

## Virtual Egocenters as a Function of Display Geometric Field of View and Eye Station Point

<sup>1</sup>Joseph Pstotka, Ph.D.

U. S. Army Research Institute

ATTN: PERI-IIC

5001 Eisenhower Avenue

Alexandria, VA 22333-5600

(703)274-5540/5545/5569

Pstotka@alexandria-emh2.army.mil or pstotka@26.1.0.50

FAX: 274-5461

### ABSTRACT

The accurate location of one's virtual egocenter in a geometric space is of critical importance for immersion technologies. This experiment was conducted to investigate the role of field of view (FOV) and observer station points in the perception of the location of one's egocenter (the personal viewpoint) in virtual space. Rivalrous cues to the accurate location of one's egocenter may be one factor involved in simulator sickness. Fourteen subjects viewed an animated 3D model, of the room in which they sat, binocularly, from Eye Station Points (ESP) of either 300 or 800 millimeters. The display was on a 190 by 245 mm monitor, at a resolution of 320 by 200 pixels with 256 colors. They saw four models of the room designed with four geometric field of view (FOVg) conditions of 18, 48, 86, and 140 degrees. They drew the apparent paths of the camera in the room on a bitmap of the room as seen from infinity above. Large differences in the paths of the camera were seen as a function of both FOVg and ESP. Ten of the subjects were then asked to find the position for each display that minimized camera motion. The results fit well with predictions from an equation that took the ratio of human FOV (roughly 180 degrees) to FOVg times the Geometric Eye Point (GEP) of the image:

$$\text{Zero Station Point} = (180/\text{FOVg}) * \text{GEP}$$

### INTRODUCTION

The accurate location of one's virtual egocenter in a geometric space is of critical importance for immersion. Furness (1992) and Howlett (1990) report that immersion is only experienced when the field of view (FOV) is greater than 60 degrees, or at least in the 60 to 90 degree FOV range. Why this should be so is not understood, nor are there theoretical frameworks for beginning to understand this phenomenon. The question is also important for dealing with simulation or motion sickness. Immersion environments are notorious for producing motion sickness, and an inaccurate location of virtual egocenters may be implicated in this noxious effect. Jex (1991) reports that simulator sickness is hardly ever felt with FOV less than 60 degrees (the complement of immersion FOV). Perhaps a key variable is the quality of immersion and the accuracy of self-localization. Informal comments by users of immersion environments have yielded many descriptions of surprising errors of self-localization. As a start this research begins to explore how egocenters are determined from perceptual arrays.

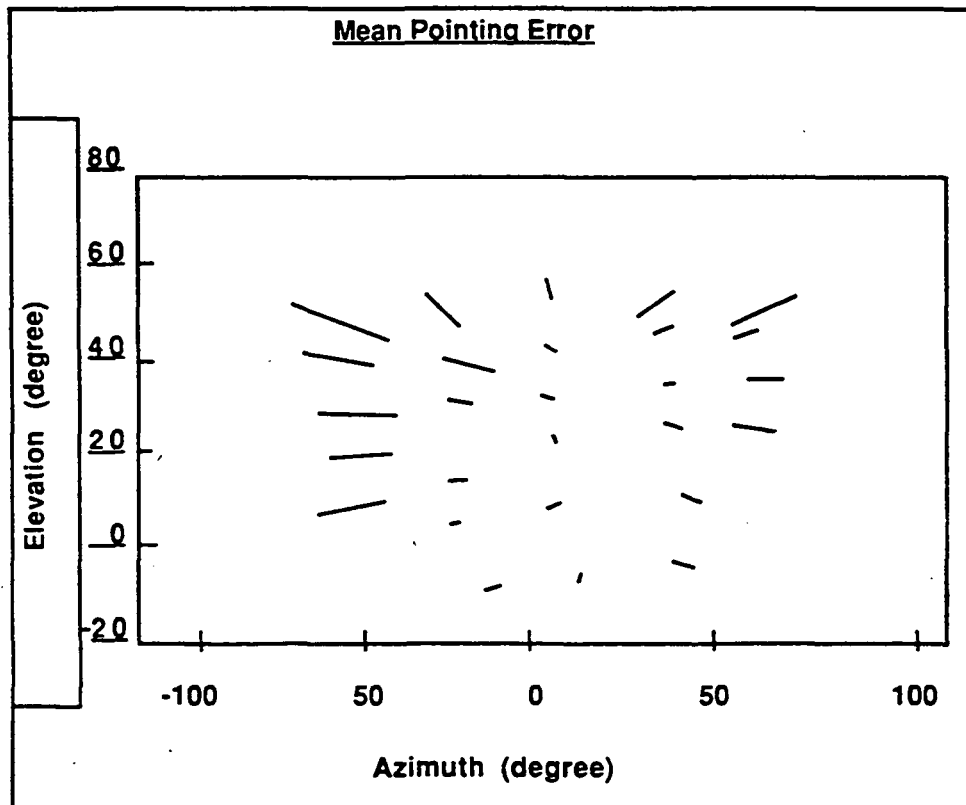
Some work exists that may be helpful to understand the psychology of egocenters (Howard, 1982; Ono, 1981). Kubovy (1986) provides an insightful description of the use of techniques by Renaissance artists to manipulate the location of virtual egocenters, and thus manipulate attitudes and emotions. Franklin, Tversky, and Coon (1992)

