Women Take a Wider View

Mary Czerwinski, Desney S. Tan[1], George G. Robertson
Microsoft Research
One Microsoft Way
Redmond, WA 98052
+1 425 703-1527
{marycz, ggr}@microsoft.com, desney@cs.cmu.edu

ABSTRACT
Published reports suggest that males significantly outperform females in navigating virtual environments. A novel navigation technique reported in CHI 2001, when combined with a large display and wide field of view, appeared to reduce that gender bias. That work has been extended with two navigation studies in order to understand the finding under carefully controlled conditions. The first study replicated the finding that a wide field of view coupled with a large display benefits both male and female users and reduces gender bias. The second study suggested that wide fields of view on a large display were useful to females despite a more densely populated virtual world. Implications for design of virtual worlds and large displays are discussed. Specifically, women take a wider field of view to achieve similar virtual environment navigation performance to men.

Keywords
3D navigation, field of view, landmark knowledge, gender effects, spatial abilities, cognitive maps

INTRODUCTION

It has long been reported that males and females navigate through the real world using different strategies [13,16]. The majority of existing research can be summarized by describing females as tending to use landmarks to navigate, while males tend to use broader bearings, such as the direction in which they are heading. This is important in the design of both 2D and 3D virtual worlds, since potentially subtle differences in these navigation strategies are often magnified, with males tending to outperform females in computer-generated environments [28].

But what if females can navigate as effectively as males through virtual environments, but simply have not been provided with the proper display parameters that best support their navigation strategies? This paper replicates and extends prior work [25], focusing on a finding that large displays coupled with wide fields of view were especially beneficial for females navigating in 3D environments. The paper also examines the hypothesis that a wider field of view enhances integration of piecemeal cognitive map information when navigating both sparse and dense environments. We present preliminary evidence that suggests that females need the support of a wider field of view in order to offload cognitive map assembly resources to perceptual processes. In addition, we have found that providing a wider field of view is especially effective on very large displays, and will present an argument as to why that is the case based on our findings. We believe that when females are provided with wider fields of view on large displays, the cognitive task of building a mental model is not as necessary, and landmark navigation is optimized. When these design conditions exist, we observe that females perform nearly as well as males on navigation tasks through virtual worlds, contrary to previous reports [3,23,28]. This paper is the first we are aware of to suggest that proper design can lead to effective female navigation performance in virtual worlds.

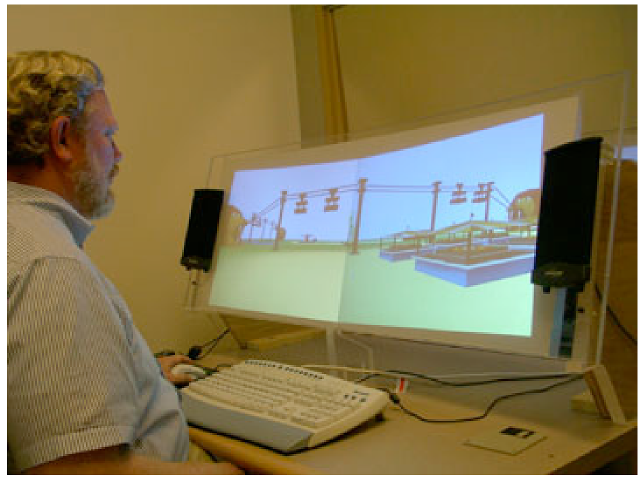

Figure 1. Arcturus 36" display showing study world.

CHI 2002, April 20-25, 2002, Minneapolis, Minnesota, USA.

[1] Currently at Carnegie Mellon University, School of Computer Science, 5000 Forbes Ave., Pittsburgh, PA 15213.

The contribution of these findings to design of computer-generated spaces is significant, given that female performance is significantly enhanced without jeopardizing male performance on 3D navigation tasks.

RELATED WORK

There exists a vast body of work on general principles in 3D navigation. Thorndyke & Hayes-Roth [26], as well as many others [21,24,28,30], have studied the differences in spatial knowledge acquired from maps and exploration. Vinson [27], Lynch [17], Passini [18], Darken et al. [6,7] and others have explored cognitive and design principles as they apply to large virtual worlds [21,27]. The latter researchers have consistently emphasized the usefulness of landmarks in supporting effective navigation.

