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 has become an area of great interest to researchers. While previous research has shown user performance benefits when tiling multiple monitors, little research has analyzed whether much larger high-resolution displays result in better user performance. We compared user performance time, accuracy, and mental workload on multi-scale geospatial search, route tracing, and comparison tasks across one, twelve (4×3), and twenty-four (8×3) tiled monitor configurations. We also compare user performance time in conditions that uniformly curve the twelve and twenty-four monitor displays. Results show that curving displays decreases user performance time, and we observed less strenuous physical navigation on the curved conditions. Depending on the task, the larger viewport sizes also improve performance time, and user frustration is significantly less with the larger displays than with one monitor.

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

Keywords: high-resolution, large tiled display, reconfigurable display, viewport size, curvature, geospatial

1   INTRODUCTION

Tiling multiple monitors to increase the amount of screen space has become an area of great interest to researchers. Previous research shows user performance benefits when using multiple monitors [7, 8, 11]. Yet there is great potential for using much larger high-resolution displays as power desktops in single-user environments. Furthermore, there is a need for design guidance for the size and form of such displays.

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

Our motivation behind the experiment is twofold:

- Quantify the user performance benefits of increasingly larger displays (greater pixel-count) for geospatial tasks (Figure 1).

- Determine if the curvature of such large displays affects user performance for geospatial tasks (Figure 2).

Figure 1: Twenty-four monitor flat configuration.

Figure 2: Twenty-four monitor curved configuration.

2   MOTIVATION

We hypothesized that user performance would improve with larger displays because users would have more data and more context visible at once, and will afford efficiently navigating the information physically using eye, head, and body movement. However, counterarguments could be that the large amount of visual information will overwhelm users, and that physical navigation will be too slow as compared to virtual navigation techniques such as pan and zoom. One could also argue that expanding the total screen size beyond the visual acuity of the eye wastes pixels.

We also hypothesized that curving the display would decrease the amount of time spent physically navigating, allowing for more time on the task. Users would only have to turn rather than walk to far away pixels. Our main motivation for curving the displays was not to find an optimal curvature but to see if there exist any benefits of curving a display compared to keeping it flat. Therefore, we chose the same radius for all curved conditions (Figure

3). The following is an analysis of the interaction between visual acuity and display curvature, demonstrating how curving a display brings pixels into visual range.
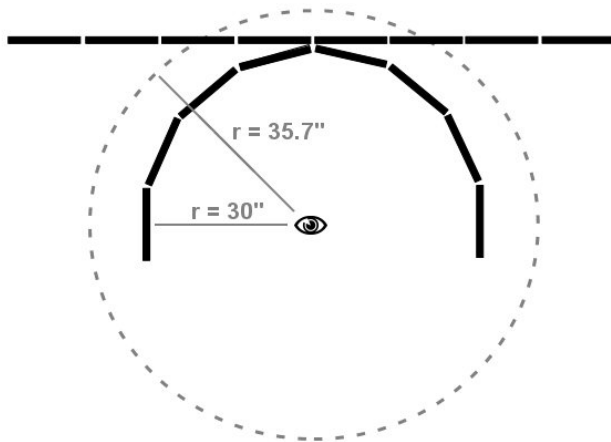

Figure 3: Visual acuity (dashed circle) and display configurations.

The display consisted of Dell 1740FPV color monitors that each had a maximum resolution of 1280×1024 and a dot pitch of 0.264mm×0.264mm. We calculated the maximum distance from which a user with normal visual acuity (20/20 vision) could resolve a 0.264mm pixel to be 90.7565cm or about 35.7 inches. This distance from the user is represented in Figure 3 by the dotted circle.

Consider what happens with flat displays. The maximum number of pixels that can be resolved on a flat display with only head and eye movements occurs when the user is standing unrealistically close to the display and looks to the left and to the right (setting aside the problem of the viewing angle for simplicity). This means the maximum display width such that all pixels are resolvable is 90.7cm×2 = 181.5cm (71.5 inches) or 6,875 pixels wide. Realistically, the user will not be standing against the display and as the user moves back fewer pixels will be resolvable. If the user is 30 inches from the center of the display, as they started in this experiment, then the number of resolvable pixels with head and eye movements is only 3,723. This is represented in Figure 3 by the intersections between the dotted circle and the eight straight blocks representing the flat display.

