four monitor users, and 3.53 for nine monitor users.

Subjects had the option of providing additional comments if so desired. The following are excerpts from these collected comments:

One Monitor Responses:

- "one monitor led to multiple zooms in and out"
- "monitor too small"

Four Monitor Responses:

- "fabulous resolution!"
- "the monitors made it easier to find things"
- "having boundaries to a screen is pretty obnoxious"
- "'step' between monitors is visually confusing"
- "missing info due to screen borders and such"

Nine Monitor Responses:

- “I didn’t have to squint to look for a place, it was easy to see.”
- “the monitor borders were very distracting”
- “a little too big”
- “personally, I’d like to have separate monitors for separate tasks, but I prefer one monitor for a single task”

3.5 Discussion

3.5.1 Subject Pool

To make the results most applicable to the wider geospatial community, we desired a subject pool comprised of experienced map and GIS users. Given the education level, coursework experience, and GIS experience reported by subjects, they provided a good representation of geospatial professionals as most are future professionals in the field themselves.

3.5.2 Elapsed Time

One way to measure the efficiency of subject use of the display size is to evaluate the amount of time taken to complete the test. The average elapsed time to complete the test dropped approximately five minutes between the one and four monitor conditions, a 29% reduction in time. Given that test sessions lasted only approximately 30 minutes at most (not including digitizing tasks), this represents a large efficiency improvement in a short span of time. If this time improvement of conservatively five minutes off of every 30 minutes (the average test completion time for one monitor was only 17 minutes) when switching from one monitor to four holds over longer periods of time, this could increase the number of tasks attended to by geospatial professionals in a typical workday. Efficiency benefits, however, are task specific, as the question-level analyses revealed a fluctuation in elapsed time results from task to task. Possible time efficiency gains in the workplace therefore hinge on the type of tasks undertaken.

The time efficiency trend of large displays may, however, have diminishing returns when the display is larger than four monitors since the four and nine monitor groups were not significantly different. In fact, the average elapsed time for the nine monitor group was three seconds longer than the four monitor group. It is also possible, though, that the nine monitor display may show further time efficiency improvements after individuals have gained experience or training with the configuration. Most subjects in this experiment (72%) had not used a

multiple monitor setup before. Switching from one monitor to four is likely an easier adjustment than moving from one monitor to nine.

3.5.3 Virtual Navigation

Virtual navigation refers to the number of mouse clicks used by subjects during the test. Tracking mouse clicks was a way to gauge the amount of display interaction used by subjects to achieve a task. There was a 140 click difference between the one monitor and nine monitor group averages, with nine monitor display users clicking on average 52% fewer times. Although the four and nine monitor groups were not significantly different, the nine monitor group average was 20% less than the four monitor group. It is possible, as mentioned before, that users need time to adjust to the nine monitor display before true efficiency effects are realized. The tendency to focus centrally on the screen and not to use the periphery (Enoch 1959) may take experience to overcome. It is also possible that virtual navigation experiences diminishing returns beyond a certain display size. The descriptive statistics show a reduction in the range of the number of mouse clicks on the larger displays. Less variability in virtual navigation shows greater agreement in user behavior and further supports the overall trend of less virtual navigation for four and nine monitor users. During this relatively short test, large display users expended less effort pointing, clicking, and navigating, allowing more free time to view and interpret the on-screen information than users of the single monitor.

Evaluating virtual navigation on individual questions revealed that the trend is more complex than it appears from the overall results. Throughout the course of many different types of geospatial tasks, or perhaps throughout the course of one's workday, time devoted to virtual navigation decreased with larger displays; however, there is a great amount of between-task variability. Of the seven statistically significant results, only two questions mimicked the overall trend of the one monitor condition having the most clicks and the nine monitor condition having the fewest. On one task, the one monitor group had the fewest mouse clicks. The task itself explains this result. For this task subjects had to select the largest region in a specific postal zone of Germany. On the multiple monitor configurations, some of the zones and internal regions crossed bezels giving them a relatively larger and distorted appearance. Subjects on the large displays spent time navigating to see the different zones bezel-free before choosing their answer.

The increase in physical navigation that accompanied the larger display sizes indicates that an increase in display size may not reduce total navigation, but may instead produce a

tradeoff with less virtual navigation supplemented by more physical navigation. Since the type of navigation people desire is a matter of personal preference, individuals could choose their display size based on the type of interaction they prefer. Another item not fully addressed in this research is the location difference of mouse clicks. As seen in Figure 3.4, there is a noticeable reduction in both the number of mouse clicks and the spatial spread of these clicks as they appear to be more concentrated near important information on the larger displays. Users not only click less often, but are better informed before they click the mouse.

3.5.4 Tool Usage

With every mouse click, we knew what tool subjects used to interact with the display and could therefore look for any changes in the distribution of tool usage. Each step to a larger display size coincided with a significantly lower proportion of zooming and panning tool usage, with a reversal from a zooming and panning majority on one monitor to a selecting and digitizing majority on nine monitors. These sets of tools are fundamentally different. Zooming and panning, used to navigate and locate information on the screen, are the information gathering portions of a task. Selecting and digitizing, used to choose an answer or interpret a solution, are the reporting portions of a task. On the larger displays, subjects directed more tool usage to answering the question than to navigating to the information necessary to determine the answer. This indicates greater task attentiveness since less zooming and panning means users had a more stable view of context and scale, a useful result especially if it holds over longer periods of time. For example, if users have an impending deadline, a larger display size may make the work more feasible or less stressful since less effort is spent navigating.

As with other results, the change in tool usage varies from task to task. The overall trend masks the influence of task type on tool usage. The task of digitizing lakes and ponds (Figure 3.6a) was one of the most difficult tasks; its tool usage mimicked the overall pattern for the test. Subjects could view the image at a larger scale initially and thus the task required less navigation. Subjects performed the question involving German postal zones (Figure 3.6b) more efficiently on the single monitor display, refuting the overall virtual navigation results. Since areas needed for the task crossed over bezels on the multiple monitor configurations, users immediately used navigational tools to move regions to uninterrupted portions of the display. Single monitor users had no problem viewing regions where they first appeared on the screen. While larger displays can reduce the use of perception affecting tools like zooming and panning

(Brown 1993), they can also increase navigation if important information stretches awkwardly across bezels.