It is surprising that few visualizations have attempted to aid the user, male or female, in finding landmarks, despite the broad consensus concerning their usefulness for both males and females in a virtual environment. Notable exceptions are found in the work of Elvins [11], Darken & Sibert [7], and Vinson [27]. Elvins created miniature virtual worlds called Worldlets that act as 3D thumbnails corresponding to landmarks viewable from any vantage point. User studies showed that navigating with the 3D Worldlets improved performance. Similarly, Darken et al. demonstrated the usefulness of natural landmarks in large virtual worlds by analyzing users' traversal paths and showing how designs with landmarks (such as lakes, hills, paths and gridlines) aided performance.

Gender and Spatial Ability

There exist good summaries of the known gender differences in spatial abilities and navigation strategies [16], and most reports tend to document male advantages in spatial tasks. More recently, several studies have been reported that suggest that these gender differences are further exaggerated when the spatial task is navigation in a virtual environment [3,23,28]. These studies suggest that females build less accurate conceptual models of an information space than their male counterparts. This performance difference has been attributed to females possessing lower spatial abilities, on average, in addition to having less proficiency with computer interfaces used to perform these tasks. The recommendation stemming from this earlier work is training in spatial abilities as well as practicing the virtual task with the user interface.

The work presented here will focus on display design details that apparently benefit females navigating virtual environments, reducing the requirement for such training. This is the first research we are aware of that shows the improvements for females navigating virtual environments with these display parameters, without a concomitant decrement in male navigation performance.

Field of View

When considering field of view, it is important to define precisely what display characteristics are being referred to in the design. There are two field of view angles that must be considered. The display field of view (DFOV) is the angle subtended from the eye to the left and right edges of the display screen. For a 16 inch wide display placed 24 inches from the user's eyes, the DFOV is approximately 37 degrees. This angle is limited by the physical display width, and can only be increased by replacing the display hardware or moving the user physically closer to the display. The DFOV can be decreased by using a window that is narrower than the screen width. The geometric field of view (GFOV) is the horizontal angle subtended from the virtual camera to the left and right sides of the viewing frustum. This angle is under control of the virtual environment designer. Most reported literature does not make the distinction between GFOV and DFOV. We believe that the term field of view (FOV) used in the literature is geometric field of view, and for this paper we will use FOV to mean GFOV.

It has been recently reported that it is harmful to deviate from a 1:1 ratio of FOV and DFOV [9]. Large deviations can cause either magnification or miniaturization of items in the virtual world, possibly leading to discrepancies between studies as well as contributing reliably to simulator sickness. Our findings demonstrate that this ratio is important, but not necessarily the variable most responsible for good performance on navigation tasks.

There has been much evidence that restricting field of view leads to perceptual, visual and motor decrements in various kinds of performance tasks [2,12,14,19,20,22], though there is some debate about what field of view parameters are optimal in design for computing tasks. However, we have found no reports in the literature suggesting that FOV restrictions are more or less harmful based on gender.

Alfano and Michel [2] had users perform a series of eye-hand coordination tasks using goggles that restricted the field of view to 9, 14, 22 and 60 degrees. The 60 degree field of view condition yielded significantly better performance than the others, but all of the FOV restrictions were reported to cause disorientation in the subjects' depth and size judgments. Chambers [5] performed FOV research and concluded that the maximum field-of-view acceptable for flight applications was about 90 degrees on a virtual display. Increasing the amount of peripheral information by increasing the field of view up to 90 degrees reportedly allowed the user to construct an overlapping sequence of fixations in memory, which should lead to faster cognitive map construction. Dolezal [8] described the effects of restricting field of view to 12 degrees, including disorientation, dizziness during rapid head movements, difficulty in tracking objects, and difficulty forming a cognitive map of unfamiliar places. He observed that eye-hand coordination is impaired, and that there was greatly reduced ability to integrate visual information across successive views. Note that the inability to form a cognitive map of unfamiliar places coincides with the decrement in the overlap of visual information across successive views.

Examining cockpit displays, Kenyon et al. [15] conducted two studies on the effects of different FOVs on the control of roll motion in cockpit displays. Response time delay and errors were found to decrease significantly with larger fields of view. However, most of the performance benefits were found with 40 or 80 degree FOVs, and there was little improvement with the full 120 degree FOV condition.

Similarly, Barfield et. al. [4] had participants judge azimuth and elevation under different conditions of field of view. The authors reported that performance was best under mid-sized FOV conditions (45 or 60 degrees) and worse under extreme FOV conditions (30 or 75 degrees). They concluded that this was because the former FOVs are closest to the display field of view and therefore result in the least amount of distortion.

In another study, Wells and Venturino [29] reported that there was no effect of FOV on performance with only three targets to process in a display, but performance was significantly degraded by fields of view of 60° or less when they increased the number of targets in the display to 9. In their study, users moved their heads less with the larger fields of view, since more of the targets were visible simultaneously on the display via eye movements.

