Evaluation of Display Parameters Affecting User Performance of an Interactive Task in a Virtual Environment

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Although the popularity of virtual environments is widely known, little is known about the usability of virtual environment displays. This paper presents experimental data on the effect of virtual environment display parameters on task performance. In this investigation, subjects performed an object recognition and 3-dimensional manipulation task in a virtual environment given real-time visual feedback by dynamic display techniques. The subjects controlled a "virtual crane" by the movements of a SpaceBall™ input device. The interaction of stereoscopic depth cues with viewpoint position is evaluated in this experiment. Six conditions were tested by the combination of one of two values of stereoscopic depth cues (present and not present), and one of three viewpoints (elevation angles of 0°, 45°, and 90°).

Keywords: stereoscopic displays, human factors, virtual environments, visualization, usability.

Introduction

As the graphics capabilities of computers increase while hardware costs decrease, computer graphic displays are becoming more widely used in engineering, industry, and science. Graphic interfaces offering dynamic stereoscopic visual displays of environments provide the user with a new tool to assist in performing interactive tasks requiring visual feedback. Stereoscopic computer interfaces place the user in a virtual environment, providing a potentially useful, but as yet an under-evaluated dimension in visualization and interactive task visual feedback. Stereoscopic cues can be used to augment an existing set of visualization cues to achieve increased performance in tasks performed in a virtual environment. However, due to its rapid and recent rise in availability, the usability of the stereoscopic computer display has not been well established. Recent research, however, indicates that stereoscopic displays provide better user performance at many 3D visual tasks than perspective 2D displays. In this experiment, the interaction of stereoscopic depth cues with viewpoint position in a dynamic virtual environment is evaluated.

Previous Work

Previous studies by the authors [6] indicated subjects perceived stereoscopic CAD displays as providing more geometric information than non-stereoscopic CAD displays. Stereoscopic wireframe, hidden line removed, and flat shaded images of an engineering model were subjectively judged to provide more geometric information than equivalent monoscopic images of the model.

Yeh and Silverstein [11] showed that the addition of stereoscopic depth cues improved the speed of altitude and distance judgements for static visual displays. In that investigation, three viewpoints (15^o, 45^o, and 90^o elevation) were tested. Subjects' altitude and distance judgement reaction times were found to be consistently faster across all viewpoints when presented stereoscopically.

Kim, et al. [5] investigated the effects of visual enhancements for monoscopic and stereoscopic displays. Results indicate that stereoscopic displays permit superior tracking performance. They also show, however, that the choice of viewpoint parameters also greatly affects the users' performance in a three-axis manual tracking task.

The effect of depth cues on relative depth judgements, visual search, cursor positioning, and subjective image quality judgements was investigated by Beaton [2]. Results indicate that stereoscopic cues improve the user's performance of visual search and interactive cursor positioning tasks, both of which are essential operations for successful performance in a 3D interactive environment.

Method

Subjects

Thirty undergraduate students, 7 females and 23 males, of Engineering Graphics and Design Visualization at the Georgia Institute of Technology served as subjects for this study. The subjects received compensation (class credit) for their participation. All subjects had prior exposure to the type of computer equipment used in this experiment. One subject was dropped from the experiment due to an insufficient understanding of English to comprehend task instructions.

Apparatus

Figure 1 shows the experimental setup. The stimuli were generated by a Silicon Graphics 4D/120 GTX graphics workstation and displayed on a 21" 120 Hz. monitor equipped with Crystal Eyes™ hardware for producing time-multiplexed stereoscopic images, permitting each eye's image to be updated at 60 Hz. All subjects wore a pair of active liquid-crystal shutter glasses linked to the hardware by an infrared signal. A SpaceBall™ served as the input device though which the subject responded to the presented stimuli and performed the task. The subjects were seated in a darkened cubicle 100 cm from the display, and were permitted to use the input device with either their left or right hand. All visual stimuli presented to the subjects followed guidelines [10] for appropriate values for maximum visual angle, and for other factors affecting image quality. Disparity did not exceed 1.6° visual angle as suggested by Hodges [4], and colors were chosen to minimize ghosting effects due to differing phosphor persistence.