Now suppose we curve the display. The maximum resolvable distance remains the same (35.7 inches). If all users had perfect vision and the display had a radius no more than 35.7 inches then all pixels are resolvable with head and eye movements. In this experiment the display radius was set to a distance (30 inches) that accommodated slightly worse than 20/20 vision. Therefore, the entire width of our curved display (10,240 pixels wide) is resolvable. This is 2.75 times more resolvable pixels than with the flat condition.

3 RELATED WORK

The majority of research related to large high-resolution displays has been about the physical construction of the display [9, 13, 18, 20, 22] or the software and algorithms available for distributing the graphics [14, 24]. 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, 26] rather than for single-user

applications. Our focus is on quantifying the user performance benefits of larger, high-resolution displays for a single user.

3.1 Single-user Benefits

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, notification, and window management across multiple monitor desktops [1, 12, 15, 16].

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, 4], that larger displays improve performance even when the visual angle is maintained [27], and that using larger displays narrows the gender gap on spatial performance [8]. In addition, Focus+Context screens are an attempt to take advantage of lower resolutions for context, and a small high-resolution area for details [5]. This technique limits the user to virtual panning rather than physically moving. However, the highest total pixel-count display used in all these experiments was a modest 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 [28]. However, in this work we do not address this particular issue; no information is hidden behind the bezels.

3.2 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 (as described in section 2).

Curving displays can be challenging; to our knowledge, you cannot currently buy a bendable LCD monitor. Dsharp is a display that uses multiple projectors in creating a curved display by carefully aligning the images [8, 25]. NASA's hyperwall allows monitors in a 7×7 tiled array to be tilted and rotated [22]. Also available are rear-projected blocks that can be stacked [23]. 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, high-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.

4 METHOD

4.1 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 pow-

ered two monitors. We removed the plastic casing around each monitor to reduce the bezel size (gap) between monitors from 4cm to 2cm. We then mounted three monitors vertically on each reconfigurable wooden stand. Since users may experience slight neck strain when looking up for long periods of time, we designed our power desktop to be 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. This configuration produced an 8×3 matrix.

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 [21]. DMX is a proxy X server that provides multi-head support for multiple displays attached to different machines. When running DMX, the display appears to be one single GNU/Linux desktop that runs a standard window manager (e.g. KDE, GNOME, Fluxbox, etc.).

For the curvature variable, we curved the display on the horizontal 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 uniform circle.

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 [6]. 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, we 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 track and mark participant mouse clicks.

All users were given a standard keyboard and mouse. The keyboard stand had wheels for easy mobility and was used across all conditions. Users could virtually navigate using the keyboard. The arrow keys controlled panning such that it seemed to move the user in that direction (egocentric view), moving the image in the opposite direction. The user could smoothly zoom with the plus (+) and minus keys (-). Users could also jump between scales using the Page Up and Page Down keys. The space bar key corresponded to a hotspot that reloaded the starting view for that task. Users were familiar with navigating by the end of the tutorial. The mouse was used for marking checks on the view for the route tracing and comparison tasks explained below.

4.2 Tasks

We chose three different task types for all conditions: 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 geographer and cartographer advice. Participants performed two of each task type, an easy and a hard task, for a total of six tasks per condition. All tasks involved navigating extremely large aerial images at multiple scales.

Search tasks involved locating a specific unaltered object in the aerial view. The easy search task involved finding the "14R" label at the end of a Chicago airport runway (Figure 4). The hard search task involved searching all of Chicago for a red bull's eye on the roof of a building (Figure 5). The bull's eye was more difficult to find because the search area was greater. Participants were told to physically point to the object when they found it so that the proctor could visually verify the answer (dependant variables are time and accuracy).