In summary, it appears that wider FOVs are important aids for many spatial tasks, helping especially with cognitive map construction and as the visual complexity of a display or the demands of a task increase.

ARCTURUS: PROTOTYPE LARGE DISPLAY

In order to test our theories, we have constructed the Arcturus, a prototype display that provides us with large fields of view, both physically and virtually (Figure 1). Display field of view is increased with the large 36-inch display (36 x 14 inches). This provides an 8:3 aspect ratio (2048 x 768 pixels), twice as wide as regular monitors.

The Arcturus comprises two projectors mounted onto the bottom of the table. These projectors rear-project onto a semi curved tinted Plexiglas surface. With careful calibration, the seam in between the two projections can be made arbitrarily small, creating a virtually seamless 2048 x 768 pixel display surface. The display is driven using standard Windows 2000 multi-monitor support.

SPEED-COUPLED FLYING WITH ORBIT

A novel navigation technique, speed-coupled flying with orbit [25], allows users to seamlessly transition between local and global views of the world while navigating. The ease with which users can navigate between different viewpoints while navigating facilitates integration of landmark, survey, and procedural knowledge.

In speed-coupled flying, the user is equipped with standard driving controls (i.e., dragging the mouse forward or backward moves the camera forward or backward; dragging the mouse left or right turns the camera left or right). The further the user drags in a particular direction, the faster the camera moves. Further, the users' forward moving speed is coupled to their viewing height and angle. The faster they move, the higher they fly, tilting to look down upon the world from a bird's eye view. This coupling of speed to height and tilt keeps the visual flow across the screen constant, to allow the user to move and locate distant targets quickly. Users may slow down or simply release the button to glide gently to the ground.

The speed-coupled flying technique is combined with an object inspection technique termed *orbiting*. Orbiting allows the user to easily get desired viewpoints of particular target objects. When the user clicks and drags on an object, the object animates to the center of the screen and the user is switched to a mode of environmental state navigation. In this mode, dragging the mouse forward/backward moves the camera toward/away from the object; dragging left/right causes the user to move around a circle parallel to the ground plane and centered at the object, always keeping the viewpoint fixed on that object.

HYPOTHESES

We ran two user studies in an attempt to isolate the variable(s) governing enhanced female navigation performance in large displays. We postulated that:

1. Wide field of view benefits female navigation in virtual worlds more so than males on a large display (as reported in [25]), since more information is available via head/eye movements, or perceptually.
2. Females should benefit more from wider fields of view as the navigation task becomes more complex, due to the offloading of cognitive map-building resources to the perceptual system. This hypothesis was tested in Experiment 2, wherein we varied the complexity of the experimental worlds.

EXPERIMENT 1

The first study attempted to replicate earlier findings that a large display benefits females much more than males. We controlled for screen size, field of view and any potential intervening variables resulting from the earlier study's use of two different displays. In this study, all experimental conditions were presented on the Arcturus display.

Method

Subjects

Thirty-two intermediate to experienced computer users (17 female) participated in the study. Participants were screened as to be unfamiliar with 3D games and were chosen from a large volunteer pool based in the greater Puget Sound area. The average age was 41 (40.56 for females, 41.46 for males), ranging from 19 to 60 years of age.

Materials and Procedure

Two screen widths (18" and 36") and two levels of geometric field of view (32.5 degrees or narrow v. 75

degrees or wide) were evaluated in this study, all on the Arcturus display. We controlled the display as well as geometric fields of view in software. For the small display field of view, we reduced the width of the display to 18 inches by setting the outer parts of the projection to be black. For the geometric field of view, we controlled the horizontal angles with which the virtual cameras perceived the world. DFOV equaled 41 degrees and 74 degrees, fairly well corresponding to the GFOV manipulations. Each of the four conditions (large or small screen width x narrow or wide field of view) corresponded to the following DFOV:GFOV ratios: small-narrow=~1:1, small-wide=~1:2, large-narrow=~2:1, and large-wide=~1:1. We will refer to the GFOV manipulations as narrow and wide FOV throughout the remainder of the paper.

