Evaluation of Viewport Size and Curvature of Large, High-Resolution Displays

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ABSTRACT

Tiling multiple monitors to increase the amount of screen space available to users has become common. While previous research has shown user performance benefits when using two monitors next to each other, almost no research has analyzed whether very large high-resolution displays result in better user performance. We compared user performance time, accuracy, and mental workload on geospatial search, route tracing, and comparison tasks across one, twelve (4×3), and twenty-four (8×3) tiled monitor configurations. Additionally, we included a display configuration that involved uniformly curving the twenty-four monitor display. Results showed that overall using twenty-four or twelve monitors resulted improved performance over one monitor for search tasks. Frustration levels were also significantly higher for one monitor than twenty-four monitor users. While there was no statistically significant difference between the twenty-four monitor flat and twenty-four monitor curved configurations, the mean task completion times were faster for the curved display. Based on the results of this experiment we hypothesize that a point of diminishing returns for user performance is found somewhere between twelve monitor and twenty-four monitor configurations, and that curving the display shifts that point towards larger displays.

Author Keywords

High-resolution, large tiled display, reconfigurable display, viewport size, curvature, geospatial

ACM Classification Keywords

H.5.2 [User Interfaces] Ergonomics, Evaluation/methodology

INTRODUCTION

Tiling multiple monitors to increase the amount of screen space available to users has become common. While previous research has shown user performance benefits when using two monitors next to each other, almost no research has analyzed whether very large high-resolution displays result in better user performance. There is great potential for using large high-resolution displays as power desktops (as opposed to powerwalls) for scaling up visualizations in single-user environments. However, there is a need for design guidance for display size and form. In particular, research has yet to discover the benefit for enabling more complex tasks and if there is a diminishing return with respect to the display size.

In this paper we explain an experiment using a large, high-resolution (96 DPI), high-pixel-count (approximately 32 million totalpixels) display. The experiment used a range of geospatial tasks that may be used in aerial imagery comparison and analysis. One of the reasons for using geospatial data is that it is high resolution, high bandwidth, and multi-scale. This type of data is also useful to various people, including those in the intelligence community.

Our motivation behind the experiment in this paper are two fold:

- Quantify the user performance benefits of increasingly larger displays (viewport sizes) for geospatial tasks.

- Determine if and how the curvature of a large display affects performance for geospatial tasks.

The first part of the experiment, which we refer to as the *viewport size comparison*, was designed to understand how people's performance and accuracy changed as the size of their display increased. In other words, we wanted to know how people's behavior changed as the viewport size (portal size) to the data increased. We hypothesized that as the viewport size increased that people's performance and accuracy would improve and their mental workload would decrease.

In the viewport size part of the experiment we had participants perform a range of geospatial tasks on one, twelve, or twenty-four monitors. Figure 1 shows an example of a participant using twenty-four monitors for the viewport size part of the experiment. This part of the experiment involved all flat displays, following the traditional powerwall concept. For examples of powerwalls or interactive display walls see [12].

Figure 1. Twenty-four monitor flat configuration

Powerwalls are traditionally used for collaboration in groups for viewing large images. However, there is great potential for individual users to gain from such large displays - a power desktop. Since users may experience slight neck strain when looking up for long periods of time, we designed our power desktop to have no more than three monitors high [2]. Therefore, the majority of the monitors were added to the width of the display, making it wider than it is tall.

The second part of the experiment, which we refer to as the *curve comparison*, was designed to explore the benefits or drawbacks of having a curved display (Figure 2). Curving the display can potentially reduce the time it takes a user to see pixels since the outermost pixels are closer.

Figure 2. Curved 24 monitor configuration

We curved the display on the horizonal plane such that the monitors would uniformly face the user. To do this the columns were faced inward such that the angle between each column was the same. Thus, the display was part of a perfect circle with a radius equal to 2.5 feet. Our main motivation for curving the displays was not to find an optimal curvature but to see if there existed any benefits of curving such a display compared to keeping it flat.

RELATED WORK

The majority of research related to large high-resolution displays has been about the physical construction of the display [8,13,18,20,21], or the software and algorithms available for distributing the graphics [14,23]. Less research has been done on the usefulness and usability of these displays. Additionally, most research has been done on using these displays for collaboration [10,17,25] rather than for single-user applications. Our focus is on quantifying the user performance benefits of a larger higher-resolution display for a single user.