---

<sup>1</sup>THE OPINIONS IN THIS PAPER DO NOT NECESSARILY IMPLY OR EXPRESS THE VIEW OF THE U.S. ARMY RESEARCH INSTITUTE (USARI). THIS RESEARCH WAS FUNDED BY THE USARI BASIC RESEARCH OFFICE. I thank Lisa Traub, Harold Goldstein and Jonus Gerrits for their help in constructing the models.

have conducted a long series of experiments examining the cues that control placement of point of view in spatial mental models derived from textual descriptions.

A series of experiments by Ellis (McGreevy and Ellis, 1986; Tharp and Ellis, 1990; Nemire and Ellis, 1991) probably indirectly reflects on virtual egocenters. Ellis and McGreevy (1986) discovered a systematic error in pointing the direction of objects in a virtual display. The error was a function of the geometric FOV of the display. They developed a complex model that accurately predicted these errors on the basis of memory for the size and shape of objects and geometric "distortion" based on linear projections. Tharp and Ellis (1990) provided an explanation based on errors of estimation of the pitch and yaw of the viewing direction used to produce the perspective projection. They argued that people have acquired, through experience of observing the world, a way of determining the effects of viewpoint rotations and perspective transformations. People use this experience to build a "table" of perspective transformations relating target azimuth to projected angle. They then use the wrong table. This is a little like saying that people project themselves at the wrong point, and so it may be possible to find an effect on the location of virtual egocenters in these conditions. The regular shape of the error (see Figure 1) could be produced by an altered location of the virtual egocenter in the display such that, in their experiment, observers felt themselves closer to the objects than the geometry of the scene should have made them feel they were. In other experiments to follow these up, Ellis and his associates found the direction of these errors systematically reversed. The cues that produce these effects are unknown but may have something to do with the relationship of the actual FOV of the display and the computed geometric FOV of the display image (FOVg). When the ratio of FOV/FOVg is greater than 1, the observers may have located the virtual egocenter too near to the objects; and when the ratio of FOV/FOVg is less than 1, the observers may have located the virtual egocenter too far from the objects. It is not clear from their data which case held, but these relationships appear to be appropriate for their results.



**Figure 1.** A schematic diagram showing the pattern of errors found by Tharp and Ellis. Nemire and Ellis (1991) added some evidence for this hypothesis by demonstrating that the enhanced structure of a pitched optic array does bias the perception of gravity-referenced eye level. This finding is a direct replication of Kubovy's arguments about egocenters and Renaissance artists, although on a much smaller scale.

These experiments reported here are an extension of Ellis' work to confirm his findings and extend his interpretation of their source.

## STIMULI

An accurate model of an office was constructed using 3D Studio on a 386 PC with VGA graphics. The model contained walls, floor, and ceiling, three tables with computers and displays, two bookshelves with empty shelves, and two wastebaskets in the room. It was rendered with Phong shading at 320 by 200 pixels with 256 colors, and looked like a reasonable cartoon of the actual office holding the equipment (see Figure 2).