Two 3D worlds were created with the Alice 3D authoring tool [1]. Frame rates varied slightly as the user moved through each of the worlds, but were maintained at around 25 frames per second. The first world, which we will refer to as the tutorial world, was 300 by 300 meters and contained 4 objects for navigation and manipulation purposes. The second world, which we refer to as the experimental world, was 500 by 500 meters and contained 23 objects, most of which consisted of carnival-themed structures, such as tents, roller coasters and rides. Each world was designed so that there were "target" cubes and "target" drop-pads. The cubes and drop-pads were dual-coded to match each other via color and numeric coding. The cubes, numbered only on one face, were to be selected and carried to the matching numbered drop-pad, where it would be placed. In the tutorial world, there were only 2 pads and 1 cube for each trial. The tutorial consisted of the user finding the cube and placing it on its corresponding pad once for each of the four navigation conditions. In the experimental world, there were 4 cubes and 4 pads. A trial consisted of the user successfully finding each cube (in any order) and dropping it on its respective drop-pad. Once all 4 cubes had been placed on all 4 drop-pads as quickly as possible, the trial was completed. We developed this task to be representative of direct manipulation and navigation during productivity tasks in an advanced computing environment (e.g., scrolling to a folder, opening it, and dragging and dropping files into it), while being relatively more engaging for the participants.

Each of the four conditions (large or small screen width x narrow or wide field of view) was presented once in fully counterbalanced order during the experimental session. In between each navigation condition, the participant answered 3 questions about that condition prior to proceeding to the next condition. A deadline of 5 minutes for each experimental task ensured that participants progressed through the session in a timely manner.

After each condition, a pointing task was carried out. In this task, we removed 2 objects and 2 drop-pads from each of the worlds. After being shown an object for 5 seconds, the user was placed in the world and asked to turn and point to the location where they thought the object had previously resided. To do this, users were provided with a virtual "pointer" on the screen, and dragging the mouse moved the pointer to the proper position, just as if they were using their pointer finger in the real world. Users pointed from 3 positions, each 60 degrees away from each other, for each of the objects. Because the drop-pads were on the outskirts of the world, we only had users do this once for each pad. We measured performance errors as being the distance between the closest part of the object and the projected pointing ray. When all trials were completed, the participant filled out more survey questions, was debriefed, and then provided with a software gratuity for participating. Prior to beginning the experiment, all participants completed the Map Memory (MV2 and MV3) subtests of the Kit of Factor-Referenced Cognitive Tests [10]. These subtests were meant to examine participants' abilities to remember the position of things on a street map (MV2), and to remember parts of a map to see if they could recognize them again (MV3). Total session time, was approximately 2 hours. Participants were run individually.

The study was run on a 450 MHz Pentium II Dell computer. The Microsoft Internet Keyboard Pro and Intellimouse input devices were used. All dependent measures of interest were recorded on the participant's computer. We collected the following measures: overall task time, travel distance, travel height in the air while traveling ("flying" is a more efficient travel mode) and user satisfaction questionnaire responses for each condition as well as overall preference. We also collected the error measures for each of the pointing tasks.

Results and Discussion

Map Memory

Scores on the two map memory cognitive subtests were compiled and submitted to a paired t-test, assuming unequal

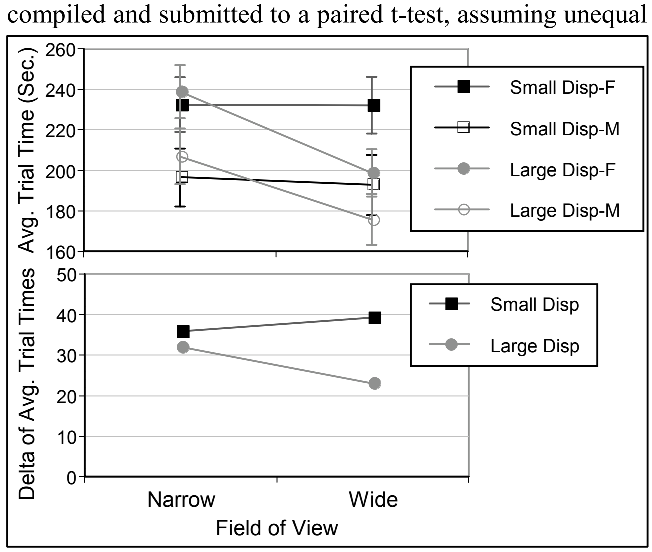

Figure 2. Effect of field of view on average trial time above; gender bias below.

variances, comparing males' scores to females'. No significant difference based on gender was obtained on this measure, t(29)=-0.29, p=0.77.