3.5.5 Subject Responses

When asked general questions about their use of computers and geospatial information, subjects provided responses that support the need for multiple-monitor research. With 28% of the subject pool reporting having used a multiple monitor configuration before (the mode being two), this study confirms not only increased use of multiple monitor configurations, but also the growing prominence of such designs for geospatial work given the geographic academic concentration of most of the subject pool (84%). Further, when asked about the map display medium most often used, subjects were almost evenly divided, with computers having a slight majority of 54% over paper maps. This response highlights a shift away from the traditional paper map and possibly even a shift over to digital dominance for those who consistently work with geospatial data.

Regardless of possible performance or processing benefits of increasingly large, multiple monitor displays, their utility comes down to personal preference and comfort of the individual user. When the questionnaire directed subjects to rate their opinion of the display size they used for the experiment, the four monitor condition had the most agreement amongst users for a display rating and also the most user satisfaction concerning its size. Such a response aligns with the large performance jumps between one and four monitor users and might indicate that a four monitor setup is the ideal size for users viewing maps and imagery. Again, this could also indicate that working with a four monitor setup is an easier configuration to quickly adjust to than the nine monitor setup, as 72% of users noted that their personal computer monitor was 17” or smaller.

3.5.6 Four Monitor Versus Nine Monitor Performance

The largest improvement gains consistently occurred between the one and four monitor displays for elapsed time and virtual navigation, while the four monitor display also received the greatest display size satisfaction rating. These results have three possible explanations. First, it may be that the four monitor configuration is the ideal size for users of geospatial information, reflected both in users’ display satisfaction responses and from their test results. Larger monitor conditions, such as the nine monitor display, would then only produce diminishing returns. Secondly, most subjects had never used a multiple monitor display before, routinely using only a

17" screen or smaller. It is possible that it was easier for subjects to adjust to a four monitor display than to a nine monitor display during the short testing period. The nine monitor display may provide additional efficiency benefits once users have experience or training with the configuration. Finally, the four monitor display may have produced greater efficiency results than the nine monitor display because of the uneven screen ratios between monitor conditions. Moving to the four monitor condition from one monitor quadrupled display space, but the move from four to nine only roughly doubled (2.25 times as large) display space. It is possible that different performance benefits would have resulted if the three monitor conditions maintained equal display area increases between conditions.

3.5.7 Effect of Bezels

Multiple monitor displays allow users to easily obtain a large size and high-resolution with a low price tag, but users do encounter bezels that break up the continuity of the display. Using the specifications of the monitor used for this experiment, the interior display space (not including the bezels framing the outside of the display) of the nine monitor configuration had approximately 85% screen area and 15% bezel area. Images or maps wider than 13.3 inches or taller than 10.6 inches would extend beyond a single monitor and cross bezels. During this experiment the open-ended responses provided on the questionnaire revealed that bezels bothered subjects and they used various navigation strategies to avoid the display interruption. For example, despite having a large amount of screen space available, large display users might reduce the size of the image they were examining so it would fit neatly on one monitor. Some users adapted use of the zoom-in tool, dragging the zoom box over an area of interest in a way that would insure that what they wanted to see would display on only one screen (Figure 3.7). Often during the test, subjects posed questions revealing that they incorrectly believed that bezels hid information from them. Some would immediately zoom and pan to check for information behind bezels, believing that trick to be a focus of the experiment.

3.5.8 Configuration Issues

When making the switch from working on a single display to utilizing the same software and hardware for multiple monitor displays, users can encounter a number of problems including, but not limited to: losing track of the mouse cursor, image distortion due to bezels, accessing information on distant portions of the display, managing windows, managing tasks, and configuration problems (Czerwinski et al. 2006). We can expect such difficulties during the

initial switch to a new display technology format, but they are unlikely to remain as permanent problems as researchers develop tools specifically for multiple monitors. For example, the issue of losing track of the mouse cursor was evident in subject behavior during the experiment. Subjects on the nine monitor condition often had to vigorously shake the mouse back and forth while watching the screen in order to catch a glimpse of the mouse cursor's location. To address this annoyance, new mouse designs can be tailored specifically for multiple monitors (Benko and Feiner 2005; Bezerianos and Balakrishnan 2005b; Robertson et al. 2005), enlarging the cursor display icon and increasing the speed of the mouse cursor across large display areas with reduced physical movement. Seam-aware screens avoid bezel issues by preventing image misalignment (Mackinlay and Heer 2004). Software is also under development that can aid window and task management, making both more efficient on large displays (Robertson et al. 2005). While user problems with large, multiple monitor displays are an issue for this research, future development of tools and software designed specifically for multiple monitors will make these problems obsolete.

3.5.9 Further Research

Multiple monitor display technology is a new area of study for cartography and GIS. This study has raised as many questions as it has answered, producing numerous avenues for further research. First, while results show that performance and efficiency benefits on large displays are task dependent, more research is necessary to delve into which specific task types and map characteristics are the best fit for different display sizes to optimize task completion time, virtual navigation, and tool usage. Also, we acknowledged the location of mouse clicks relative to pertinent task information as an aspect of virtual navigation but the issue needs additional attention to explore possible changes in the spatial dispersion of mouse clicks on various display sizes. Finally, the reason for the top performance of the four monitor over the nine monitor display is the subject of a future study. To investigate the hypothesis that nine monitor users need more experience and training to realize full performance benefits, a longitudinal study will be conducted with only the nine monitor display.