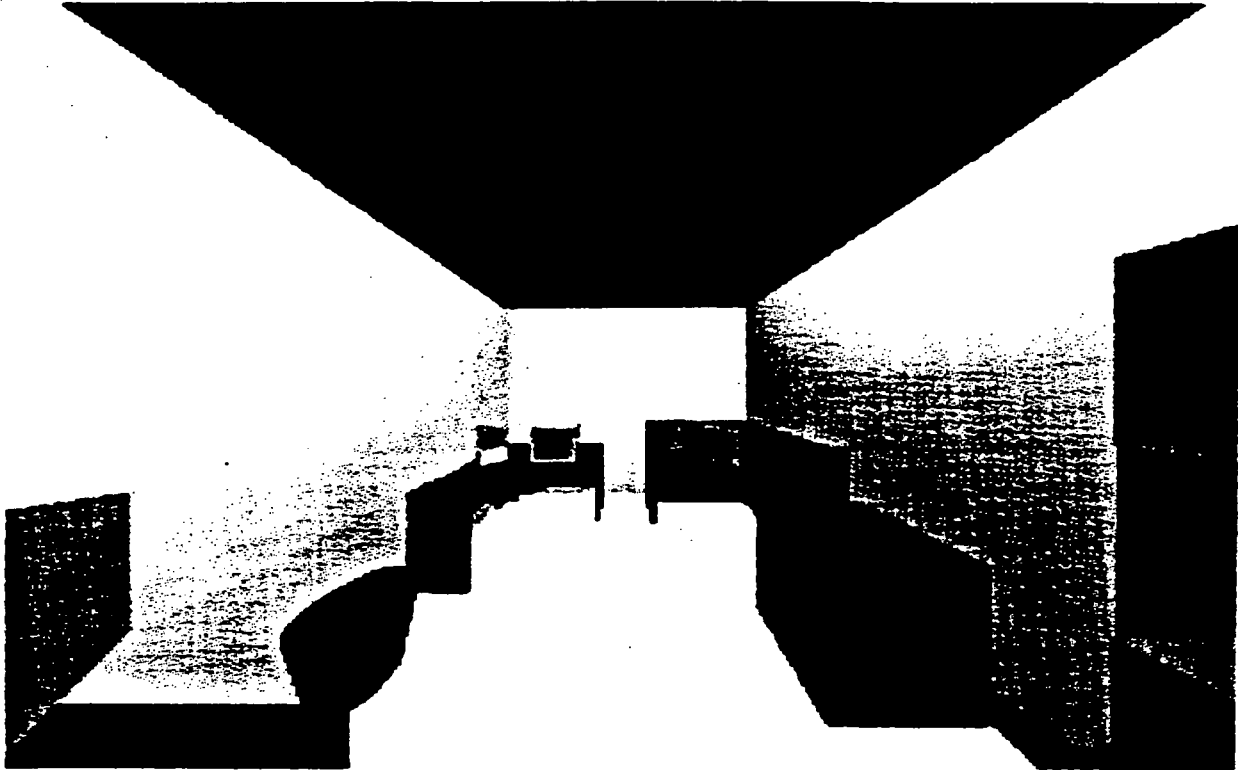


Figure 2. A black and white photocopy of the color screenprint of a 135 mm lens view of the experimental room.

Animations of this model were then created showing a stationary camera located at the geometric center of the room panning slowly 360 degrees around the room. Four animations were created with four different lenses for the scene: 17, 28, 50, and 135 mm. The geometric field of view for each of these lenses was: 140, 86, 48, and 18 degrees, respectively, where 140 degrees is similar to a fish-eye lens and 18 degrees is a telephoto view. The animations were viewed on a flat screen Zenith monitor whose screen dimensions were 190 by 245 mm. Subjects viewed the animations from two locations 800 and 300 mm from the screen. At those sites the screen subtended a FOV of 17 and 45 degrees, approximately. FOV is calculated by  $2 \times \text{atan}(.5 \text{ width of monitor} / \text{distance of eye point})$ . Although their heads were not restrained mechanically, Ss held their positions reasonably well.

The geometric eye point of each of these lenses was 40, 140, 290, and 800 mm in the room. These projection points are independent of the viewer's location. They are dependent on the actual size of the viewing screen. Thus the two viewing sites for the subjects corresponded approximately to the geometric eye points for the lenses of 135 and 50 mm.