Single-user Benefits on Large High-Resolution Displays

One common single-user scenario is using multiple monitors to expand the desktop. There are two paradigms for multiple monitor users, either the idea of partitioned spaces used as different rooms, or used as one large space [11]. People tend to use monitors to the left or right as separate rooms and monitors that are tiled vertically as single spaces [2]. There are many open issues with interaction [1, 12], notification [16], and window management [15] across multiple monitor desktops.

Because our application is for geospatial analysis, we are more interested in the *one large space* paradigm. Research in this area has shown that large high resolution displays can result in better performance than panning and zooming on smaller displays [3], that larger displays improve performance even when the visual angle is maintained [26], and that using larger displays narrows the gender gap on spatial performance [7]. However, the highest total pixel-count display used in these experiments was a 3×3 tiled monitor display with 3840×3072 total pixels. With this experiment, we go beyond those totals to much larger displays.

A concern when using a tiled display is the impact of the bezels. Mackinlay and Heer [19] suggested techniques of working around these issues. Other research suggests that discontinuities are only a problem when combined with an offset in depth [27]. However, in this work we do not address this particular issue, so no information is hidden behind the bezels.

Reconfigurable Displays

One question that arises is if there is a point of diminishing returns. For example, is there a point where a wider field of view no longer increases user performance? Additionally, at what point are there so many pixels in a large high resolution display that performance no longer increases? One method of decreasing the access cost is to curve the display so when a user turns their head the display is still at an equal distance from them.

Curving displays can be challenging, after all you can't currently bend a monitor. Dsharp is a display that uses multiple projectors in creating a curved display by carefully aligning the images [6,24]. NASA's hyperwall allows monitors in a 7×7 tiled array to be tilted and rotated [21]. Also available are rear-projected blocks that can be stacked [22]. However, to the authors' knowledge, there is no empirical comparison of user performance between flat and curved displays.

In summary, this experiment builds on and extends previous research by considering single user performance on geospatial tasks using a larger higher-resolution display than used in other experiments. It also considers the user performance benefits of reconfiguring the display by uniformly curving it when other research considered only a curved display or only flat displays. Without demonstrated user performance benefits the cost of single user large-high resolution display would be hard to justify.

METHOD

Hardware and Software Used

The display was made up of twenty-four seventeen inch LCD monitors and twelve GNU/Linux computers. Each monitor was set to the highest resolution of 1280×1024. Each computer powered two monitors. We removed the plastic casing around each monitor to reduce the bezel size (gap) between monitors. We then mounted three monitors vertically on reconfigurable wooden stands. We designed the display to be three monitors tall because we have found that having them any taller or shorter causes neck strain for the user [2]. This configuration produced an 8x3 matrix (Figure 3).

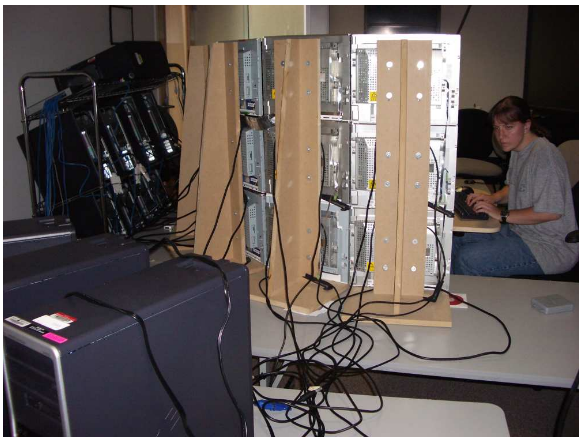

Figure 3. Computer cluster behind the curved display

We networked the twelve GNU/Linux computers together in a private network using a gigabit switch. We then installed DMX (Distributed Multihead X) to create a unified display [9]. DMX is a proxy X server that provides multi-head support for multiple displays attached to different machines. For all appearances to the user, when running DMX the display appears to be one single GNU/Linux desktop that runs a standard windows manager(e.g. KDE, GNOME, Fluxbox, etc.).

All users were given a standard keyboard and mouse. The keyboard stand had wheels for easy mobility and was used across all conditions.

For the experiment we used a modified version of the NCSA TerraServer Blaster, an open-source application that Paul Rajlich from NCSA (National Center for Supercomputing Applications) wrote for visualizing imagery from the national TerraServer database using Chromium [5]. Chromium is an open-source application that uses real-time parallel rendering of openGL.

