Tracking User Navigation and Performance on High-Resolution Displays using a Dynamic Real-Time Strategy Game

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ABSTRACT

The use of multiple monitors on a single computer is increasing as the cost of monitors goes down. Unfortunately, little is known how performance and navigation are affected as people increase the number of monitors they use. This paper discusses the outcome of an experiment that tracked the navigation and performance of participants as they played a popular strategy game on one, four, and nine monitors. The results show that having only one monitor was a clear disadvantage in both performance and the percent of time participants navigated. Participants performed significantly better on the four and nine screens than the one screen. Also, the larger the screen, the less participants navigated. On the one screen, participants navigated 27% of the game, while only 12% on the four screens, and 6% on the nine screens. There was also found to be a *positive* transfer from the smaller to larger screens, but no transfer (positive or negative) from the larger to smaller screens. How results can be generalized to geospatial visualizations, military applications, and surveillance systems are discussed.

CR Categories: K.6.1 [Management of Computing and Information Systems]: Project and People Management—Life Cycle; K.7.m [The Computing Profession]: Miscellaneous—Ethics

Keywords:

1 INTRODUCTION

With technological improvements, monitor cost continues to decrease as resolution increases. With monitor cost going down more people are able to afford multiple monitor configurations for one computer. Multiple monitors are usually configured in a series of desktop monitors that are either placed beside each other or are stacked in an array.

As people buy monitors they are faced with a tradeoff when increasing resolution. When one increases resolution, one must increase the physical size of the screen, increase the pixel density (dots per inch) of the screen, or increase a combination of both physical size and pixel density. In this study we chose to increase the physical size of the screen while maintaining the pixel density. We plan to do further studies on comparing the tradeoff of pixel density to physical size when increasing resolution in the future. One reason for this decision is that increasing physical size (e.g. adding more monitors) is currently more affordable.

This paper attempts to show how large, high-resolution screens help people increase their performance on different tasks. It is based on the results from Ball and North[2] which show that people perform differently at basic navigation tasks with a static view on different resolutions. They show that people do not always perform better at higher resolutions. Using one, four, and nine monitor configurations, they showed that if the target size is large enough people can zoom out to get an adequate overview of the visualization. However, they show that as the target size gets smaller users are not able to use zoom to get an adequate overview, thus necessitating a more detailed view. As the target size gets smaller, the larger the viewport (the more monitors used), the better the performance.

This paper differs from [2] in several ways. Whereas the previous study had a static environment, this study used a dynamic environment. Also, constant monitoring of computer input from the user was recorded and expert users were used instead of a random population. This study also used an environment where the participants were under stress to perform accurately and as quickly as possible as they had to quickly respond to changing situations.

There are many real-world applications that focus on dynamic monitoring and geospatial visualizations that could benefit from high resolution displays. Some of these applications include but are not limited to: Navigation of geospatial environments, emergency response systems, wide scale surveillance and military war gaming. For the purpose of this experiment, we used a real time strategy game since it incorporates many properties from each of these real-world scenarios.

The game we used is Wargus, an open source game based on WarCraft®II. WarCraft®II was a popular strategy game in the mid to late '90's developed by Blizzard Entertainment. Participants were told that they were playing on WarCraft®II and could not tell a difference between the real game and Wargus. Figure 1 shows an example of Wargus being played on the nine monitor configuration.

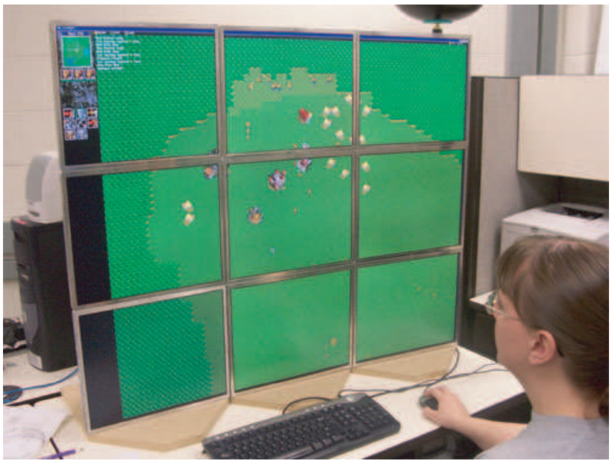

Figure 1: Example of Wargus being played on nine screens at a resolution of 2400x1800

We held 12 tournaments with three participants at each tournament for a total of 36 participants. Each participant played three games on each of three different monitor configurations: one monitor, four monitors, and nine monitors. In other words, each participant played on each monitor configuration once. By modifying the open source game engine that was designed to play Wargus, we were able to add code that tracked user navigation and performance as well as modify the source to allow larger resolution sizes.