3.6 Conclusion

Multiple monitor displays provide an entirely new geospatial visualization opportunity that can help to capitalize on the availability of large, high-resolution datasets. In general, when

compared to a single monitor, four and nine monitor display designs reduced elapsed time to complete a map reading test, reduced the amount of virtual navigation used throughout the test, and altered tool usage from mostly zooming and panning on the single monitor display to mostly selecting and digitizing on the nine monitor display. Reduced elapsed time means subjects attend to more tasks on multiple monitor displays than can be addressed on single monitors in the same amount of time. Less virtual navigation indicates the possibility of less effort for manipulating the mouse and more effort focused on viewing and interpreting on-screen information. Finally, the tool usage shift from zooming and panning to selecting and digitizing represents a shift from a majority of tool usage engaged for information gathering to tool usage predominantly used for answering a question. Less zooming and panning also means users maintained a more stable sense of context and detail. These potential benefits, however, are dependent upon map or image type and task type.

Overall, multiple monitor configurations create the possibility for enhancing geospatial data interaction as increased high-resolution display space allows for both greater context and detail in a single view. On larger displays, a user spends more time and effort on analyzing the data, rather than on clicking and altering the view on the screen. Further research will help to understand fully the utility of multiple monitor displays for geospatial information by addressing topics such as digitizing accuracy and boundary interpretation, display usage strategies over time, window management of multiple applications, and what map, image, and task types are best suited for different display sizes.

3.7 Acknowledgements

We thank our computer science research associates Dr. Chris North, Dr. Robert Ball, and Beth Yost for their technical assistance and research suggestions. Special thanks to the Center for Geospatial Information Technology at Virginia Tech for housing the subject testing site and especially to the ever-reliable James Dunson for his technical knowledge and assistance. We must also thank all of our subject volunteers for their participation that made this research possible. This research was funded by a grant from the Advanced Research and Development Activity (ARDA) for the Geo-spatial Intelligence Information Visualization Program.

References

- Ball, R. and C. North. 2005a. An analysis of user behavior on high-resolution tiled displays. In *International Conference on Human-Computer Interaction (INTERACT '05)*, 350-364.
- Ball, R. and C. North. 2005b. Effects of tiled high-resolution display on basic visualization and navigation tasks. In *Extended Abstracts CHI '05*, 1196-1199.
- Ball, R., M. Varghese, B. Carstensen, E. D. Cox, C. Fierer, M. Peterson, and C. North. 2005. Evaluating the benefits of tiled displays for navigating maps. In *International Conference on Human-Computer Interaction (IASTED-HCI '05)*, 66-71.
- Baudisch, P., N. Good, V. Bellotti, and P. Schraedley. 2002 Keeping things in context: A comparative evaluation of focus plus context screens, overviews, and zooming. In *Human Factors in Computing Systems (CHI '02)*, 259-266.
- Benko, H., and S. Feiner. 2005. Multi-monitor mouse. In *Human Factors in Computing Systems (CHI '05)*, 1208-1211. Portland, Oregon.
- Bezerianos, A., and R. Balakrishnan. 2005. View and space management on large displays. *IEEE Computer Graphics and Applications* 25 (4):34-43.
- Brown, A. 1993. Map design for screen displays. *Cartographic Journal* 30 (2): 129-135.
- Carstensen, L. W. 2005. *Geog/Geos 4048 – Text*: Virginia Tech University Printing Services.
- Czerwinski, M., G. Robertson, B. Meyers, G. Smith, D. Robbins, and D. Tan. 2006. Large display research overview. In *Human Factors in Computing Systems (CHI '06)*, 69-74. Montreal, Quebec, Canada.
- Czerwinski, M., G. Smith, T. Regan, B. Meyers, G. Robertson, and G. Starkweather. 2003. Toward characterizing the productivity benefits of very large displays. In *International Conference on Human-Computer Interaction (INTERACT '03)*, 9-16.
- Enoch, J. 1959. Effect of the size of a complex display upon visual search. *Journal of the Optical Society of America* 49:280-286.
- Grudin, J. 2001. Partitioning digital worlds: Focal and peripheral awareness in multiple monitor use. In *Human Factors in Computing Systems (CHI '01)*, 458-465.
- Hutchings, D. R., M. Czerwinski, B. Meyers, and J. Stasko. 2004a. Exploring the use and affordances of multiple display environments. In *Workshop on Ubiquitous Display Environments at UbiComp 2004*, 1-6.
- Hutchings, D. R., G. Smith, B. Meyers, M. Czerwinski, and G. Robertson. 2004b. Display space usage and window management operation comparisons between single monitor and multiple monitor users. In *Advanced Visua Interfaces*, 32-39. Gallipoli, Italy.

- Lloyd, R. 1997. Visual search processes used in map reading. *Cartographica* 34 (1):11-32.
- Lloyd, R., and R. L. Bunch. 2003. Technology and map-learning: Users, methods, and symbols. *Annals of the Association of American Geographers* 93 (4):828-850.
- Lloyd, R. and M. E. Hodgson. 2002. Visual search for land use objects in aerial photographs. *Cartography and Geographic Information Science* 29 (1):3-15.
- Lloyd, R. M. E. Hodgson, and A. Stokes. 2002. Visual categorization with aerial photographs. *Annals of the Association of American Geographers* 92 (2):241-266.
- Mackinlay, J. D., and J. Heer. 2004. Wideband displays: Mitigating multiple monitor seams. In *Extended Abstracts of Human Factors in Computing Systems (CHI '04)*, 1521-1524.
- Ni, T., D. A. Bowman, and J. Chen. 2006. Increased display size and resolution improve task performance in information-rich virtual environments. *Graphics Interface 2006*:139-146.
- Polys, N. F., S. Kim, and D. A. Bowman. 2005. Effects of information layout, screen size, and field of view on user performance in information-rich virtual environments. In *ACM Virtual Reality Software and Technology 2005*, 46-55.
- Robertson, G., M. Czerwinski, P. Baudisch, B. Meyers, D. Robbins, G. Smith, and D. Tan. 2005. The large-display user experience. *IEEE Computer Graphics and Applications* 25 (4):44-51.
- Simmons, T. 2001. What's the optimum computer display size? *Ergonomics in Design* Fall 2001:19-25.
- Slocum, T. A., R. B. McMaster, F. C. Kessler, and H. H. Howard. 2005. *Thematic Cartography and Geographic Visualization*. Second ed. Upper Saddle River: Pearson Prentice Hall.
- Tan, D. S., and M. Czerwinski. 2003. Effects of visual separation and physical discontinuities when distributing information across multiple displays. In *Computer-Human Interaction Special Interest Group of the Ergonomics Society of Australia (OZCHI)*, 184-191.
- Tan, D. S., D. Gergle, P. G. Scupelli, and R. Pausch. 2003. With similar visual angles, larger displays improve spatial performance. In *Human Factors in Computing Systems (CHI '03)*, 217-224.
- Ware, C. 2004. *Information Visualization: Perception for Design*. San Francisco: Morgan Kaufmann Publishers.
- Wood, C. 1993. Visual search centrality and minimum map size. *Cartographica* 30:32-44.