Performance Data

Since there were no significant effects in the percent correct data, they were removed from further analysis. The average trial times, pointing error, distance traveled and height of travel were submitted to a 2 (gender) x 2 (screen size) x 2 (field of view) repeated measures Multivariate Analysis of Variance. All variables but gender were tested within subjects. Significant main effects of display size, F(4,27)=15.5, p<.001, and field of view, F(4, 27)=4.2, p=.009 were observed. On average, larger display conditions resulted in less pointing error (15.4 v. 14.8 meters error for small v. large displays, respectively); greater distance traveled (5461 v. 6918 meters on average); more flying (average heights of 14.9 v. 15.5 meters); and faster trial times (213.5 v. 205 seconds, respectively). Wider fields of view had a similarly beneficial effect on average performance for pointing error (15.3 v. 14.8 meters error); distance traveled (6601.7 v. 5777.4 meters); travel height (14.6 v 15.8 meters); and trial time (218.7 v. 199.85 seconds, respectively).

The between subjects tests for gender reached significance for trial time, F(1,30)=5.9, p=.02; and borderline significance for travel height, F(1,30)=3.3, p=.07. In both cases, males were faster than females in their average trial times (192.9 v. 225.5 seconds, respectively) and had higher average travel heights (16.5 v. 13.8 meters, respectively). Motivated by our previous research [25], a planned comparison was used to determine whether or not there was a significant difference between males and females in the large display, wide field of view condition for trial time. The difference between males and females was not significant at the p=.05 level, t(28)=-1.32, p=0.1, one-tailed. Since the large screen, wide field of view condition in this study used the same display parameters as those previously reporting gender-specific benefits [25], we consider this result a replication of that preliminary finding.

Figure 2 shows trial time data as well as the differences (male-female delta) between men and women under the various conditions. The lower, delta graph clearly shows a reduction in gender bias in the large display, wide field of view condition.

A borderline significant interaction between field of view and gender emerged from the analysis, F(4,27)=2.3, p=.08. Across three of the measures (trial time, travel height and pointing error), females benefited more than males from wider fields of view, but the interaction only reached significance for the distance traveled metric. Figure 3 demonstrates how wider fields of view bring out markedly different strategy differences between males and females for this measure. Females travel less distance (concurrent with shorter trial times) in wider fields of view, while men travel further (also with shorter trial times) in wider fields of view. Both genders "flew" higher in wider fields of view. Why men flew further distances remains unclear from this data, and will be the subject of future studies examining strategies more closely. However, it should be noted that the height data reveals that something about female navigation strategies is supported in the wide field of view condition, allowing for shorter travel distance and faster travel methods

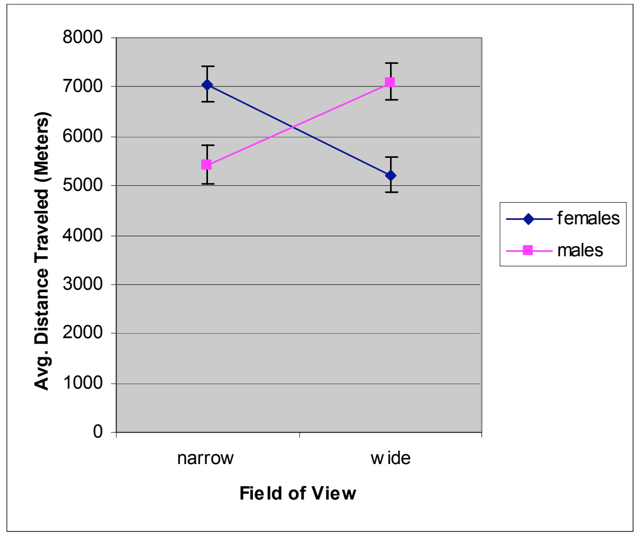

Figure 3. Effect of field of view on distance traveled, including +/- one standard error of the mean.

User Satisfaction

At the end of the session, we asked users which condition provided more information for performing the tasks. 18 participants chose the large display, wide field of view condition (9 females), followed by 8 choosing the small display, large field of view (5 females). In other words, 12/15 males and 14/17 females chose the wide field of view condition as providing the most information, both significant results by binomial tests.

Discussion

This first study revealed the typical male overall superiority in navigating in a 3D world, for both travel times and travel height. However, in terms of travel times, male superiority is reduced in the large display, wide field of view condition. This study also demonstrated the overall benefits of a wider field of view when navigating for both genders, replicating similar findings presented in the Introduction. The fact that our large display, wide field of view condition also supports a 1:1 DFOV:GFOV ratio cannot fully account for this finding, since our small display, narrow field of view also provides a 1:1 DFOV:GFOV ratio. The study further revealed opposing gender strategies for dealing with wider fields of view, with females choosing to navigate shorter distances than males in those conditions. What is driving these strategy differences remains unclear and is a subject for future research.