The model geometry for the stimuli is depicted in figures 2 and 3. Figure 2 shows the stimuli as presented in the 45° elevation stereoscopic condition. For the purposes of this illustration, the left and right eye images are shown side by side and reversed. This figure can be viewed stereoscopically by crossing your eyes so as to merge the two images into a central 3D image. Figure 3 depicts the 90° monoscopic view of the model.

Procedure

The subjects performed an object recognition and 3-dimensional manipulation task given real-time visual interface feedback by computer graphic animation. The subjects controlled a "virtual crane" model by the movements of a SpaceBall™ input device, and manipulated a virtual object with the crane and placed the object into an appropriate virtual bin of similar shape. The virtual space was presented by the interface as prescribed by the experimental

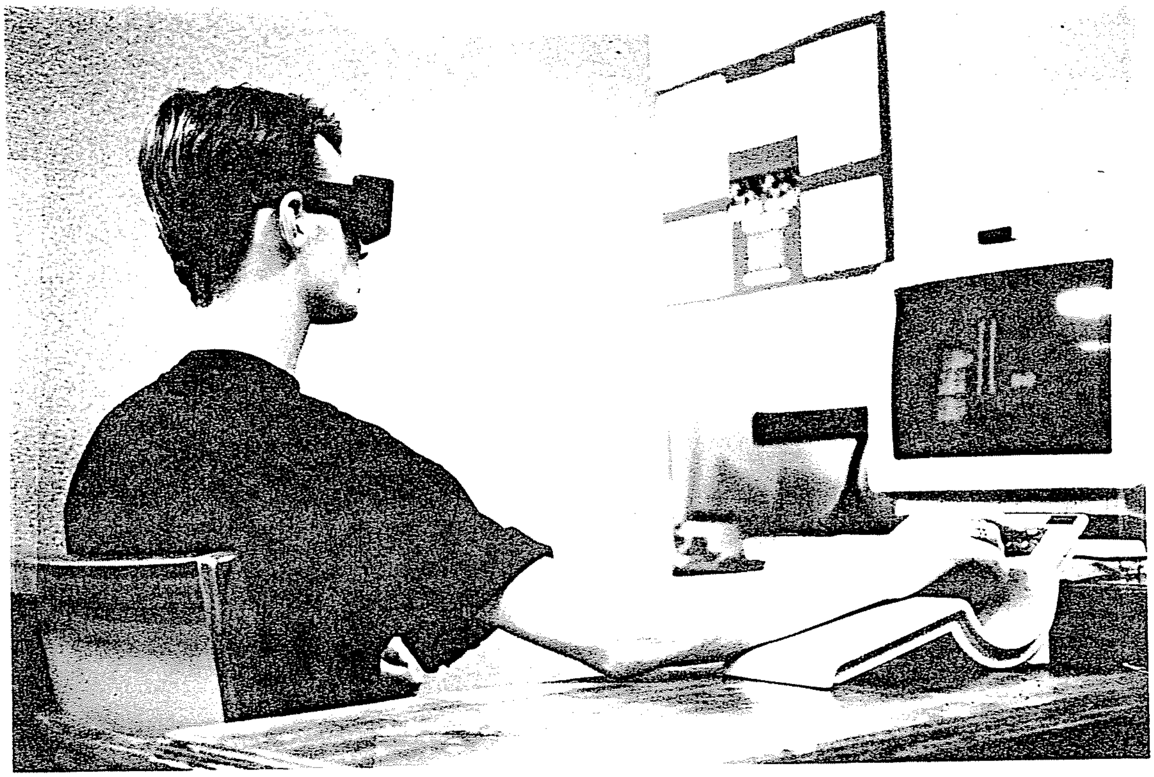

Figure 1. The experimental setup. The stimuli is generated by a Silicon Graphics 4D/120 GTX graphics workstation and displayed on a 21" 120 Hz. monitor equipped with Crystal Eyes™ hardware for producing time-multiplexed stereoscopic images, permitting each eye's image to be updated at 60 Hz. The subject is wearing a pair of active liquid-crystal shutter glasses linked to the hardware by an infrared signal. A SpaceBall™ served as the input device though which the subject responded to the presented stimuli and performed the task. The subjects were seated in a darkened cubicle 100 cm from the display, and were permitted to use the input device with either their left or right hand. A portion of the cubicle was removed and the room lighted for the purposes of this photograph.