## PROCEDURE

Subjects were asked to view the animations binocularly, with corrected vision, and determine the location and path of the camera in each animation. The room was normally lit by recessed ceiling lights. They were told that the animation was of the very same room where they sat. They were shown a bitmap hardcopy of the room from an overhead view and asked to trace the path of the camera on it. ( See Figure 3.) They were not specifically told that the geometric "camera" was mathematically or "theoretically" stationary in the animations.

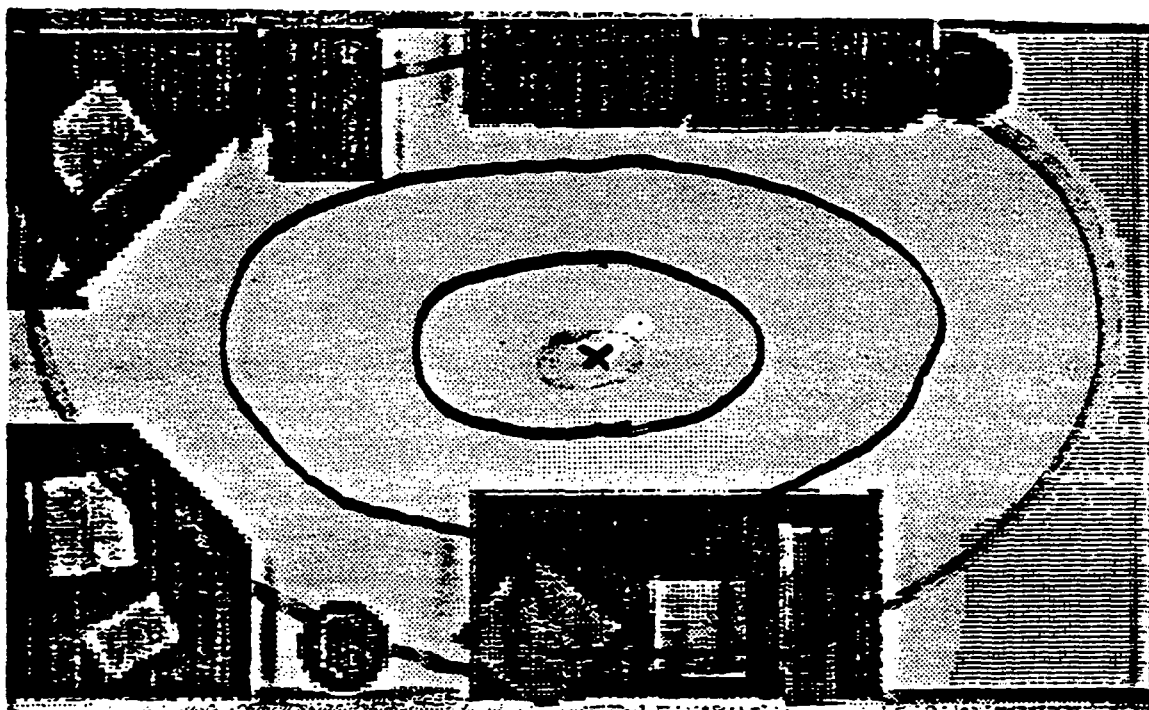


Figure 3. An overhead view of the experimental room. Subjects traced the camera path as shown with representative traces derived from the four views of the experiment.

Fourteen students and colleagues with a variety of psychological training served as experimental subjects without pay. Ten of these Ss were asked at the end of the experiment to select for each animation the viewing station that produced the least camera motion.

## RESULTS

In general, the subjects had no difficulty describing the apparent paths of the camera as they saw it as oval paths of varying eccentricity centered on the geometric center of the room. The diameters of the ovals varied with the focal length of the lens. The radius of these ovals in mm for each animation and station point are given in Table 1. A positive number indicates that the virtual egocenter was behind the observer's eye station point; and a negative number indicates the camera was stationed in front of observer's eye station point. A zero would indicate the geometric center of the room, the observer's eye station point.

Both viewing station points yielded similar relationships between the radius of motion and the geometric FOV of the animations (see Table 1), but the viewing station point of 800 mm produced a concave function, whereas the viewing station point of 300 mm produced a convex function.