The purpose of our study was to evaluate the usefulness of high-resolution displays when dealing with a dynamic environment in a geospatial setting. Our research questions follow:

- Which resolution generates the highest score in the game?
- How will resolution affect user navigation and behavior?
- Which resolution is preferred by participants?

Based on the results from [2] and [15] our hypothesis was that the score would be highest on the nine monitor configuration. We anticipated that navigation would be the most on the one monitor configuration and the least on the nine monitor configurations due to increased awareness. Based on [1] we anticipated that participants would prefer the larger configurations. We did not anticipate any particular interface issues or changes in user behavior besides those already cited in [2].

2 Related Work

As multiple monitor usage has increased several studies have been performed to evaluate different aspects of the usefulness of larger and/or multiple screens. In general, these studies have focused on task performance for two to three monitors compared to one monitor or large projector-sized screens compared to one monitor.

For larger screens, such as projector-based displays, there have been several studies that have shown better performance on the larger screen than a similar smaller counterpart, such as a desktop monitor. Such studies have shown an increase in memory[8][17], spatial performance [15], 3D virtual navigation [16], and multi-tasking [13]. A few different interaction techniques have also been developed to use on large screens such as [10][12].

On multiple monitors there have also been several studies showing improvements in user performance. Such studies include an increase in performance in multi-tasking[1] [5], basic navigation[2], and offset gender bias in performance [6][14]. A few interaction techniques developed on multiple displays include pen-based approachs[7], mouse-based approachs [11][4], and head-tracking approaches [9].

In a unique study, Baudisch et al. [3] performed an experiment showing advantages of having a high resolution screen embedded in a low resolution screen. In effect, they created a focus plus context screen without spatial distortion.

3 Game Specifics

WarCraft®II is a strategy game based on gathering resources, building up forces, and attacking and destroying enemy forces. Each user creates a base where all forces are created and all resources are returned to. Using a map that is shown from above (similar to satellite views) one can see a limited area of each map based on the resolution of the screen.

Users are able to select units (attack and non-attack forces) by clicking on individual units or using a selection box to select multiple units. Each type of unit has different attributes and are controlled by control buttons on the left side of the screen. Hot keys are also available for each control button. In addition, a minimap, or inset can be used to see an overview of the map or to quickly navigate to a certain area of the map (standard overview and detail technique).

In this rest of this section we discuss changes we made to the game, the resolution of the monitors used, and how one navigates in the game.

3.1 Software Changes to Game

The base resolution of WarCraft®II is 640x480 and does not extend over one monitor. In other words, WarCraft®II can only be played on one monitor at a low resolution. Instead of using WarCraft®II we used Wargus, an open-source project that enables use of WarCraft®II data. Stratagus, the graphics engine that runs Wargus, allows for play across multiple monitors at varying resolutions. In order to play Wargus on Stratagus, one must own a legal version of WarCraft®II.

Stratagus is a free cross-platform real-time strategy game engine, capable of playing against human or computer opponents. As it is open-source, we were able to alter the source code to allow it to play on resolutions up to 2400x1800 with little noticeable slow down. In order to get the game ready for real-time networked playing we successfully sped up the game by modifying game engine:

- Frame skipping
- Added additional support for large resolutions
  - Modification of clipping
  - Modification of presentation of some graphics
  - Forced 8 bit drawing mode (256 colors)
- Added navigational tracking
  - Number of right and left clicks
  - Amount moved in the x and y
  - Amount of usage of minimap
- Track all game data (e.g. Amount of resources, kills, score, etc.)

The game allows multiple people to play each other across a network. One computer acts as server and synchronizes the game speed with all the other computers so that during the tournaments all computers are at the same game speed.

3.2 Screen Resolution

For the experiment we used three computers. The first computer had one monitor (see figure 2.a). The second computer had four monitors that were tiled together in a 2x2 matrix on a stand (see figure 2.b). The third computer had nine monitors that were tiled together in a 3x3 matrix on another stand (see figure 2.c).