Figure 4: Easy search task for "14R" label on the flat twenty-four monitor condition
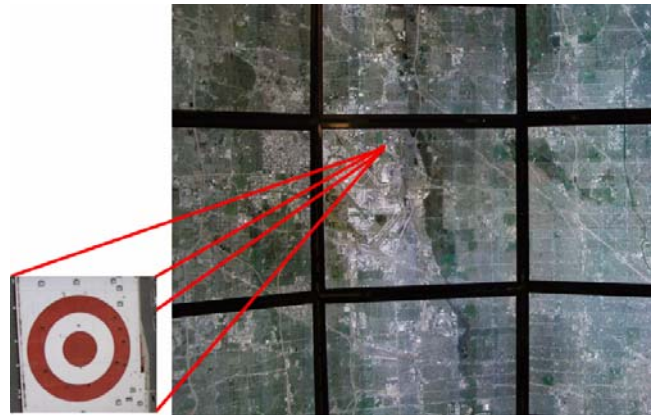

Figure 5: Hard search task for a red bull's eye on the curved twenty-four monitor condition

For the route tracing tasks, users followed a given route, marking underpasses/overpasses along the route. A green arrow and red octagon icon indicated the start and stop points on the route, and fictitious highway icons were added along the route for guidance (Figure 7). Users could mark checks anywhere on the imagery with the mouse. The instructions were to mark all underpasses/overpasses along the route and inform the proctor when complete (dependant variables are time and accuracy).

The easy task was to mark underpasses along a portion of Expressway 402 East of Atlanta, GA (labeled Highway 8) (Figure 6).
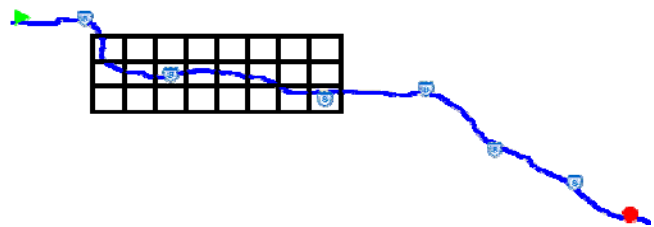

Figure 6: The easy route tracing task with respect to the twenty-four monitor display at a frequently zoomed scale

The hard task was to mark overpasses along a portion of Highway 60 in Los Angeles, CA (labeled Highway 64) (Figure 7). Overpasses were more difficult because identifying a road underneath the route requires a closer inspection; whereas, with the underpasses, roads crossing over the route stand out.

Figure 7: Route tracing task on the curved 24 monitor condition

In the image comparison task users could toggle between two aerial views (Figure 8). One view was an older 1988 black and white view of the area using DOQ (Digital Orthographic Quads) imagery, and the other was a recent 2003 color view. 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 or lakes. Users could click on blocks to mark a check, signifying a change. Users had fives minutes to check as many blocks on the grid that had urban changes (dependant variable is accuracy).

Figure 8: Image comparison task

4.3 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 conditions. 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 curved with radius equal to 30 inches (Figure 3). In general, one can create different curvatures by adjusting the radius. We tested five of the six conditions (Table 1). The one monitor curved condition is not applicable since one cannot curve a single monitor.

Table 1: The five conditions tested

	Flat	*Curved*
1 monitor	✓	
12 monitors	✓	✓
24 monitors	✓	✓

Viewport size and curvature were between-subject variables because of the time it takes to reconfigure the display. The order of tasks within each task type was counterbalanced using two 4×4 Latin Square designs, where one dimension represented the task type and the other dimension represented four of the eight participants. Each task type had one easy and one hard task. 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 40 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-seven of the participants were male and 13 were female. All had normal to corrected-normal vision. All participants reported having daily use with computers.

4.4 Procedure

Each user took about one hour to complete the experiment. The tasks took no longer than 5 minutes each as there was a timeout at 5 minutes.

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. The tutorial covered the buttons used for keyboard navigation. Users were told that they were allowed to physically move around, and were given a stool and rolling keyboard stand.

Users were given written instructions for each task on a piece of paper and were allowed to ask for any clarification. Then the experiment began.

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

5 RESULTS

5.1 Completion Time

Task completion time was measured for both the route tracing and search tasks. For the comparison tasks participants were always given 5 minutes, therefore completion times for the comparison tasks were not analyzed. Times for participants that timed out after 5 minutes were recorded as 5 minute task completion times. One participant was thrown out as an outlier, since that participant timed out on every task, regardless of difficulty level.