By interpolating these points, one can determine where Ss would have seen no camera motion.

For the 800 mm view site, the paths had 0 diameter with 60 degree FOV or a geometric eye point of approximately 250 mm.

For the 300 mm view site, the paths had 0 diameter with 80 degree FOV or a geometric eye point of approximately 150 mm.

**Table 1** Radius of Camera Path (and distance from eye station point (ESP)) as a function of FOVg and Station Point

	<b>Geometric Field of View of Room</b>			
<b>Station Point</b>	18	48	86	140
<b>Group 1 - 300 mm</b>	-541.3	-278.7	83.7	912.5
<b>Group 2 - 800 mm</b>	-785.0	-77.5	416.3	538.8

The mean locations for the station points with least camera motion were 9112, 1092, 291, and 53 mm from the monitor for the four geometric fields of view of 18, 48, 86, and 140 degrees, respectively, whose geometric eye points were 800, 290, 140, and 40 mm.

## DISCUSSION

It appears that the egocentric station point is affected by the geometric FOV of the displayed image; the relationship between the viewing site and the geometric eye point, and the actual FOV of the image. The location of the egocenter is NOT experienced as the same as the geometric station point of the camera under any of the conditions of these experiments. It appears that the location of the egocenter and the geometric station point of the camera would coincide only with a 180 degree FOV display.

It appears that the least egocenter motion was produced in these experiments with a FOV that varied between 48 and 86 degrees, curiously close to the required limits in order to experience satisfactory immersion (Furness, 1992). However, this appears to be an accident of the stimulus conditions in this experiment. Egocenter motion was almost completely nullified for the 17 mm lens ( and 140 FOV) at a viewing site of 50 mm ; and for the 28 mm lens (and 86 FOV) at a viewing site of 290 mm. The other two animations did not appear to have a station point that yielded 0 camera path; although the station points selected by subjects did appear to reduce the absolute value of the camera path substantially. This finding needs to be explored further. It may be related to the finding that immersion is not satisfactory with displays that are less than 40 degrees because no satisfactory compromise exists between the conflicting cues of linear perspective and the visual system's need for a visual field of 180 degrees to find a stationary egocenter.

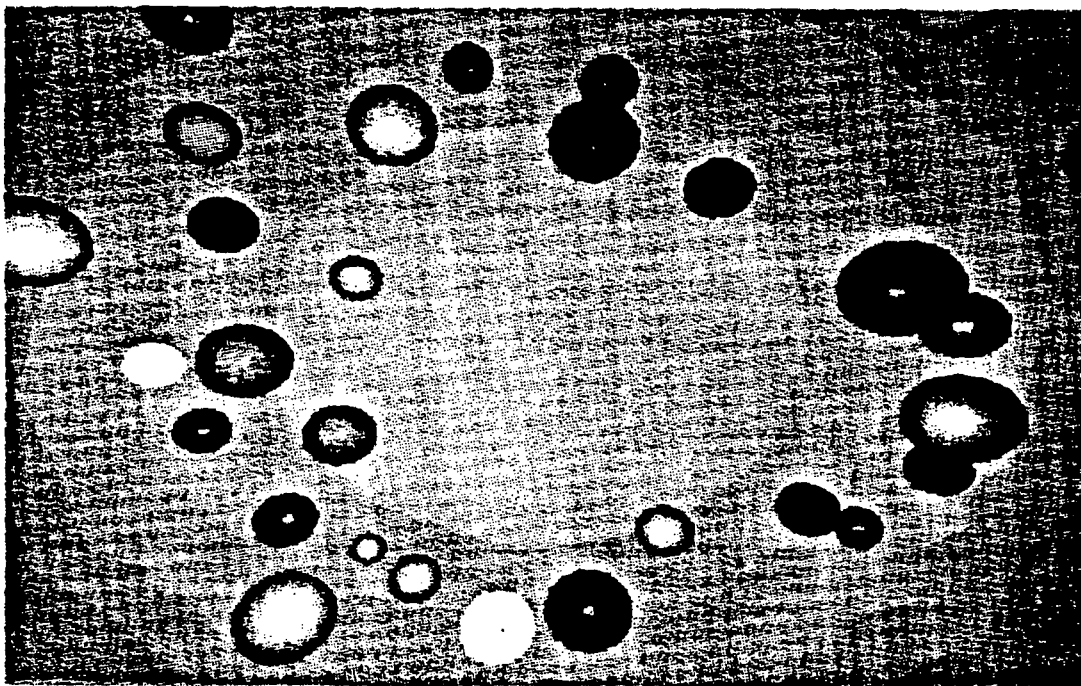
**Frame Effects.** Ss repeatedly remarked that they appeared to be using the frame of the monitor as the frame of reference of their retinal field. When asked to describe what was happening, they said they appeared to be contracting their field of attention to the frame of the monitor, and then treating that as if it were their entire 180 degree visual field. If they were in fact doing this at a processing level, then the geometric eye point of the animation would not be determined by the size of the monitor, but by the virtual size of their expanded attentional field, roughly 180 degrees. The geometric eye point would then be expanded by a similar ratio, yielding the enlarged path of the camera with smaller FOVg. In fact, if one proposed that the zero station point is determined by the product of the animation's geometric eye point (GEP ) times the ratio of 180/FOVg, one could calculate the predicted station points for zero camera motion.