Figure 2: a) One monitor configuration. b) Four monitor configuration. c) Nine monitor configuration

As explained earlier, the base resolution of WarCraft®II is 640x480. The four monitor computer had a resolution of 1600x1200 and the nine monitor computer had a resolution of 2400x1800. The one monitor configuration was kept at such a low resolution for the purpose of seeing how a large resolution of the same game affects the original game. The reason the other monitor configurations were not set at a higher resolution was due to real-time performance. 2400x1800 was the highest resolution we could obtain while keeping the game at real-time speeds on the nine monitor configuration.

Figure 3 shows approximately the difference in resolution of the one monitor configuration to the nine monitor configuration.

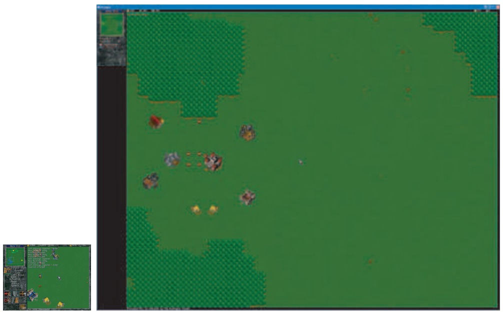

Figure 3: a) One monitor screen shot at a resolution of 640x480. b) Nine monitor screen shot at a resolution of 2400x1800. The screen shots are place beside each other at approximately the right size ratio

However, although the *screen's* resolution is what was specified in the previous paragraph, the viewport resolution of the battle field (e.g. not the control buttons, minimap, etc.) is smaller. The actual viewport resolution is 450x450 for the one monitor, 1410x1150 (8 times the size of the one monitor) for the four monitor configuration, and 2210x1760 for the nine monitor configuration (2.4 times the size of the four monitor configuration and 19.2 times the size of the one monitor configuration).

3.3 Game Navigation

There are two navigation techniques used in WarCraft®II:

- Overview and detail: Minimap or inset (see figure 4).
- Panning: Arrow keys or the mouse.

Figure 4: The yellow arrows indicate the location of the minimap on the screen. The red arrow points to the rectangle which represents the portion of the map that is displayed in the viewport

Both navigation techniques can be used by users at any time. Use of the minimap is similar to conventional overview and detail techniques. One is able to move the outlined rectangle that represents the position of the viewport by dragging it or by clicking on any area of the minimap.

Panning can be performed by using the arrow keys on the keyboard or by using the mouse. When using the mouse the user moves the cursor to the side of the map in the direction he wants to navigate to. For example, if the user wants to move to the right, he moves the mouse to the far right of the screen and viewport pans accordingly.

4 Experiment Setup

Using a tournament style approach, we held 12 tournaments. There were three participants in each tournament (total of 36 participants) that played each other three times. We performed a full factorial design where all monitor orderings were completed six times. In other words, each participant played at each monitor once and after six participants we completed a full factorial of monitor orderings. As we had 36 participants we were able to complete six full factorial designs. All map sizes were also tested with every monitor order twice.

Our independent variables follow:

- Monitor configurations: One, four, or nine monitors
- Map size: small, medium, and large.

As explained earlier, we altered the source code of the game to test for the following dependent variables:

- Minimap usage
- Percent of time navigating per map
- Score (algorithm that creates final score is predetermined by WarCraft®II based on the number of destroyed enemy units and enemy buildings)

4.1 Game Play

In order to test specifically how much different resolutions affected participants all game sounds and noise was turned off in order to not avoid a confounding variable.

We created scenarios and maps specifically for the game. In the interest of time and complexity, only a limited type of units could be used in the game:

- Peasant - used to harvest wood, gold, build building, and repair buildings. Limited attack capability.
- Footman - High health (can receive a large number of hits before dies), high damage, but limited range.
- Archers - Medium health, medium damage, high range.
- Suicide Bomber - Low health, extreme damage, low range. Suicide bombers blow themselves up and all surrounding units around them.

Also, in an interest of time, all three scenarios started the participants off with all available buildings used in the game. We only allowed participants to have buildings that corresponded to the creation of the above list of units. In WarCraft®II most maps start with only a peasant (used to create buildings, harvest resources, ect.) so that it takes several minutes to build all the necessary buildings.

This small list and limited resources (e.g. gold) made it possible to have shorter game times. In general, participants volunteered their time for approximately 1.5 hours. Also, having only four units made the game more fair so that participants varying in skill at controlling more advanced units would not dominate the game. We also reduced complexity of the game as people were not able to gather mass amounts of resources and mindlessly produce as many attack units as possible.