It is our belief that wider fields of view allow better tracking of environmental information and spatial orientation via head/eye movements, offloading the mental map development task to the perceptual system. As this is typically an easier cognitive task for males versus females, females may benefit more from the wide field of view conditions, at least on large displays. The evidence for this claim comes from the average trial time data, wherein females performed as well as males in the large display, wide field of view condition. The good news is that these benefits come without a concomitant decrement in male performance. For Experiment 2, we decided to focus specifically on why wider fields of view on large displays were helping females navigate more efficiently.

EXPERIMENT 2

Experiment 2 was conducted to isolate factors governing the benefits of a wide field of view that improved female (as opposed to male) navigation performance. For this reason, only females were required as participants. Our hypothesis is that females in these conditions are freed from the need to mentally integrate spatial information about the environment due to its availability via head/eye movement, i.e., the perceptual channel. If this is the case, we would expect to see a greater benefit of this offloading to perceptual senses when we vary the complexity of the world. To this end, the second study varied world complexity by the design of two separate worlds: a sparse world, containing approximately half of the items as the worlds used in Experiment 1, and a dense world which was similar to that used in Experiment 1. Our hypothesis was that the wide field of view would be beneficial to females in both world complexity variations, but relatively more helpful in the complex world.

Method

Thirteen females, aged between 22 and 52 (average 36.7 years), participated in the study. As before, users were experienced with Windows and no 3D gamers were included in the subject pool. None of the participants had taken part in any of the earlier studies.

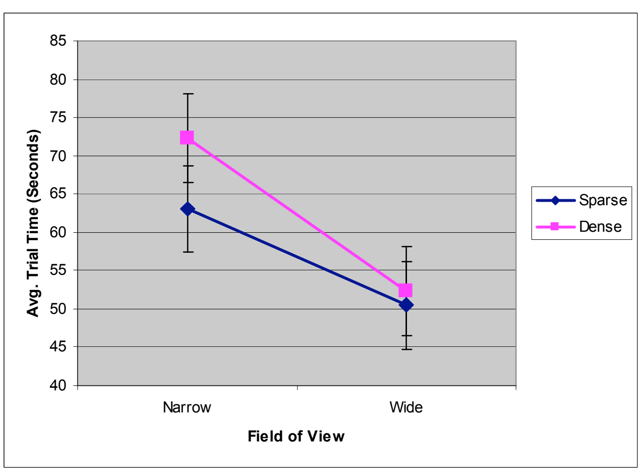

Figure 4. Study 2 average trial times, including +/- one standard error of the mean.

The cube acquisition and placement task remained the same as in the first study, with the exception that we eliminated the pointing tasks and the map memory pretests to reduce overall session time. We varied the complexity of the world between a sparse world (12 circus items) and a dense world (23 circus items) making for a 2 (world complexity) x 2 (field of view) design. Only the large display condition was used, since the most interesting performance benefits were observed in this condition during the first study. The same dependent measures were collected as in Experiment 1, and trial order across conditions was counterbalanced across participants. Total session time was about one hour.

Results and Discussion

Overall Trial Time

A 2 (sparse v. dense world) x 2 (narrow v. wide field of view) RM-ANOVA was carried out on the average trial data (no reliable effects were observed for the percent correct data). A significant main effect of field of view was obtained, $F(1,13)=17.2$, $p=.001$, as was a significant main effect of world complexity, $F(1,13)=4.5$, $p=.05$. The field of view x complexity interaction was not significant $F(1,13)=0.7$, $p=0.4$, due to large variance and an overall lack of power. Dense worlds required, on average, longer navigation times (62.3 v. 56.7 seconds for dense v. sparse worlds, respectively). This finding demonstrates that our complexity manipulation was indeed successful. In addition, a wider field of view was observed to lead to reliably faster navigation, on average (67.7 v. 51.4 seconds for narrow v. wide field of views, respectively). Although the wide field of view was relatively more advantageous for the dense world conditions, on average, than the sparse, this interaction was not reliable. Therefore, our hypothesis #2 that a wider field of view benefits female performance due to offloading cognitive map assembly tasks to the perceptual system was not strongly supported, although we did observe a strong benefit for wide field of views. We find the lack of difference in performance time in the wide FOV conditions between sparse and dense worlds to be important, given the overall significantly harmful effect of increasing world complexity on performance time. These data are presented in Figure 4.

Total Distance Traveled

A 2 (sparse v. dense world) x 2 (narrow v. wide field of view) RM-ANOVA was carried out on the average distance traveled. A significant main effect of field of view was obtained, $F(1,13)=23.7$, $p<.001$, but no other main effects or interactions reached significance at the $p=.05$ level. Overall, wider fields of view afforded females the ability to travel significantly shorter distances in order to find the cube targets. Once again, wider FOV benefited the dense world condition relatively more, on average, but the effect did not reach significance, $F(1,13)=1.34$, $p=0.2$, possibly due to lack of power. Comparing the two wide field of view conditions shows there is no difference in the distance traveled between the sparse and dense worlds. We find this to be striking, given the overall reliably detrimental effect that increasing world complexity has on travel distance.