We modified the NCSA TerraServer Blaster application in a variety of ways. First, modified the application by increasing its download and caching efficiency. Second, we modified the application by adding direct keyboard and mouse input; previously the application only ran from a console window. Thirdly, we added code to allow automatic tracking of participants activities with the application.

Users could navigate using the keyboard. The arrow keys allowed the user to pan. This was an egocentric view such that panning virtually moved the user in that direction, moving the image in the opposite direction. The user could smoothly zoom in and out by holding the plus (+) and minus keys (-) down. Users could also zoom by jumping between scales using the *Page Up* and *Page Down* keys. The space bar button was a hotspot that brought the user back to the starting view for that task. Users were familiar with this navigation by the end of the tutorial. The mouse was used for marking checks on the view, which is explained further below.

Tasks

For the experiment we chose three different task types: search, route tracing, and image comparison. We chose search and route tracing tasks based on previous research in geospatial data on larger displays [4]. We chose an image comparison task based on expert geographers and cartographers. Participants performed two of each task type (an easy and a hard task) for a total of six tasks. All tasks involved navigating extremely large aerial images at different scales.

Search tasks involved locating a specific unaltered object in the aerial view. The hard search task involved searching all of Chicago for a real bullseye on the roof of a building (Figure 4). Participants were told to physically point to the located object when they found it so that the proctor could visually verify the answer.

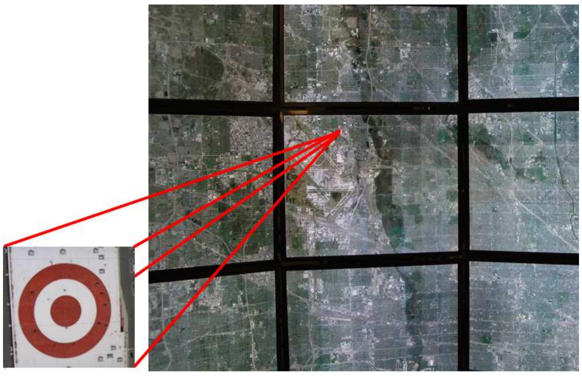

Figure 4. Search task for bullseye on the curved 24 monitor condition

For the route tracing tasks, users followed a given route, marking either overpasses or underpasses along the route. A green arrow and red octagon icon indicated the start and stop points on the route (Figure 5). Users could mark the imagery with checks with the mouse each underpass/overpass using the mouse. Users were instructed to tell the proctor when they had completed the task.

Figure 5. Route tracing task on the curved 24 monitor condition

In the image comparison task users could toggle between two aerial views (Figure 6). One view was an older black and white view of the area using DOQ (Digital Orthographic Quads) imagery, the other view was a more recent view in color. The images were captured several years apart. Superimposed on the views was a 30×15 grid. The task was to identify blocks in the grid where there were urban changes. For example, an urban change might be where there are new buildings, destruction of old buildings, new roads, etc. This did not include natural phenomena such as trees, water or other earthworks. Users could click on a block to *check* that there is a change. Users had fives minutes to check as many blocks on the grid that had urban changes.

Figure 6. Image comparison task

Experimental Design

The independent variables were viewport size, curvature, task type, and task difficulty. We chose three viewport sizes: one monitor, twelve monitor, and twenty-four monitor configurations. For the one monitor condition the TerraServer application was simply resized to fit one of the middle monitors. For the twelve monitor condition the application was expanded to half of the display such that it filled a 4×3 matrix of monitors.

For the curvature variable, we chose two curvatures: flat and a curve with radius equal to 2.5 feet (Figure 7). In general, one can create different curvatures by adjusting the radius.

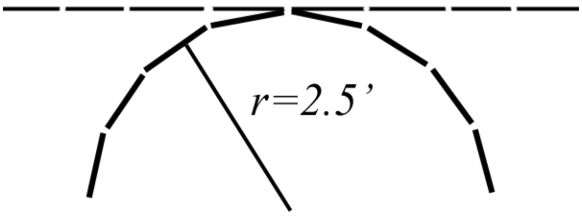

Figure 7. Flat form versus the curved form with a radius of 2.5 feet (0.762 meters)

Our main goal was to test user performance on the two variables viewport size and curvature. We chose to test 4 of the six conditions (Table 1). The one monitor curved condition is not applicable since you can not curve a single monitor. We also did not test the curved twelve monitor condition because we thought the most improvement from curving the display would be seen when it is widest.