4.2 Participants

For the study we had 36 participants that each played at least 100 hours in WarCraft®II prior to participation. All participants were between the ages of 18 and 23 with the average of 20. The participants were 1 female and 35 male. All participants were undergraduate students from a variety of majors. The average time playing games per week is 9 hours a week ranging from 5 to 20+ average hours of game play a week on various video games.

4.3 Protocol

All game play was held in the same room participants were asked to hold to an honor code of not looking at each other's screens. All participants held to this honor code.

The three participants in each tournament were given 10 minutes on an initial monitor configuration (one, four , or nine monitors) to refamiliarize themselves with the game and the screen size. Each participant was randomly assigned to an initial monitor configuration. After the practice session, the players then had a 2 minute break. The three participants then played each other on the monitor configuration that they had previously practiced on. After the first game, the participants were given another 5 minute break where they could freely talk about the game. After the break the participants then rotated clockwise or counter clockwise around the testing laboratory to the next monitor configuration. Each odd group rotated clockwise while every even group rotated counter clockwise. For example, on the first rotation (rotating clockwise) participant 1 moved from the one monitor configuration to the 4 monitor configuration. Participant 2 moved from the four monitor configuration to the nine monitor configuration, etc.

After the first rotation, participants were then given an additional 5 minutes to practice the game at the new monitor configuration. After 5 minutes of practice the participants were given a 2 minute break then played a game against each other. After the second game, participants were then allowed a 5 minute break, rotated to the next monitor configuration, practiced at the new monitor configuration, were given a 2 minute break then played a last game against each other.

The reason for allowing and even encouraging talking during each five minute break was to allow participants to share strategies and tactics that they might have with the others to help facilitate a more even and fair playing environment. Also, by talking about the games participants are able to vent and verbalize what they were not allowed to do during game play.

Before a tournament began participants were asked to fill out a simple questionnaire asking their age, gender, computer proficiency, and average number of hours they play video games a week. During the 5 minute break between games and after the last game, participants were asked to estimate approximately what percent of their time they spent navigating the battle field. After all games were completed in the tournament participants were asked which screen they preferred, and if the larger monitor configuration helped and how.

5 QUANTITATIVE RESULTS

This section explains the three major results from our study. First, how score is correlated to resolution size, second, how navigation is correlated to resolution size, and how there was a *positive* when going from a smaller to larger monitor configuration and no negative transfer when going from a larger to smaller monitor configuration.

All statistical analyzes were performed in SAS's JMP using standard ANOVA techniques.

5.1 Correlation of Score to Resolution Size

There appears to be a correlation of score to screen size. With a statistical significance of $p < 0.01$, we found that score statistically varied by screen size. Also, there was not found any interaction effects between screen size and map size ($p = 0.76$). Multicollinearity was tested for and not found.

The game calculates score by the number of destroyed enemy units and enemy buildings. The average score on the one monitor was 2207, approximately 80% of the four and nine monitor configurations. The score for the four and nine monitor configurations were approximately equal, 2659 and 2790 respectively.

This improvement of performance due only to a larger viewport size is important in that it has implications for normal life as well. For all geospatial dynamic environments, these results could be used. For example, surveillance and tracking of people or aircraft, traffic control, military usage, etc.

5.2 Navigation Results

As explained earlier, we modified the open source Wargus graphics engine to track user input. Among our finding we found that the amount of time spent navigating differed among the different sized resolutions. With a statistical significance of $p < 0.0001$ we found that participants navigated in the following way:

- On 9 monitors, participants navigated an **average 5%** (**median: 1%**) of the time.
- On 4 monitors, participants navigated an **average 10%** (**median: 5%**) of the time.
- On 1 monitor, participants navigated an **average 24%** (**median: 25%**) of the time.

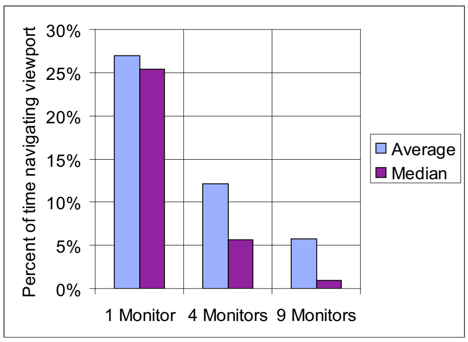

Figure 5: This graph shows approximately what percent of the time participants spent navigating the viewport of the map

As can be seen by the above bulleted list, the average score varied from the median score. In figure 6 one can see that there is a difference in navigation for each screen and map interaction with a statistical significance of $p = 0.079$.