Chapter 3 Figures

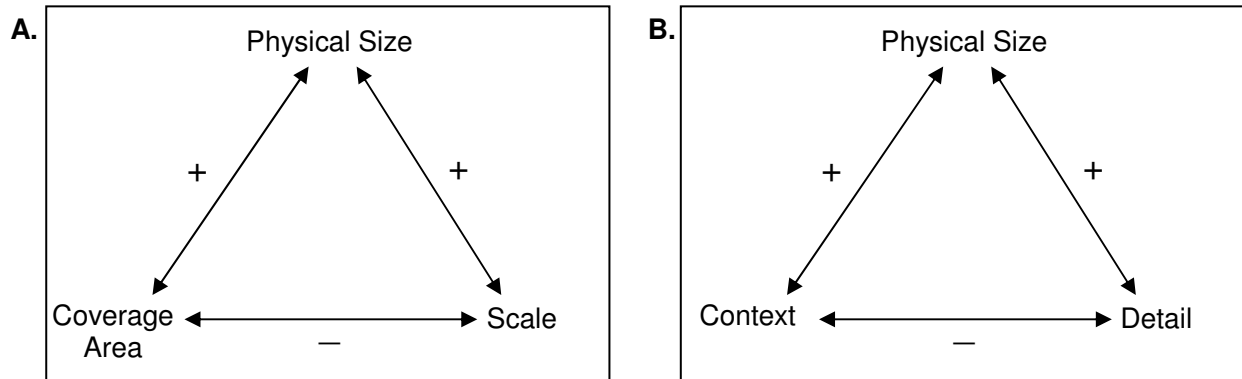


Figure 3.1. A) Tradeoff relationships in map design B) Tradeoff relationships for map perception (modeled after Carstensen 2005). Mathematical symbols note the positive and negative relationships between items.



Figure 3.2. Multiple monitor display constructed of nine 17" flat screen LCDs (3840 x 3072 pixels). Note the presence of bezels in the interior of a multi-display system because of current display technology for LCD panels.

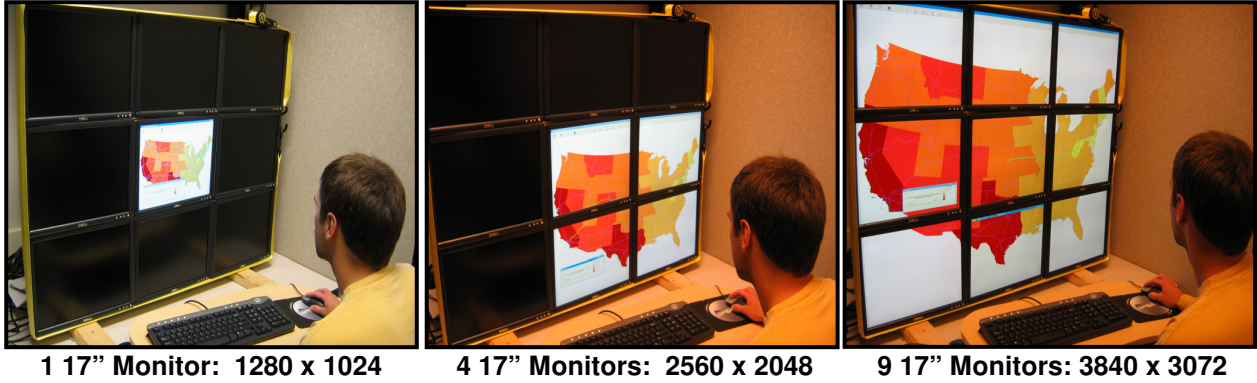


Figure 3.3 Three display size conditions used in the experiment. Pixel dimensions are noted under each condition.