User Satisfaction

When asked which field of view they preferred, 11/13 of the participants chose the wide field of view, significant by binomial test. Some of the females' responses about how the wide field of view helped them are included below:

--"The wide view was easier to use different reference points to locate or to go back to pick up a box. Same with the dense view-had more to make reference to; as opposed to the sparse world-had a lot of empty space."

--"With the wide field of view, you can quickly pinpoint the object and move toward it. The small field of view causes you to lose your orientation but it is more challenging."

--"I prefer to see everything at once, in kind of an overview."

--"When I could see more of the objects, I could get to the item I wanted to much easier."

DISCUSSION

Study 2 provides evidence that a wider field of view benefits females in both sparse as well as dense worlds. In fact, both in terms of travel time and distance traveled, a wide field of view allows females to perform as quickly, traveling less distance, in dense as well as sparse conditions. The observation that wide fields of view can minimize the need to travel in densely populated worlds, with equivalent performance to sparser, less complex worlds, is important for virtual world design.

CONCLUSION AND FUTURE WORK

We reported two studies examining navigation and direct manipulation performance in 3D virtual worlds. The study tasks were chosen to mimic advanced desktop computing behavior requirements to increase generalizability of the results to future user interface designs. Study 1 demonstrated the advantages of wider fields of view and larger displays on performance across multiple measures for both genders. In addition, study 1 replicated an earlier finding that a large, 36" Arcturus display, coupled with a wide field of view (75 degrees), improves female navigation speed performance to the point that it is indistinguishable from male performance, confirming our hypothesis that wider field of view benefits should be stronger on a large display . This improvement is not accompanied by a decrement in male navigation performance. A second study further showed that females navigating with wider fields of view can be effective even under reliably harmful complexity manipulations. This study did not strongly confirm our hypothesis that a wider field of view should be relatively more beneficial as navigation tasks become more complex, so future research is needed to investigate more carefully the specific gender strategies supported by wider fields of view, with both males and females.

A number of independent measures, in addition to literature review, provide converging evidence that the reliable navigation improvements come from male and female users perceiving more information via head/eye movements in the large display, wide field of view conditions. We believe that the ability to perceive more information via eye tracking frees up cognitive resources that might otherwise be engaged in building a cognitive map of the environment, a task more problematic for females than for males. Females, who tend to navigate by landmark, and who tend to fare better on spatial location memory tasks, will benefit from wider fields of view, in our opinion, in computing tasks requiring navigation through complex information displays.

More work needs to be done to detail the benefits and exact parameters surrounding this preliminary design principle, including which search and retrieval tasks are isomorphic to our laboratory tasks for these effects to generalize. We intend to investigate this issue further, specifically manipulating the number of items available across a number of field of view settings. We think one of the reasons the benefits of wider FOVs can best be seen on large displays is because the ratio of display FOV to geometric FOV is also optimized to 1:1 in that case; hence we intend to extend these findings to even larger prototype displays and wider fields of view that come closer to real world parameters. Implications for these findings permeate many avenues of computing, and may prove critical to the educational and work settings experienced by both males and females in traditionally more spatial disciplines, such as architecture and CAD.

ACKNOWLEDGEMENTS

We would like to thank Gary Starkweather for building the Arcturus prototype display. Barbara Tversky and Steven Ellis provided insightful discussions about these findings, as did our CHI reviewers.

REFERENCES

1. Alice 3D Authoring Tool, see http://www.alice.org/.
2. Alfano, P. L., Michel, G. F. (1990). "Restricting the field of view: perceptual and performance effects." *Perceptual and Motor Skills,* 70 (1), 35-45.
3. Astur, R. S., Ortiz, M. L., & Sutherland, R., J. (1998). A characterization of performance by men and women in a virtual Morris water task: A large and reliable sex difference. *Behavioural Brain Research*, 93, 185-90.
4. Barfield, W., Lim, R., & Rosenberg, C. (1990). Visual enhancements and geometric field of view as factors in the design of a three-dimensional perspective display. *Proceedings of the 34th Annual Meeting of the Human Factors Society*, 1470-1473.