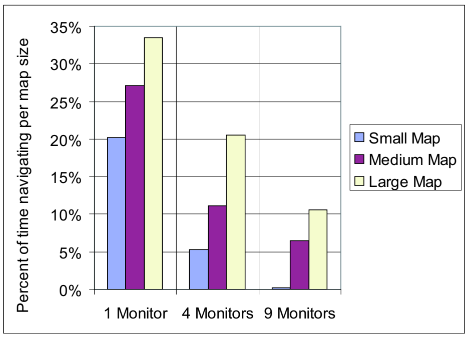

Figure 6: This graph shows approximately what percent of the time participants spent navigating the viewport of the map related to the size of the map

The percent of time navigating is almost the same when the ratio of the map size compared to the viewport size is similar. For example, looking at figure 6 and comparing it to table 5.2, one can see that for the four monitor configuration with the medium map, the percent of navigation is almost the same as the nine monitor configuration with the large map, 11.1% and 10.6% respectively.

Table 1: This table compares viewport size to map size. What is shown is the percentage of the map that can be seen in the viewport of the given display resolution

	One monitor	Four monitors	Nine monitors
Small	4.83%	38.66%	92.74%
Medium	2.15%	17.18%	41.22%
Large	1.21%	9.66%	23.18%

We calculated the percent navigation by tracking the amount of times the viewport was moved during a single game tick. A game tick is defined as a single cycle the game goes through to detect user input and update the game appropriately. However, this is representation of time as it just takes game cycles into account and not actual wall clock time. Due to this and other minor factors in the game we cannot conclusively report the exact percent of navigation. However, we report the percent of navigation as close as possible given the limitations of the game.

With the minimap we were able to track all interaction with it. Minimap interaction examples include: moving the viewport with the minimap, issusing movement commands of units by right-clicking on the minimap.

With a statistical significance of $p < 0.001$ we found that the amount of times a user would use the minimap with the one monitor was greater than the four monitors which was greater than the nine monitors. As can be seen in figure 7, participants used the minimap less as the viewport size increased.

Looking at figure 8 one can see the different sizes of the viewport area on the two minimaps shown. The outlined rectangle in the minimap shows the amount of the map that the user can see on the corresponding number of monitors. Using the largest map used for the experiment, one can see that only a small part of the map can be seen when using one monitor (figure 8.a). However, using nine monitors, a much larger area of the map can be seen by the user at once (figure 8.b). By being able to see more at once of the screen, it is not necessary to move the minimap as much to see the entire map.

We also found that panning navigation (whether by using the keyboard of mouse) was different on the different monitor configurations with a statistical significance of $p < 0.0001$.

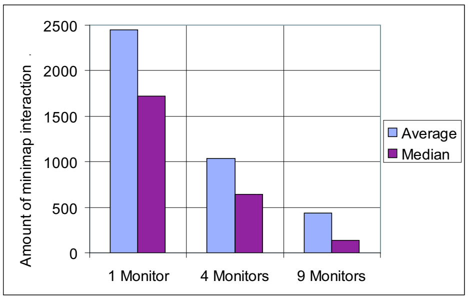

Figure 7: This graph shows the average number of times mouse interaction was detected in the minimap per game

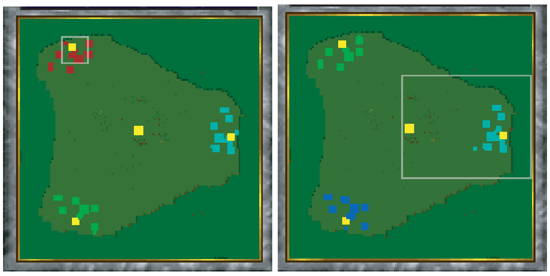

Figure 8: a) One monitor minimap b) Nine monitor minimap. The outlined rectangles in the minimap shows how much of the map the user can see. The one monitor configuration sees only 5% of what the user on the nine monitor configuration sees

Looking at figure 6 one can see how the average amount of navigation that took place on the different monitors differs according to the map size. On average there was little or no navigation on the nine monitors with the small map as the small map was only slightly larger than the nine monitors. However, as the map size increased so too did the navigation.