	Flat	*Curved*
1 Monitor	x	
12 Monitor	x	
24 Monitor	x	x

Table 1. The four conditions tested

Viewport size and curve were between-subject variables because of the time it takes to curve the display. Although configuring the takes less than an hour, it is not practical to do so between tasks.

The order of the task types was counterbalanced using two 4x4 Latin Square designs, where one dimension represented the task type and the other dimension represented four participants. Within each task type (e.g. the two search tasks), half of the participants would get the easy task first and the other half would get the harder task first.

For each condition we used eight participants for a total of 32 participants. All participants were undergraduate or graduate students. The majority of the participants were computer science majors with a few exceptions. The average age of the participants was 25 with a range between 21 and 31 years old. Twenty-two of the participants were male and ten were female. All had normal to corrected-normal vision. All participants reported as having daily use with computers.

Procedure

Each user took about one hour to complete the experiment. The tasks took no longer than 5 minutes, and there was a timeout of 5 minutes on all tasks.

Before beginning the experiment, participants were asked to fill out a demographic questionnaire as well as inform the proctor of any physical conditions such as color-blindness or claustrophobia. Participants had a training session on how to use the program before beginning the experiment in a tutorial. The tutorial covered the buttons used for keyboard navigation. Users were told that they were allowed to physically move with the keyboard stand.

Users were given written instructions for each task on a piece of paper. After answering any clarification questions the user may have had, the area for the task was displayed for the user to begin the task.

Participants were timed on every task. For the search tasks, the time it took for the user to find the target and whether the user found the target was recorded. For the route tracing tasks, the time it took the user to mark the last check was recorded. Where the user marked the checks was also recorded for accuracy measures. If the user took more than five minutes, they were stopped at the 5 minute timeout and only the checks marked until the timeout were recorded for the accuracy. For the image comparison tasks, the number of checks that the user marked within five minutes was recorded.

After every task type (i.e after both search tasks), participants were asked to complete the NASA Task Load Index (NASA-TLX) rating both tasks.

RESULTS

Task Completion Times

Task completion time was measured for both the route tracing and search tasks. For the compare tasks participants were always given 5 minutes, therefore completion times for the compare tasks were not analyzed. Additionally, times for participants that timed out after 5 minutes were recorded as 5 minute task completion times. While they may not have completed the tasks, this is the minimum amount of time it would have taken participants to complete the tasks. The one monitor conditions had the most times outs. Seven of sixteen users timed out for search tasks, whereas only two or less users timed out in all other display configurations.

Analysis of variance showed a main effect for viewport size, task type, and task difficulty, and an interaction effect from viewport size × task type. Search tasks were significantly faster than route tracing tasks and easy tasks were significantly faster than hard tasks. Post-hoc analysis of the viewport conditions showed a statistically significant difference ($p<.05$) between twenty-four monitors (158s) and one monitor (200s) such that participants using twenty-four monitors were faster. For the viewport size × task type interaction post-hoc analysis showed a statistically significant difference between completion times for search tasks such that one monitor search task completion times (164s) were slower than both twelve monitor search task completion times (75s) and twenty-four monitor search task completion times (86s) (Figure 8).

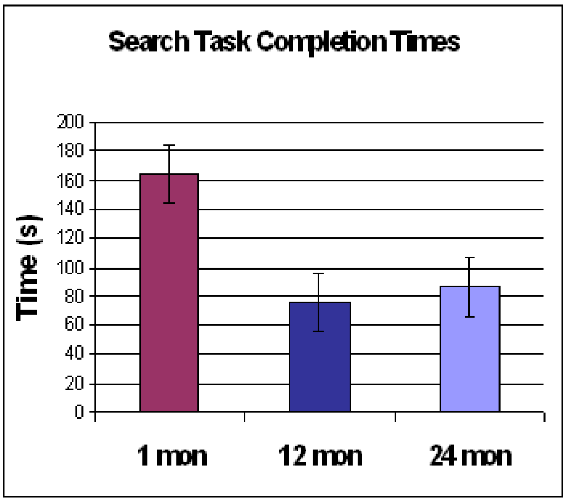

Figure 8. Search task time averages for 1,12,24 flat conditions: both 12 and 24 were significantly faster than 1

Comparing the twenty-four monitor flat (158s) configuration to the twenty-four monitor curved (146s) configuration revealed no statistically significant differences. However, overall across the four configurations the twenty-four curved condition resulted in the fastest average completion times (one monitor μ=200s, twelve monitors μ=169s, twenty-four flat μ=158s, twenty-four curved μ=146s).