5.1.1 Overall Completion Times

We performed a 3-way ANOVA. Analysis of variance showed a main effect for display configuration ($F(4,136)=3.52$, $p=0.009$), task type ($F1,136)=134.9$, $p<0.001$), and task difficulty ($F(1,136)=15.39$, $p<0.001$). Search tasks were significantly faster than route tracing tasks and easy tasks were significantly faster than hard tasks. Post-hoc analysis of the display configurations showed a statistically significant difference ($p<.05$) between several of the display configurations.

Figure 9 shows the results of the post-hoc analysis. Non-overlapping confidence intervals are statistically significant at the alpha level of 0.05. All large display conditions, except for the twelve flat condition, are statistically faster than the one monitor condition. Furthermore, the twenty-four curved condition is faster than the twelve flat condition.
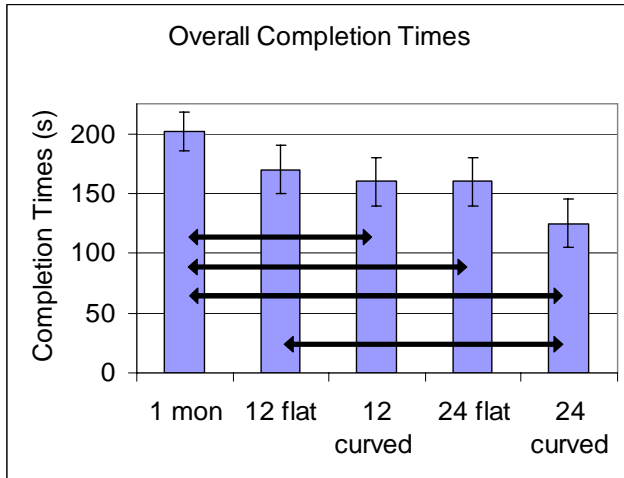
Figure 9: Performance times (s) of all display configurations. Non-overlapping error bars indicate statistical significance (significantly different conditions also linked by arrows).

Figure 9 shows the general trend that increasingly larger viewport sizes and curved displays reduce performance time. However, an interesting observation is that by curving the twelve monitor condition (158.5s) the performance times roughly equated that of the twenty-four flat condition (158.3s). However, by curving the twenty-four monitors the performance time again decreased for the twenty-four curved condition (124s).

Analysis of variance also resulted in non-significance for difference between flat (157s) and curved (143s) conditions. The one monitor condition was not included in the analysis as it did not have a curved counterpart.

5.1.2   Task Specific Completion Times

Since, 48% of participants for the hard route task and 26% of the hard search task timed out regardless of the display condition, the hard tasks were not analyzed in this section. This section only shows the results for the easy tasks.

As the experimental design was an incomplete factorial design (Table 1) we analyzed the easy tasks by performing two different analyses of variance. The first analysis was a mixed-model three-way ANOVA where the curvature and viewport size were between subject and the task type was a with-in subject factor. Note, here task difficulty is eliminated as a factor because hard tasks are not analyzed. This first ANOVA did not include the one monitor condition, because it is not relevant to the curvature variable.

The resulting analysis showed that there were main effects for viewport size, curvature, and task type. There was also an interaction between the task type and viewport size ($F(1,27)=10.26$, $p=0.003$). For viewport size, we found that participants performed faster on the twenty-four monitors (112 seconds) than the twelve monitors (145 seconds) ($F(1,27)=7.18$, $p=0.012$). For curvature we found participants performed faster on the curved displays (111 seconds) than the flat displays (146 seconds) ($F(1,27)=7.82$, $p=0.009$) (Figure 10).
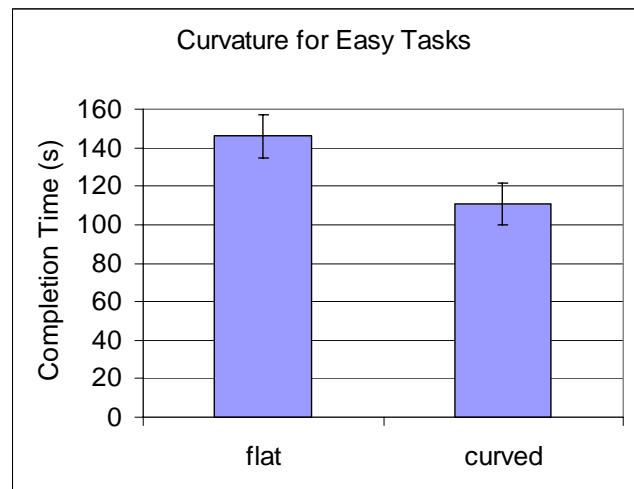