5. Chambers, W.W. (1982, April). Visual technology research simulator. Flight simulation-avionic systems and aero medical aspects. *Royal Aeronautical Society's Flight Simulation Symposium*, London.
6. Darken, R., Sibert, J. (1993). A toolset for navigation in virtual environments. *Proceedings of UIST '93,* ACM Press, 157-165.
7. Darken, R., Sibert, J. (1996). Navigating in large virtual worlds. *The International Journal of Human-Computer Interaction, 8*(1), 49-72.
8. Dolezal, H. (1982). Living in a world transformed: Perceptual and performatory adaptation to visual distortion. New York: Academic Press.
9. Draper, M.H., Viirre, E.S., Furness, T.A. & Gawron, V.J. (2001). Effects of image scale and system time delay on simulator sickness within head-coupled virtual environments. *Human Factors, 43(1)*, 129-146.
10. Eckstrom, R.B., French, J.W., Harman, HH. & Dermen, D. (1976). Kit of Factor-Referenced Cognitive Tests. Princeton, J.J.: Educational Testing Service.
11. Elvins, T., Nadeau, D., Schul, R., & Kirsh, D. (1998). Worldlets: 3D thumbnails for 3D browsing. *Proceedings of CHI '98*, ACM Press, 163-170.
12. Hagen, M.A., Jones, R.K., & Reed, E.S. (1978). On a neglected variable in theories of pictorial perception: truncation of the visual field. *Perception and Psychophysics*, 23, 326-330.
13. Halpern, D. F. (2000). Sex Differences in Cognitive Abilities, 3rd Edition. Lawrence Erlbaum Associates, Inc., NJ.
14. Hosman, R., van der Haart, J. (1981). Effects of vestibular and visual motion perception on task performance. *Acta Psychol.*, 48, 271-281.
15. Kenyon, R.V., Kneller, E.W. (1993). The effects of field of view size on the control of roll motion. *IEEE Transactions on Systems, Man, and Cybernetics*, 23(1), 183-193.
16. Kimura, D. (1999). Sex and Cognition. MIT Press, Cambridge, Mass, pp. 1-66.
17. Lynch, K. (1960). The Image of the City. Cambridge, Massachusetts: The MIT Press.
18. Passini, R. (1984). Wayfinding in Architecture. New York: Van Nostrand Reinhold.
19. Patrick, E., Cosgrove, D., Slavkovic, A., Rode, J., Verratti, T., & Chiselko, G. (2000). Using a large projection screen as an alternative to head-mounted displays for virtual environments. Proceedings of CHI 2000, *CHI Letters 2(1),* 478-485.
20. Piantanida, T.P., Boman, D., Larimer, J., Gille, J., & Reed, C. (1992). Studies of the field-of-view/resolution tradeoff in virtual reality. *Proceedings of the SPIE: Human Vision, Visual Processing and Digital Display III*, 1666, 448-456.
21. Ruddle, R., Payne, S., & Jones, D. (1999). The effects of maps on navigation and search strategies in very-large-scale virtual environments. *Journal of Experimental Psychology: Applied, 5,* 54-75.
22. Sandor, P.B., Leger, A. (1991). Tracking with a restricted field of view. *Aviation, Space, and Environmental Medicine*, 62(11), 1026-1031.
23. Sandstrom, N. J., Kaufman, J., & Huettel, S. A. (1998). Males and females use different distal cues in a virtual environment navigation task. *Cognitive Brain Research*, 6, 351-60.
24. Siegel, A., White, S. The development of spatial representations of large-scale environments. In H. Reese (Ed.), *Advances in Child Development and Behavior, 10*, 10-55. New York: Academic Press.
25. Tan, D.S., Robertson, G.G., & Czerwinski, M. (2001). Exploring 3D navigation: combining speed-coupled flying with orbiting. Proceedings of CHI 2001*, CHI Letters 2(1),* 418-425.
26. Thorndyke, P., Hayes-Roth, B. (1982). Differences in spatial knowledge acquired from maps and navigation. *Cognitive Psychology, 14*, 560-589.
27. Vinson, N. (1999). Design guidelines for landmarks to support navigation in virtual environments. *Proceedings of CHI '99*, ACM Press, 278-285.
28. Waller, D., Hunt, E., & Knapp, D. (1998). The transfer of spatial knowledge in virtual environment training. *Presence: Teleoperators and Virtual Environments*, 7(2), 129-143.
29. Wells, M.J., Venturino, M. (1990). Performance and head movements using a helmet-mounted display with different sized fields-of-view. *Optical Engineering*, 29(8), 870-877.
30. Witmer, B., Bailey, J., Knerr, B, & Parsons, K. Virtual spaces and real world places: Transfer of route knowledge. *International Journal of Human-Computer Studies, 45*, 413-428.