Task Accuracy

Search task accuracy was recorded as either 100% (1.0) or 0% (0.0) since participants either did or did not find the target within 5 minutes. For the route tracing tasks accuracy was recorded as the number of underpasses or overpasses that the participant selected compared to the actual number of under or overpasses. For example, if a person found 14 of 28 underpasses, their accuracy was 0.5 or 50%. Because of difficulties measuring the accuracy of comparison tasks, and the very low accuracy percentages, we do not report accuracy measures for the comparison task.

Analysis of variance showed main effects for viewport size ($p=0.04$), task difficulty ($p<.01$) and viewport size × task type. Easy tasks were significantly more accurate than hard tasks. Post-hoc analysis showed statically significant differences at the 0.05 level for viewport such that overall the twelve monitor configuration (0.88) was more accurate than one monitor (0.67) (Figure 9).

Post-hoc analysis of the viewport size × task type interaction effect showed that for search tasks accuracy was lower on one monitor (0.56) than on either twelve monitors (0.93) or twenty-four monitors (0.81).

Comparing the twenty-four monitor flat configuration to the twenty-four monitor curved configuration showed no statistically significant differences. However, overall the twenty-four curved accuracy (0.85) was similar to the twelve flat accuracy (0.88) and the means of both were higher than the means for twenty-four flat (0.78) and one monitor (0.67).

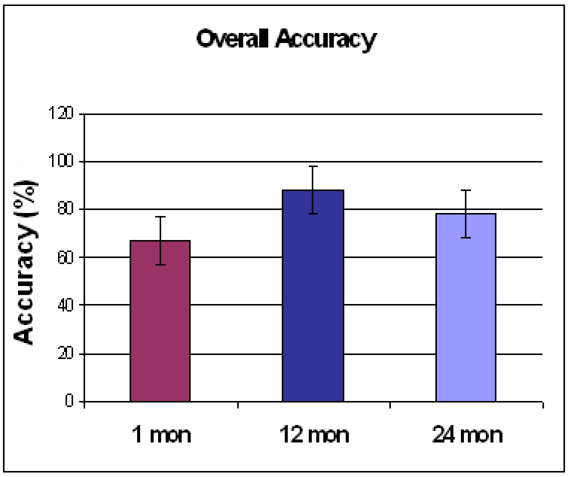

Figure 9. Accuracy averages: 12 was significantly more accurate than 1

Mental Workload

Mental workload was measured using the NASA Task Load Index. Seven scales (mental demand, frustration, etc.) were each measured on a scale from 0-100 where 100 was good and 0 was a poor rating for that factor. Because of difficulties participants reported with the software and with comprehension, we decided to analyze only reported measures of mental demand, physical demand, effort and frustration.

Using analysis of variance and followed by post-hoc analysis, the only statistically significant difference was on the level of frustration reported by users. Participants using one monitor reported significantly higher frustration levels than participants that used twenty-four monitors ($p<.05$).

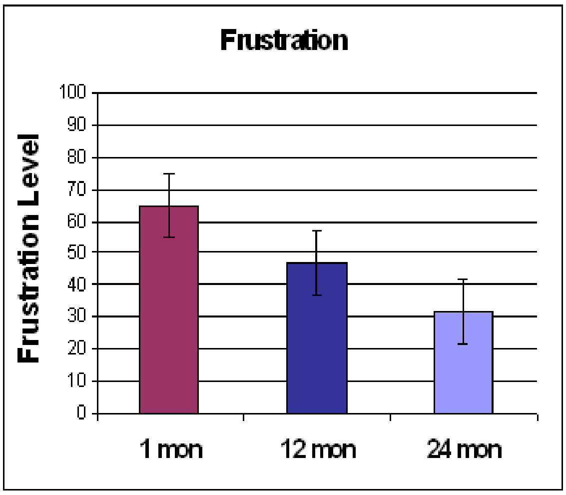

Figure 10. Frustration averages: 1 was significantly more frustrating than 24

Observations

In general, we observed differences in how users interacted in the different conditions. First considering the viewport size, there was a striking difference between one monitor and the flat twenty-four monitor condition. In the one monitor condition users tended to use more virtual navigation than those in the flat twelve and twenty-four monitor conditions. Specifically, users zoomed in and out significantly more on the one monitor condition to regain their overview of the task area. In the larger viewport sizes users tended to use more physical navigation. This included standing up, walking, leaning towards the sides of the display, and head turning. Often the user's technique for accomplishing the task was the same (e.g serial searching), but the technique was applied with virtual navigation in the one monitor configuration and with physical navigation in the larger configurations.