Figure 10: Average completion times for easy tasks on twelve and twenty-four monitor curvature conditions

Lastly, for the task type we found that that the search tasks were faster than route tasks ($F(1,27)=186.1$, $p<0.01$).

We used Fisher's protected t-test as a post-hoc comparison to further investigate the viewport size and task type interaction. For the route task we found that the twenty-four monitors (178 seconds) were faster than the twelve monitors (251 seconds), whether flat or curved ($p=0.004$). For the search task showed that the twenty-four monitors (46 seconds) was not statistically different than twelve monitors (38 seconds) ($p=0.58$) (Figure 11).
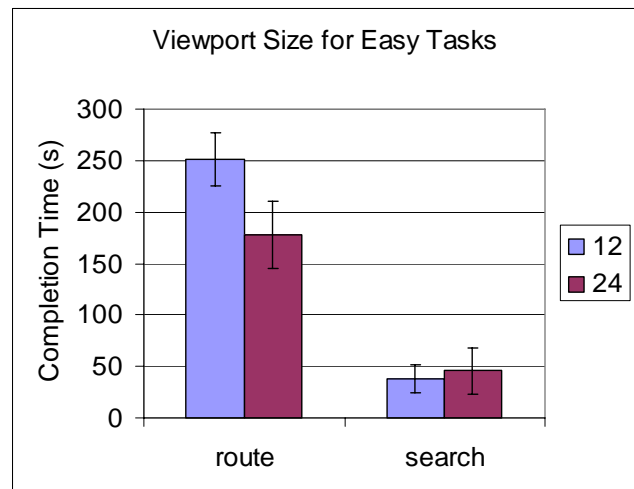

Figure 11: Average completion times for easy search and route tasks on twelve and twenty-four monitor viewport sizes

The second analysis was a mixed design two-way ANOVA that took into account the one monitor condition; the variables were display configuration (i.e. one monitor, twelve flat, twelve curved, 24 flat, and 24 curved) and task type (i.e. easy route and easy search). The result was an interaction between the task type and display configuration ($F(4,34)=4.24$, $p=0.007$).

Post-hoc one-way ANOVAs showed that both the search task ($F(4,34)=4.03$, $p=0.009$) and the route task were statistically significant ($F(4,34)=3.84$, $p=0.01$). Protected t-test results for the search task show that the twelve flat, twelve curved, and twenty-four curved conditions were statistically faster than the one monitor condition, and the twenty-four curved condition was statisti-

cally faster than the twenty-four flat condition with p<0.05 (Figure 12). The same test for the route task shows that twenty-four curved is statistically faster than twelve curved and twelve flat with p<0.05 (Figure 13).
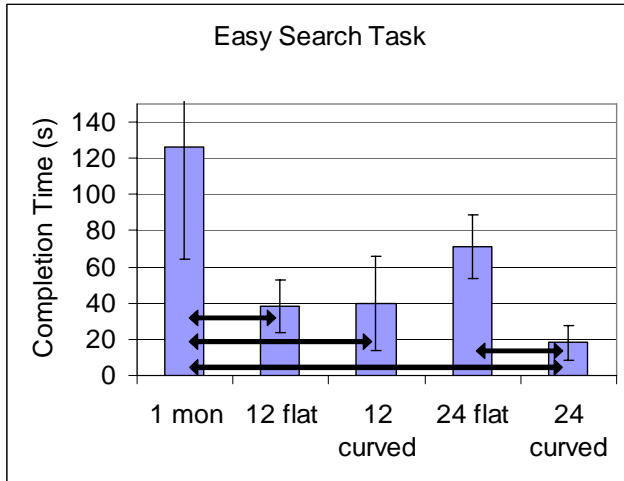
Easy Search Task