$$\text{Zero Station Point} = (180/\text{FOVg}) * \text{GEP}$$

For this experiment these predictions are: 8000, 1100, 287, and 50 mm. quite close to the empirical values of : 9112, 1092, 291, and 53 mm. This seems to indicate that when the FOVg is 180 degrees, the egocenter is located correctly, but when the FOVg is less than 180 degrees, the egocenter is displaced proportionately.

**Size of the Effect.** Although the eye station points for reduced motion are described by a simple relationship, the width of the camera path is not clearly related to any of the variables. For most of the variables we have only two points (the 300 and 800 mm eye station points) and that is not enough to specify the functional relationship. Qualitatively it appears that for arm's length ESPs width of path is approximately linearly related to FOVg, with small FOVg leading to the feeling of being very close up to the objects, and large FOVg leading to the feeling of being very distant from the objects. However, this effect of FOVg is moderated by eye station point in complex ways for which we need much more data. The effect of eye station point (ESP) appears to be affected by its relation to the geometric eye point (GEP) too. If ESP is closer to the object than GEP, especially when the FOVg fills the eye's field of view; then the virtual egocenter appears to be closer than the GEP. However, this effect appears only to hold for the large FOVg, larger than 45 degrees. It is also true that only with these FOVg is there a point where camera motion was found to be zero. For smaller FOVg, the camera motion could be minimized but not reduced to zero.

**Effect of Size.** The familiar size of objects might be affecting this illusion of virtual egocenter placement. Objects like chairs and tables and monitors have roughly expected sizes or degrees of visual angle from every distance. Egocenter location could be computed from that information as well as the perspective lines of the image or the kinetic depth effects of the turning motion. It is not clear what the role of size is. At the smallest FOVg in this experiment (18 degrees) objects had a 1:1 size ratio with objects in the real world; yet the impression was not one of being the real world distance from them, but of being very close to them, 785 mm or 98% of the distance closer, in fact. Still it is very easy to redo this experiment with objects that have no familiar size; and even to remove linear perspective cues by using balloons in a spherical room (See Figure 4). Preliminary explorations with these figures indicates some differences in the perception of relative motion, namely it is very difficult to perceive these figures as stationary, but not apparently in the main findings of this paper.



**Figure 4.** Top view of a room full of round balls suspended in space.

Size constancy effects may in fact be related to the egocenter effects found in this paper. A brief review of the literature (Hochberg, 1978; Yonas and Hagen, 1973) indicates no general awareness of the possible effects of FOV size or FOVg size on the perception of distance to objects or object size constancy. This appears to be a promising avenue of research. In fact there is very little research on the nature of virtual space as perceived from geometrically created views of everyday scenes.

**Simulation Sickness.** Although no one became nauseous, everyone reported some degree of discomfort with viewing the displays larger than 60 degrees FOVg, especially the largest. Several people asked to look away from the 140 FOVg display to reorient themselves during the experiment.