5.3 Positive and Negative Transfer

We also found that there was a *positive* transfer when participants went from a smaller monitor configuration to a larger monitor configuration and a no positive or negative transfer when participants went from the larger monitor configuration to a smaller monitor configuration. For example, if a participant went from a smaller monitor configuration to a larger then on average his score would increase by 508 points. However going from a larger monitor configuration to a smaller monitor configuration had little to no effect as participants would generally increase their score by only 2 points. The average score for the first game (whether then going to a larger or smaller monitor configuration) was roughly the same.

We found a statistical significance of $p = 0.07$ between the two directions (going to a larger versus going to a smaller monitor configuration. Using a power analysis to estimate how many people would be required to get to the standard threshold of alpha = 0.05, we estimate we would need to run seven more participants through the experiment.

One reason for such a high p is due to the way we measured transfer. We considered only the difference in score between the first game and the second game. We did this as only one third of all participants always moved to a larger or smaller monitor configuration after each game. The other two-thirds of the participant would switch directions of orderings to complete the full factorial design. As a result, we only used the score difference between the first and second game.

6 QUALITATIVE RESULTS

This section highlights many of the most common observations during the course of the study.

6.1 Strategies

Since there were three participants playing the game, one of the most common strategies used was to wait for another person to attack another player and then attack the aggressors base. For example, a recurrent strategy would be for participant 1 (p1) to attack participant 2 (p2). While p1 was attacking p2, participant 3 (p3) would then attack p1's base as p1's base would have fewer units to defend with.

However, exactly how each battle would play out would depend on which monitor configuration p1, p2, and p3 were currently at. Regardless of actual individual skill, if p1 were on the one monitor configuration then when p3 attacked p1's base he would not notice as quickly (if at all) as when p1 were on the four or nine monitor configurations. If p1 were on the four or nine monitor configurations and attacked p2 and p3 attacked p2's base then p2 would usually notice and try to defend his base.

Another variation of the same strategy is when p3 is on the one monitor configuration. For example, if p1 were to attack p2, then instead of p3 attacking p1's base, p3 usually would not even be aware that a battle is taking place.

As score is based on the number of kills to enemy units and number of buildings destroyed, the participant on the one monitor configuration would often have a lower score simply because he was not aware that battle were being waged. As a result there would be fewer enemy forces to destroy and would often receive a lower score. As mentioned in the above section, the average score associated with the one monitor configuration was lower than the other two scores with a $p < 0.04$.

In general, the four and nine monitor configurations were more aggressive than the one monitor configuration. As a result of greater awareness the four and nine monitor configurations not only navigated less, but they also performed better.

6.2 Base View

Construction and configuration of one's base can be important as all units are created at one's home base. With the one monitor configuration it was repeatedly observed that all buildings were built close to each other as all of one's base could not be seen at once and participants tried to minimize the amount of navigation spent just trying to view and manage one's base.

However, observing the participants on the four or nine monitor configuration, one could see that their base generally sprawled compared to the one monitor configuration as all of one's base could be seen at once on either the four or nine monitor configuration.

Participants on the one monitor configuration would often frantically navigate their base. They would appear to be constantly looking for threats in and around their base while at the same time maintaining their base.

On the four and nine monitor configurations participants would place their base in the middle of screen. As they could see their entire base there was not a need to be constantly navigating through their base as participants would be able to look for threats and maintain their base without scrolling. As a result of seeing more they would be able to look for threats in a wider area than simply in around their base. However, following basic psychology principles of focusing on the middle of the screen, participants on the four and nine monitor configurations would keep their base in the middle of the screen (except during battle situations) even when it was their advantage to have it moved to one side. For instance, there were many cases in which on the nine monitor configuration participants would have been able to see all of their own base and part of another participants if they had moved their view of their base to one side.

6.3 More Global Understanding

As mentioned in the previous subsection, the four and nine monitor configurations were able to look for threats further than just beyond their base. As a result they were able to respond to threats much faster than on the one monitor. For example, participants on the one monitor configuration would often respond to a threat after one or more of their buildings had been damaged or destroyed.

However, with the four and nine monitor configurations, participants would often respond to threats before the threat even attacked. As mentioned above, there were suicide bombers in the game that could cause a great deal of damage, but were easily destroyed themselves. On the one monitor configuration participants would often either not see the suicide bomber but would simply notice later that a building or group of their units had been damaged or destroyed, or would notice the suicide bomber but not be able to react quickly enough. With the four and nine monitor configurations most suicide bombers were noticed and adequate retaliation could be used before the suicide bomber damaged anything.