Figure 12: Performance times for the easy search task for all display configurations. Non-overlapping error bars indicate statistical significance (significantly different conditions also linked by arrows).
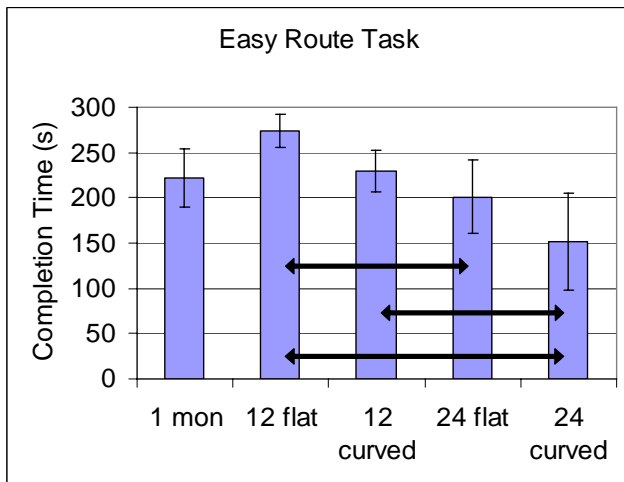
Easy Route Task

Figure 13: Performance times for the easy route task for all display configurations. Non-overlapping error bars indicate statistical significance (significantly different conditions also linked by arrows).

In summary, we did not find an interaction between curvature and viewport size. However, we did find an interaction between viewport size and task type. This indicates that curvature helped with performance times regardless of viewport size and that viewport size helped more with the route task than the search task.

This difference between tasks could be explained due to the nature of the tasks themselves. The route task was very long and utilized the wide screen space, whereas the search task involved a square area, fitting more easily in the twelve monitor display with little zooming.

5.2 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 marked 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%. Comparison tasks were recorded as the total number of differences marked by each participant.

Similar analysis as section 5.1.2 was performed with accuracy. A three-way ANOVA looking specifically at viewport size and curvature found a main effect of task type (F(3,81)=43.57, p<0.01). Similarly, a two-way ANOVA that took the one monitor condition into account also found a main effect of task type ((F,3,102)=55.77, p<0.001). In other words, the accuracy of the tasks themselves were different, but the different display conditions did not have an effect.

5.3 Mental Workload

Mental workload was measured using the NASA Task Load Index. Four scales, mental demand, physical demand, effort and frustration were each measured on a scale from 0-100 where 100 was high and 0 was a low rating for that factor.

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 on all but the twelve flat condition (p<.05).

The lack of significant difference in the other three scales (mental demand, physical demand, and effort) may be due to the wording of the corresponding survey questions. Several of the subjects indicated that they were confused by those questions.
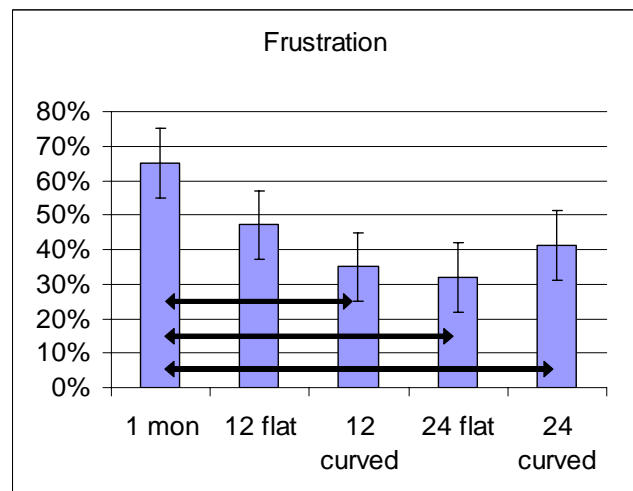
Frustration

Figure 14: Frustration averages for all display configurations. Non-overlapping error bars indicate statistical significance (significantly different conditions also linked by arrows).

5.4 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 the one monitor condition and the larger display conditions. 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 display 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 strategy 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.