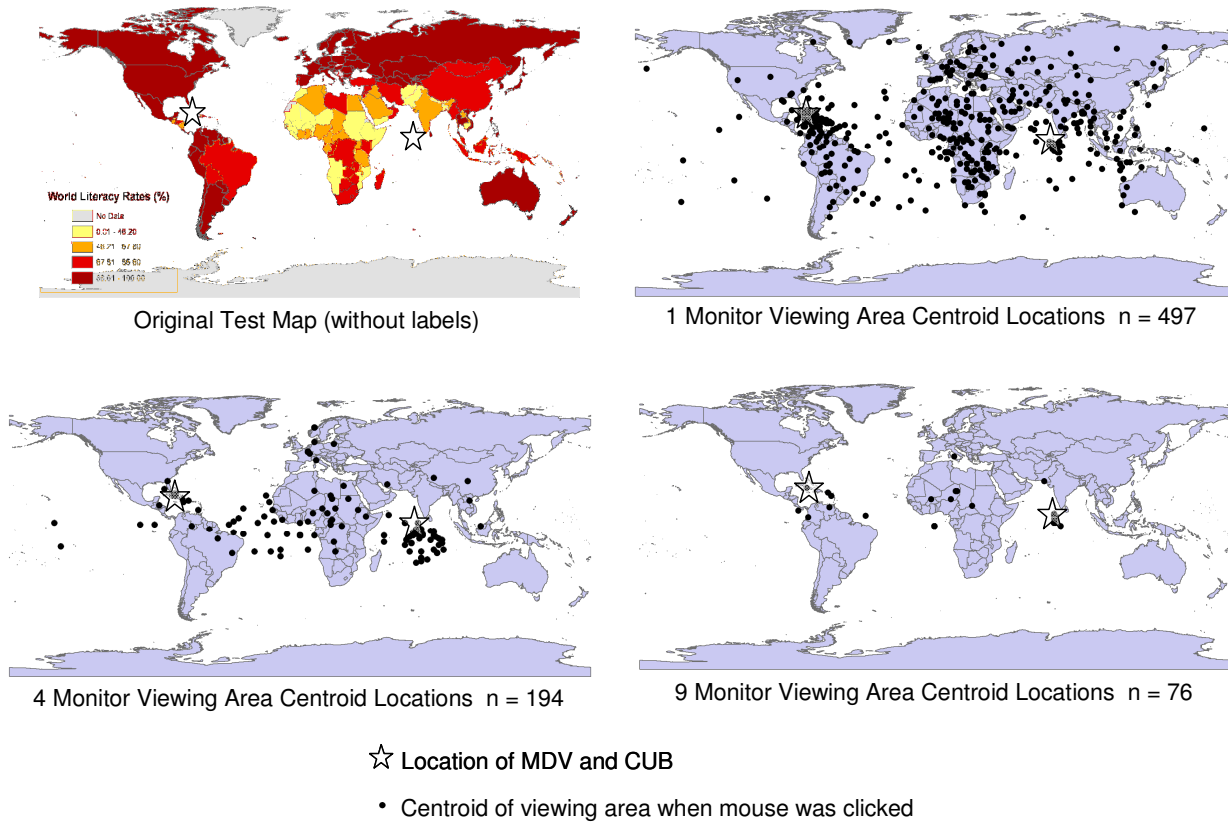


Figure 3.4 Centroids of viewing areas for all subject mouse clicks on a task comparing literacy rates of CUB (Cuba) and MDV (Maldives). Each point represents the centroid of the zoom window area subjects were viewing when making a mouse click. The stars noting the locations of CUB and MDV are here to show centroid locations relative to necessary task information; they were not on the map during the test.

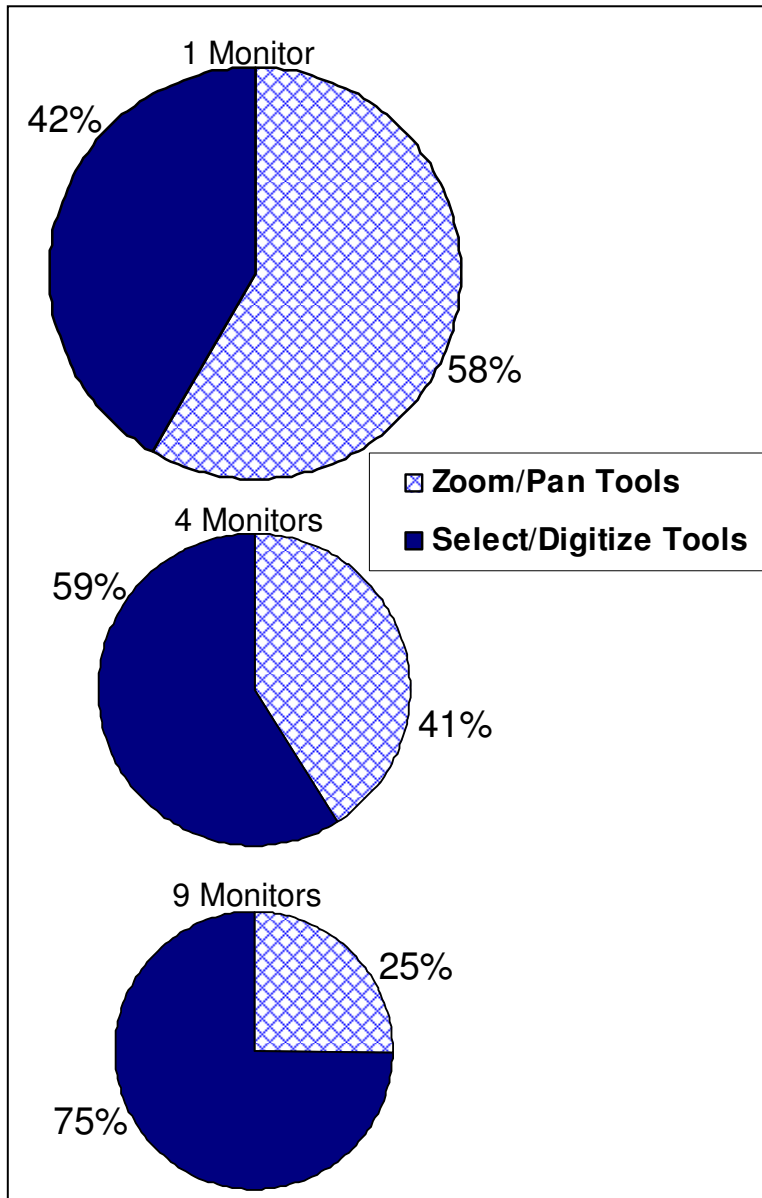
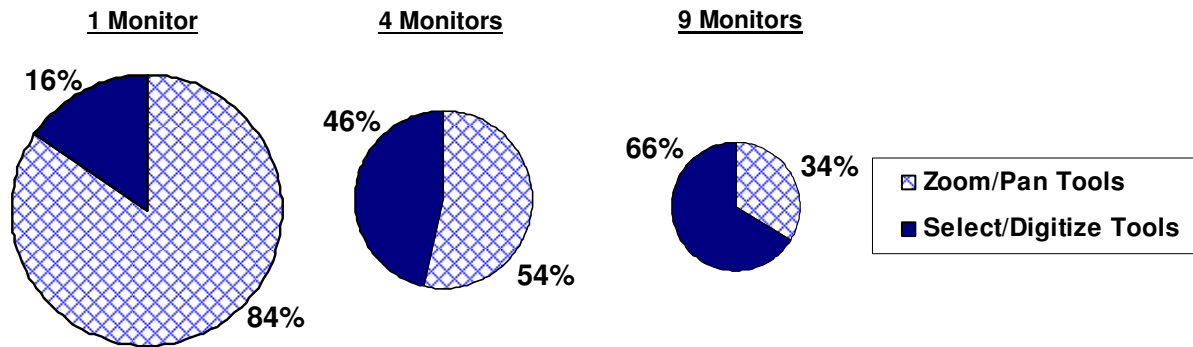


Figure 3.5. Usage distribution of zoom/pan tools versus select/digitize tools for the entire test by monitor condition. Pie charts are sized in proportion to the amount of virtual navigation used on the task. The larger the circle, the more tool usage mouse clicks used by subjects on that particular display size.