In general, participants using the four and nine monitor configurations would adapt to the suicide bombers and create a defense especially for the use of destroying incoming suicide bombers. In general, the four and nine monitor configurations were able to successfully defend against the suicide bombers. However, the one monitor configuration generally would not be able to succeed in defending their base successfully even if a defensive force were constructed as they simply would not see the suicide bombers in time to react.

There were several times that were observed when one participant attacked the participant on the one monitor configuration and the participant on the one monitor configuration would not even notice until several building and units had been destroyed.

In the opposite extreme one participant on the one monitor configuration tried to surrender his game even though he had a sizable army left to battle with. The reason for his surrender is that he had forgotten that he had that army and did not see it until the proctor told him that he could not surrender until all his units were destroyed. As a side note, the proctor knew that the participant had the additional army because he saw them on the nine monitor configuration.

An interesting note on the nine monitor configuration is that participants were able to evaluate the battle field and realize if they were going to lose even before going into battle. For example, by looking and quickly summing all of one's own forces and all of the opposition's forces participants were able to determine if they would lose in an ensuing battle even before such battles began.

In general users on the larger monitors configurations had more insight into the map. Participants on the larger monitor configurations were able to see their entire base, the surrounding area, and quickly view the entire map faster than the one monitor configuration.

6.4 Changing Monitor Configurations

As explained earlier, there was a *positive* transfer when changing from smaller to larger monitor configurations and no transfer when changing from larger to smaller. However, Participants vocalized their discomfort of going from a large screen to a small screen where little or nothing was said when going from a smaller monitor configuration to a larger one. Specifically, almost every participant that played a game on the nine monitor configuration and then played a game on the one monitor configuration verbally complained about the loss of viewport size.

6.5 Bezels

Although bezels were only 3/4 of an inch between screens, several participants felt that the bezels were distracting especially on the four monitor configuration. Participants generally agreed that the intersection of bezels in the middle of the display was a distraction (see figure 9).

Figure 9: This image shows how participants view the four monitor configuration and see bezels in the middle of the display

Another problem with the bezels is that they gave the illusion that armies had more units than they actually did causing spatial distortion. Looking at figure 9 it appears that buildings that are on the monitor boundary are wider than they actually are. Similarly when a group of units crossed monitor boundaries it appeared to many participants that there were more units than that actually existed.

6.6 Aware of limited view

The most skilled participants in the study were found to use the larger viewport on the nine monitor configuration to their advantage. Since they had knowledge that their opponents had a smaller viewport, they knew it would require much more navigation to gain a complete understanding of what was going on in the battlefield. Thus, the player on the nine monitor configuration would make an informed decision as to which portions of the map the other players would not be navigating over, and move a small group of troops to that area. As the game was fast paced, there is not enough time for players with a smaller viewport to navigate to the corners since they need to focus their efforts elsewhere. Due to this, the corners of the map made an ideal location for the players on larger configurations to send their troops. In most cases these units would remain undetected until much later.

6.7 Notification Systems and Controls

The nine monitor configuration held advantages over the other configurations in that it showed the most area of the map at once. However, almost universally participants agreed that the notification systems and controls in the game were harder to use. In the game there exist several types of notification systems and controls. Looking at figure 4, one can see that there are several buttons and the minimap on the left panel. On the top panel are several statistics that are important in the game that report total resources and units. On the bottom panel one can see how much a potential unit cost if one does a mouse over (as shown). In addition, important messages are printed to the top left of the viewport of the map. All of these controls and notification systems are easy to use as they are all close together. However, when using the nine monitor configuration it can be difficult to both use and see all of the notification systems and controls. Following Fitt's law, it is more difficult to scroll to a control on the left panel (which is towards the top of the screen on the nine monitor configuration) then look down to the bottom panel to see the cost of each unit. Neck strain and other physical problems arise when trying to view the top panel to see how many resources and units one has.

As the four monitor configuration was not as tall as the nine monitor configuration neck strain was not said to be a problem. However, it still takes longer to mouse over a control button then look down at the bottom panel for its cost on the four monitor configuration than the one. More research should be done to determine how to most effectively overcome this problem.

6.8 Subjective vs. Objective Reporting

After the completion of every game the participants were asked to report the percent time they thought they spent navigating. As we also tracked all of their input we were able to compare both how much they actually navigated and how much they thought they navigated. Results of the question showed that participants thought that they navigated approximately 2 to 2.5 times more than they really did.