Considering curvature, users physically interacted with the largest displays in different ways. For example, on the flat twenty-four monitor condition more users would either stand or walk; in that condition, five out of eight users stood up at least once. In the curved twenty-four monitor condition, however, users would turn their heads or their body. It may be because of this change in physical navigation that performance times were faster when the display was curved.

Even though the twenty-four monitor display was physically large, most participants did not stray far from their stool, despite clear instructions during the tutorial that they may feel free to move around. One possible explanation is that participants could only interact with the keyboard and mouse, and if participants moved away from their seat then they would have to either move back to the keyboard or move the rolling stand with them. Although the wheeled stand provided in this experiment brought mobility to the keyboard and mouse, it is clear that there may be a need for alternate input devices.

Furthermore, users changed their area of focus less frequently on the flat twenty-four monitor condition than those on the curved twenty-four monitor condition. 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 (even if they stood at some point) 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. Therefore, it appears that curving the display results in the users making use of a greater percentage of the available pixels more frequently.

6 CONCLUSION

In this paper we compare viewport size and curvature of large, high-resolution (96 DPI), high-pixel-count (up to approximately 32 million pixels) displays for realistic image analysis tasks. The primary contributions of this paper include the following:

In general, **increased viewport size improves user performance**, but it is task dependent. Overall, the larger display sizes improved performance over smaller sizes. On search tasks, both the twelve and twenty-four monitor conditions improve performance over one monitor, and were approximately 2-6 times faster. For route tasks, the twenty-four monitor condition improves performance over the twelve monitor condition and was approximately 50% faster.

The nature of the task and data is related to the viewport size in complex ways. The route task was very large data, but somewhat linear and horizontal (Figure 6). The large and wide twenty-four monitor display probably correlated well with the size and shape of the task data. Also, its linear structure was easy for users to virtually navigate, even with the small one-monitor screen. Whereas, the search task data was square in shape and not as large in size (Figure 4), and required full 2D navigation of the entire space. Hence, the larger display sizes had the advantage of minimal virtual navigation, while the one monitor screen size required a lot of complex virtual panning and zooming. The

twelve and twenty-four monitor display sizes probably had similar performance due to the square shape of the data, which did not need to take advantage of the wide aspect ratio of the twenty-four monitor display. The observed **reduction in virtual navigation and increase in physical navigation** correlates to improved user performance. Combining increased visual imagery with physical navigation was beneficial in this case.

Curved displays improve performance over flat displays regardless of viewport size. For the easy tasks, curvature performance was approximately 30% faster than flat. Of all five display conditions, user performance was the best on the curved twenty-four monitor condition. Curvature improved performance probably because users could better utilize the left and right outermost pixels on the display (as shown in section 2). In the flat twenty-four monitor condition, for example, users were at least 4 feet away from the furthest pixels. However, in the curved twenty-four monitor condition the user was never more than 2.5 feet from any given pixel.

Physical navigation changes from standing and walking to turning when the display is curved. We observed that the physical navigation was different on the flat and curved conditions. The change from standing and walking around the flat display to turning in the curved display support our visual acuity hypothesis. When combined with the fact that curved displays improved performance, this indicates that this type of physical navigation was more efficient for users and better enabled them to visually access and process the imagery.

We also show that **user frustration is significantly less on the largest display** (twenty-four monitors) than the one monitor condition. This might indicate an optimal configuration, in which the fastest form of physical navigation reduces frustrations of virtual navigation.

We also found that **user frustration is significantly less on the larger displays** than on the one monitor condition. This might correspond to the greater use of human visual capacity and more natural physical navigation that reduces potential frustrations of virtual navigation.

7 FUTURE WORK

We would like to find out why and how curving these large, high-resolution displays improve user performance. Does curving the display improve performance because the position of the data, whether it is in the middle or edge of the display, no longer matters? Does curving the display allow users to compare virtually far apart objects faster because they are physically closer? Furthermore, is there is a tradeoff between detailed insights and overview insights to the data? Specifically, if the details are more accessible to users on the curved form, will they find more detailed insights and less overview insights when using the curved display than when using the flat display?

We plan to answer these questions in a second experiment, as well as quantify the physical navigation with motion tracking using the Vicon system.

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