A) Michigan Aerial Photograph – Digitize lakes and ponds.



B) Germany Postal Zones Map – Select the largest postal region within postal zone 3.

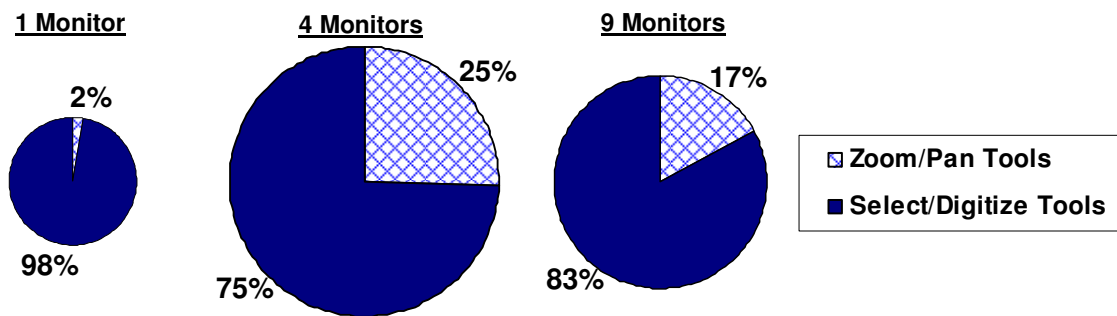


Figure 3.6. A) Zoom/pan versus select/digitize tool usage among monitor conditions on an aerial photograph digitizing task. B) Zoom/pan versus select/digitize tool usage among monitor conditions on a size comparison task that crosses bezels on the larger monitor conditions. Pie charts are sized in proportion to the amount of virtual navigation used on the task. The larger the circle, the more tool usage mouse clicks used by subjects on that particular display size.

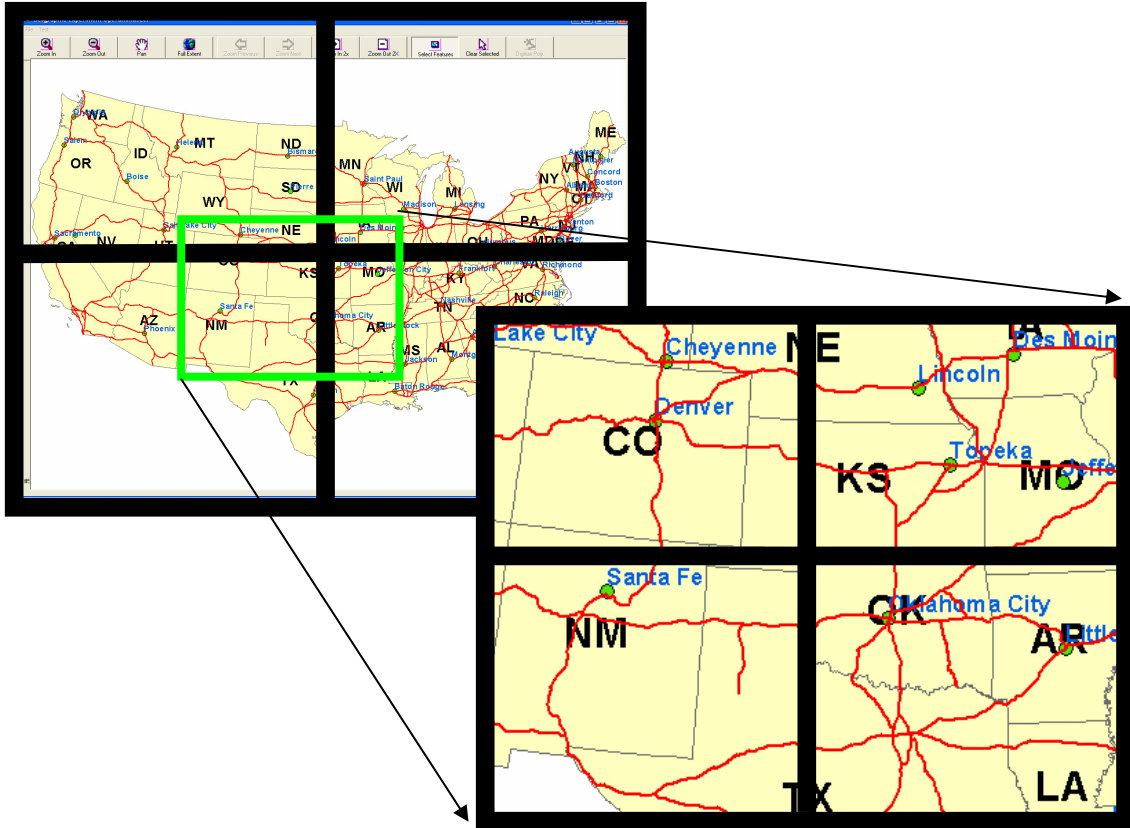


Figure 3.7. Example of zooming tactics used to avoid bezels. Black borders represent the bezel locations on a four monitor display. On this U.S. Interstates map created using ESRI data, a user who wishes to see Colorado (CO) may draw a zoom box as seen on the left on the full map so that the redraw would have Colorado in its entirety on just one monitor.