7 Participants Responses

As mentioned above, we asked participants to respond to two questions:

- Which screen size did you prefer the most and why?
- Did the larger configurations help you in any way? How?

7.1 Preference

Participant's preferences varied both for which monitor they liked better and the reason why. 16% of the participants preferred the one monitor configuration over the four and nine. The reasons stated that they preferred the it was because the one monitor did not have bezels and they had more familiarity with only one monitor.

On the other hand, 63% of the participants preferred the four screens. The different reasons follow: Much more of the battle field could be seen than the one monitor configuration. The nine monitor configuration was too large. It is hard to see the notification systems that often appear at the very top of the screen. The nine monitor configuration make it hard to control the minimap which is located towards the top of the screen. The nine monitor configuration was too unfamiliar and hard to adapt to in the short period of time that the participant used it. Lastly, the nine monitor configuration caused neck strain due to looking up so much.

For the nine monitor configuration, 20% of the participants preferred it over the four and one monitor configurations. Their reasons were that less navigation was required and they were able to see more at once (greater awareness).

In general, it appeared that people had a hard time adapting to the nine monitor configuration, similar to [1] due to additional height of the monitors rather than additional width. Also, participants that preferred the one monitor configuration generally preferred only one monitor because they felt uncomfortable with the novel screens of four and nine monitor configurations. As a result, the four monitor configuration seems to be preferred as it showed a larger view of the battle field, but was not too tall like the nine monitor configurations.

7.2 Larger Configurations Help

In response to the question of whether the larger configurations helped and why, the vast majority agreed (90%) that it helped and a few disagreed (10%). For the participants that did not think that the larger monitor configurations helped, they explained that it is harder to keep track of units and harder to keep track of surroundings and entire battle field. In general they felt that the larger configurations were overwhelming.

For the majority that agreed that the larger monitor configurations helped, they explained that less navigation was required. In addition, increased understanding on the entire battle field which also helped keep track of units, one's own home base, and the surroundings. Also, they felt that it is easier to create global strategies as opposed to small local strategies. Lastly, it is easier to maintain one's base while *simultaneously* attack others; easier to do offense and defense.

8 CONCLUSION

Our first research question asked which resolution generates the highest score in the game. Although observations showed and participants reported greater awareness on the nine monitor configuration compared to the four monitor configuration, the average score (performance) was almost the same with no statistical significance between them. However, the four and nine monitor configuration did better than the one monitor configuration. These results differ from our hypothesis in that we conjectured that the nine monitor configuration would have the highest score.

Our second research question asked how resolution affects user navigation and behavior. In response, we found that the larger the monitor configuration the less navigation required. We also found that users on the one monitor configuration were not able to concentrate on the map as a whole due to the increased amount of time required to navigate.

To answer our third research question of which resolution is preferred by participants we found that our hypothesis was correct in that participants preferred the four monitor configuration monitor. 60% of participant's preferred the four monitor configuration to the nine and one monitor configurations. There reasons varied, but mainly the one monitor configuration was too small. The nine monitor configuration in contrast was too tall which caused neck strain and it was more difficult to use the notification systems and controls.

In our hypothesis we did not anticipate these problems with the game interface. However, we found that the interface that was designed for a single monitor was not adequate for use with the nine monitor configuration. The notification systems and controls that were close together on the one monitor were far apart and difficult to use on the nine monitor configuration.

Perhaps, one reason why participants did not do better on the nine monitor configuration in score is due to the inadequacy of the notifications systems and control design that was targeted for one monitor but did not extend well to the nine monitor configuration.

Due to the inadequacies of the location of the notification systems for the nine monitor configuration, we recommend various alternatives. First, instead of having all the notifications systems on the border of the screen, all notifications could be in the middle of the screen. Also, information and controls about specific units could be place around the units themselves. Or, place notification system closer to the bottom of the screen to reduce neck strain.

The results of this experiment can be readily used in many real-world applications that focus on dynamic monitoring and geospatial visualizations. Fundamentally, being able to see more and navigate less helps people focus more of their attention on what is being presented on the screen.

9 FUTURE WORK

In the future we will continue work in this area. First, we plan on comparing tradeoffs of increasing pixel density to increasing physical size when increasing resolution. Second, we also plan to research how to best show important information, display non-intrusive notification systems, and position important controls (such as buttons) to minimize neck strain and navigation on large displays. Thirdly, we plan to analyze how form factors of large displays, such as height and width, influence people's performance and behavior.

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