In the twelve and twenty-four monitor conditions, many users would adjust their technique for their second task of the same task type. For example, in the first image comparison task users would often search serially, but for the second task they would get an overview of the area looking for obvious changes before zooming in to compare details.

Users interacted physically with the display in different ways on the flat and curved twenty-four monitor conditions. In the flat condition users would either stand or walk; five out of eight users stood up at least once. In the curved condition users would turn their heads or turn their body position. It appeared that there was more physical navigation on the curved condition; however, the physical movements were less strenuous than standing and walking.

Furthermore, users changed their area of focus less frequently on the twenty-four flat configuration than those on the twenty-four curved configuration. Often users on the flat display would focus on nine or twelve monitors at a time. Sometimes their focus area would shift from the left side of the display to the right side of the display over the course of the task. However, most users preferred to sit and use the center of the display as their focus area. On the curved condition users would switch their area of focus more often by a quick turn of the head.

DISCUSSION

If we had not included timeouts or made them longer, we believe we would have found statistical differences on task completion times for the route tracing tasks. If timeouts had been dropped, people in the one monitor condition found the target fast, but most users did not find it at all (only three found it in the one monitor condition). The one monitor condition may have been just as accurate but much slower if there was no timeout.

It is possible that we have hit a point of diminishing returns with width for the flat condition. Note that the shape of the displays were different (different aspect ratios) and also that twelve monitors is 12 times 1, but twenty-four monitors is only 12 times 2 so there was a much greater increase from one to twelve than twelve to twenty-four. If the increase had been proportional, say one monitor against six monitor against twenty-four monitor displays, then we may have found a difference between six and twenty-four.

While we did not intentionally balance for gender, in all display configurations there were either 2 or 3 females and 5 or 6 males. Although with these small numbers it would be unfair to statistically compare the groups, we noticed that with this small population females performed the fastest in the twelve monitor configuration than the twenty-four monitor configuration. It may be worth further exploring if the narrowing of the gender gap happens only within a particular field of view range, and begins to widen again as the display becomes increasing large. The Czerwinski study used a curved display approximately the same width as our twelve monitor configuration [6].

Potential for Curved Displays

Our results show time and accuracy improvements from one monitor to the larger flat conditions. Although, there was no significant differences between the twelve and twenty-four monitor conditions we found that the twelve monitor condition often performed better than the twenty-four flat condition. We believe this is because the flat twenty-four configuration required too much physical navigation. However, the curved twenty-four condition performed better than the twelve condition on the search and route tracing tasks (Figure 11). Therefore, it is possible that the curved twenty-four monitor condition eliminated disadvantages of the flat twenty-four monitor condition. This suggests that as the display gets larger curving the display will allow performance improvements. As a result, we plan on running the curved twelve monitor display condition to further test this.

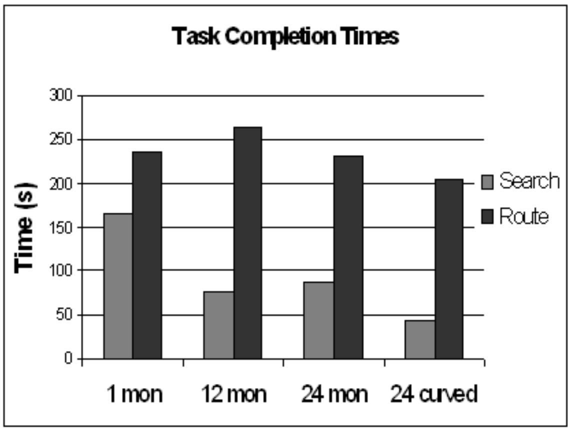

Figure 11. Search and route task times for all configurations

CONCLUSION

Previous work showed that users perform geospatial tasks better on larger displays than the standard one monitor display [4]. However, until this point research has only showed that displays up to nine monitors can improve user performance. In this paper we show performance can be increased with displays beyond nine monitors to twelve and twenty-four. We also show that curving displays around participants can have a positive effect on performance.

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