Chapter 3 Tables

| Coverage | Content | Format | Question | Answer Type | Purpose |
|-------------------|-------------------|--------|--|-------------------|---|
| Africa | DEM | Raster | Which area has the greatest concentration of high elevation? | Multiple Choice | DEM Interpretation |
| Europe | Countries | Vector | Select country 49. | Select Feature | Search task – large target |
| | | | Select country 63. | Select Feature | Search task – small target |
| | | | Which is larger, 23 or 27? | Type in | Size comparison – neighboring objects |
| | | | Which is larger, 14 or 41? | Type in | Size comparison – distant objects |
| Europe | Ferry Routes | Vector | What is the shortest ferry route between 33 and 39? | Type in | Distance perception Zoom-in required |
| Germany | Postal Zones | Vector | Select the largest postal region within postal zone 3. | Select Feature | Size comparison – 10+ objects |
| | | | Which postal zone has more postal regions, 1 or 4? | Type in | Counting task |
| Missouri | Road Map | Raster | What college is located near Sedalia? | Type in | Visual search – central location |
| | | | Name the state park west of Kirksville. | Type in | Visual search – peripheral location |
| Northern Michigan | Aerial Photograph | Raster | Digitize as many lakes and ponds as you can find. | Digitize | Raster digitizing Air Photo Interpretation |
| US | Interstates | Vector | Select the shortest route between Atlanta, GA and Sacramento, CA | Select Feature(s) | Route tracing – horizontal |
| | | | Select the shortest route between St. Paul, MN and Little Rock, AR | Select Feature(s) | Route tracing – vertical |
| World | Lights at Night | Raster | This image represents city lights visible at night. Which area probably is the most urbanized? | Multiple Choice | Data inferencing |
| World | Literacy Rates | Vector | Though this map does not illustrate income patterns, residents of which of the following countries likely have the lowest incomes? | Multiple Choice | Data inferencing |
| | | | How many countries touching IND are in the lowest literacy category? | Multiple Choice | Counting task Attribute comparison |
| | | | Digitize NER in Africa. | Digitize | Vector digitizing |
| | | | Comparing the literacy rates of MDV and WSM, MDV's literacy rate is: | Multiple Choice | Attribute comparison |

Table 3.1 Test map and image characteristics and associated questions and response types.

| Monitor(s) | Minimum (seconds) | Maximum (seconds) | Average (seconds) | ANOVA | Tukey Grouping |
|-------------------|--------------------------|--------------------------|--------------------------|----------------------|-----------------------|
| 1 | 590 | 1699 | 1029.16 | F = 9.86 p < .001 | A |
| 4 | 496.5 | 1475 | 729.29 | | B |
| 9 | 486 | 1006 | 732.94 | | B |

Table 3.2. Elapsed time by monitor condition in seconds for entire test session. Increased draw times on larger monitor conditions taken into account. Tukey's studentized range tests conducted at $\alpha = .05$. Groups with the same Tukey grouping letter are not significantly different.

| Map | Task | 1 Mon. \bar{x} (seconds) | 4 Mon. \bar{x} (seconds) | 9 Mon. \bar{x} (seconds) | ANOVA | Tukey Grouping | | |
|-----------------------|---|-------------------------------|-------------------------------|-------------------------------|------------|----------------|--------|--------|
| | | | | | | 1 Mon. | 4 Mon. | 9 Mon. |
| US Interstates | Select shortest route (vertical endpoints) | 124.42 | 67.58 | 101.68 | $p < .05$ | A | B | A B |
| Africa DEM | Find region of highest elevation | 18.37 | 9.74 | 12.26 | $p < .01$ | A | B | A B |
| Missouri Road Map | Find a park near a specific city | 85.68 | 43.05 | 40.53 | $p < .001$ | A | B | B |
| Europe–Ferry Routes | Find shortest route between 2 countries | 83.63 | 65.95 | 60.05 | $p < .05$ | A | A B | B |
| World Lights at Night | Find most urbanized area | 26.79 | 19.05 | 15.58 | $p < .01$ | A | B | B |
| World Literacy Rates | Compare rates of 2 distant countries | 196.68 | 129.16 | 105.37 | $p < .01$ | A | A B | B |

Table 3.3. Question level elapsed time by monitor condition in seconds. Only tasks showing at least one group as statistically significant are shown. Tukey’s studentized range tests conducted at $\alpha = .05$. Groups with the same Tukey grouping letter are not significantly different. Mon. = monitor.

| Monitor(s) | Minimum (mouse clicks) | Maximum (mouse clicks) | Average (mouse clicks) | ANOVA | Tukey Grouping |
|-------------------|-----------------------------------|-----------------------------------|-----------------------------------|------------------------|-----------------------|
| 1 | 90 | 623 | 269.00 | F = 11.52 p < .0001 | A |
| 4 | 79 | 324 | 160.58 | | B |
| 9 | 64 | 299 | 128.26 | | B |

Table 3.4. Virtual navigation by monitor condition in mouse clicks for entire test session. Tukey's studentized range tests conducted at $\alpha = .05$. Groups with the same Tukey grouping letter are not significantly different.

| Map | Task | 1 Mon. \bar{x} (mouse clicks) | 4 Mon. \bar{x} (mouse clicks) | 9 Mon. \bar{x} (mouse clicks) | ANOVA | Tukey Grouping | | |
|----------------------|--|------------------------------------|------------------------------------|------------------------------------|----------|----------------|--------|--------|
| | | | | | | 1 Mon. | 4 Mon. | 9 Mon. |
| Europe - Countries | Size comparison of 2 neighboring countries | 2.42 | 1.26 | 1.53 | p< .05 | A | B | A B |
| US Interstates | Select shortest route (vertical endpoints) | 42.63 | 19.58 | 29.11 | p< .05 | A | B | A B |
| Germany Postal Zones | Select largest region in a zone | 3.16 | 9.89 | 6.47 | p< .05 | A | B | A B |
| Missouri Road Map | Find a college in a specific city | 5.53 | 1.21 | 2.05 | p< .001 | A | B | B |
| Missouri Road Map | Find a park near a specific city | 10.79 | 1.42 | 1.11 | p< .0001 | A | B | B |
| Europe-Ferry Routes | Find shortest route between 2 countries | 7.58 | 11.37 | 5.37 | p< .05 | A B | A | B |
| World Literacy Rates | Determine number of neighboring countries with similar rates | 3.05 | 2.32 | 1.32 | p < .05 | A | A B | B |