## CONCLUSION

Clearly much work remains to be done if we wish to specify exactly how people interpret constructed geometric displays to select their egocentric viewing spot. Yet this work is very necessary if we wish to be able to create three-dimensional models that have the power to generate a truly satisfying and natural immersion experience.

For psychological theory, this research opens the possibility of dealing quantitatively with very abstract constructs, like virtual egocenters, in ways that were either impossible or very difficult without the new VR technologies. Clearly parametric studies need to be carried out in detail to create a nomograph of functions relating egocenter to FOVg and viewing station points. This pilot work suggests that even very close viewing station points such as those with head mounted displays (HMDs) are not immune to illusions caused by FOV that are smaller than 180 degrees. Their possible implication in more severe phenomena like simulator sickness, or less severe discomfort and dislike of HMDs, is only one further direction that needs exploration. It is clear, for instance, that these sorts of egocenter illusions adapt out very quickly in a VR environment. However, after adaptation is more or less complete, are there still physiological conflicts that can be detected in response to the conflicting cues of linear perspective and reduced FOV? Are there aftereffects that return to the real visual world?

Other, broader theoretical issues that need exploration are higher order cognitive implications of these new relations between multiple realities. When we view the animation apparently rotating on the monitor, somehow we build up a model of the room. That model is also somehow projected into the same space as the real room that we occupy. While viewing the animation, we have both an egocenter in real space, and a virtual egocenter in the space of the animation. It appears from these experiments that those egocenters interact with each other so that we feel some conflict as we rotate and move in one and remain stationary in the other. What are the long term effects of this conflict? For instance, if parts of the visual field, or even half or more of it were blocked out and replaced with active noise, would observers begin experiencing something like lateral neglect? What would happen if we decorrelated color patches from objects? We know for instance, that color is processed in separate pathways from form (Livingstone and Hubel, 1987). Using VR technologies, could these separate pathways be made explicit and what would its effects be? What are the memory implications for conflicts between one reality and another? What are the physiological processing correlates of immersion? How can MRI technologies be used to provide converging evidence for these findings? These are only some of the interesting psychological questions that need a firm base of experimental data to rest the initial creation of exploratory theoretical frameworks.

## REFERENCES

- Ellis, S. R. (Ed.), (1991) *Pictorial Communication in Virtual and Real Environments*. London: Taylor and Francis.
- Franklin, N., Tversky, B., and Coon, V. (1992) *Switching points of view in spatial mental models*. *Memory & Cognition*, 20(5), 507 - 518.
- Furness, T. (1992) Personal communication.
- Hochberg, J. E. (1978) *Perception*. Englewood Cliffs, NJ: Prentice-Hall, Inc.
- Howard, I. P. (1982) *Human Visual Orientation*. New York: Wiley.
- Howlett, E. M. (1990) *Wide angle orthostereo*. In Merritt, J. O. and Fisher, S. S. (Eds.) *Stereoscopic displays and Applications*. Bellingham, WA: The International Society for Optical Engineering.

Jex, H. R. (1991) Some criteria for teleoperators and virtual environments from experiences with vehicle/operator simulation. In Durlach, N. I., Sheridan, T. B., and Ellis, S. R. **Human Machine Interfaces for Teleoperators and Virtual Environments**. Moffett Field, CA: NASA Conference Publication 10071.

Kubovy, M. (1986) **The psychology of perspective and Renaissance art**. Cambridge: Cambridge University Press.

Livingstone, M. S. and Hubel, D. H. (1987) Psychophysical evidence for separate channels for the perception of form, color, movement, and depth. **Journal of Neuroscience**, 7, 3416 - 3468.

McGreevy, M. W. and Ellis, S. R. (1986) The effect of perspective geometry on judged direction in spatial information instruments. **Human Factors**, 28, 439 - 456.

Nemire, and Ellis, S. R. (1991) Optic bias of perceived eye level depends on structure of the pitched optic array. Presented at the **Psychonomic Society**, San Francisco, CA.

Ono, H. (1981) On Well's (1792) law of visual direction. **Perception and Psychophysics**, 30, 403-406.

Yonas, A. and Hagen, M. (1973) Effects of static and kinetic depth information on the perception of **size** in children and adults. **Journal of Experimental Child Psychology**, 15, 254-265.