Table 3.5. Question level virtual navigation by monitor condition in mouse clicks. Only tasks showing at least one group as statistically significant are shown. Tukey's studentized range tests conducted at $\alpha = .05$. Groups with the same Tukey grouping letter are not significantly different. Mon. = monitor.

| Monitor(s) | Minimum (%) | Maximum (%) | Average (%) | ANOVA | Tukey Grouping |
|------------|-------------|-------------|-------------|------------------------|----------------|
| 1 | 28.64 | 77.70 | 55.48 | F = 22.38 p < .0001 | A |
| 4 | 6.33 | 64.71 | 37.34 | | B |
| 9 | 9.02 | 48.48 | 24.52 | | C |

Table 3.6. Percentage of zoom/pan tool use out of total tool usage for the entire test by monitor condition. Tukey's studentized range tests conducted at $\alpha = .05$. All three groups are significantly different.

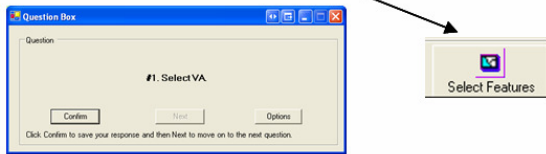
| Monitor(s) | 1) Much too small | 2) Somewhat small | 3) Neither small nor large | 4) Somewhat large | 5) Much too large |
|-------------------|--------------------------|--------------------------|-----------------------------------|--------------------------|--------------------------|
| 1 | 11.11% | 50.00% | 38.89% | 0% | 0% |
| 4 | 0% | 0% | 84.21% | 15.79% | 0% |
| 9 | 0% | 0% | 57.89% | 31.58% | 10.53% |

Table 3.7. Percentage distribution of display ratings by monitor condition.

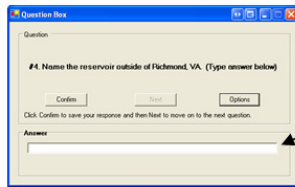
INSTRUCTIONS

You will be asked a series of questions pertaining to maps and images that will be displayed. There are four types of responses:

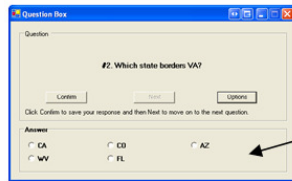
1. **Select** questions where you respond by clicking on the answer in the map/image using the “Select Features” tool.



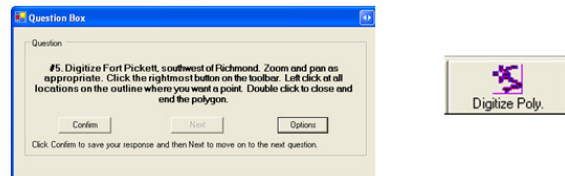
2. **Type** questions where you type your response in the text box provided.



3. **Multiple choice** questions where you select your response from those provided.

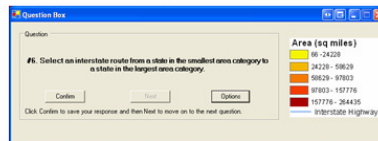


4. **Digitize** questions where you digitize an object on the screen using the Digitize Poly tool. Left click everywhere around the object that you would like a new point. Double click to close your digitized polygon. Right click to delete the last polygon created if needed.



After responding to a question, click **Confirm** to move to the next question.

Note: Some maps/images may require a legend for interpretation. If so, the legend will appear in the right side of the question box.



All necessary labels will appear at full extent unless otherwise specified in the question box (ex. “Labels will appear at a larger scale.”)

Appendix 1: Subject handout explaining testing program response formats.




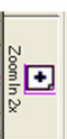







Toolbar

The toolbar is located at the top of your screen during the experiment. It contains all the tools you may need to explore the maps and images and provide the designated response type.

This is how the toolbar will appear on the display:



Description of Tools


| | | | |
|--|---|--|---|
|  | Zoom In: Enlarges the area you select (with a bounding box), showing greater detail |  | Zoom Next: Returns to the zoomed scale that you hit "Zoom Previous" from |
|  | Zoom Out: Shows a larger portion of the map or image but with less detail, (area selected by a bounding box) |  | Zoom In 2x: Shows the map or image twice as large |
|  | Pan: Grabs the map where you click on it and allows you to move it in any direction without changing the current scale/level of detail |  | Zoom Out 2x: Shows the map or image at half of its current size |
|  | Full Extent: Shows the entire map or image |  | Select Features: Allows you to click on a map and choose features (selected features will be highlighted in light green) |
|  | Zoom Previous: Goes back to the previous scale you zoomed to |  | Clear Selected: Clears all selected map features <i>if you wish to only clear the last feature selected, simply right click.</i> |
| | |  | Digitize Poly: Allows you to digitize a polygon on the map or image, left click everywhere on the map or image you would like a point, double click to close and finish the polygon. <i>Right click to clear the last polygon created.</i> |

Note: Maps initially appear at full extent. You cannot zoom out or pan at full extent.

DATE: February 2, 2006

MEMORANDUM

TO: Bill Carstensen Geography
Candice Luebbering Geography

FROM: Carmen Green 

SUBJECT: **IRB Exempt Approval:** "Multiple Monitor High-Resolution Displays and Map Reading Performance" IRB # 06-049

I have reviewed your request to the IRB for exemption for the above referenced project. I concur that the research falls within the exempt status. Approval is granted effective as of February 2, 2006.

Virginia Tech has an approved Federal Wide Assurance (FWA00000572, exp. 7/20/07) on file with OHRP, and its IRB Registration Number is IRB00000667.

cc: File

Department Reviewer: Lawrence S. Grossman
OSP 0170

**The vita has been removed from
the scanned document**