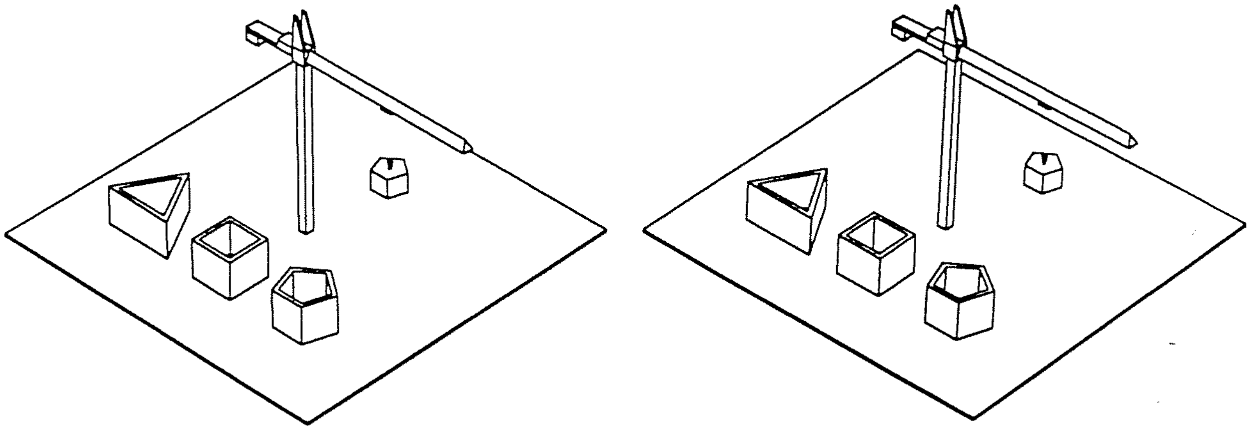

Figure 2. The left-eye and right-eye images of the model as presented in the 45 degree elevation stereoscopic condition. This figure can be viewed stereoscopically by crossing your eyes so as to merge the two images into a central 3D image.

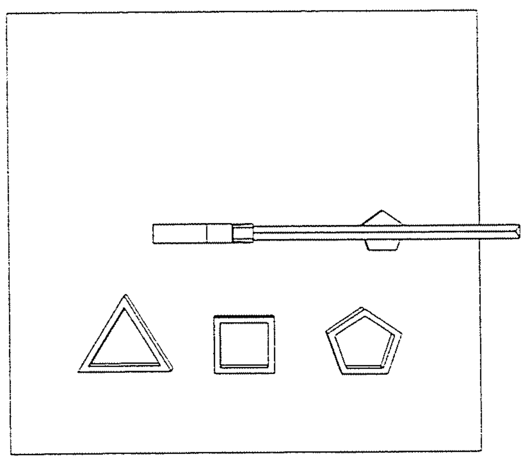

Figure 3. The 90 degree elevation monoscopic view of the model.

conditions. The object type varied randomly across three simple geometric solids: a three-sided, four-sided, or five-sided prism. The goal of the task is to place the object in the bin of the same shape. After the subject successfully placed the virtual object in a bin, the crane reset its position, and a new object was presented to be recognized and manipulated. The task ended when the subject placed all of the pre-determined number of objects into bins.

This investigation is composed of a 2 x 3, two-factor, between-subjects independent measures design. The subjects are assigned randomly to each experiment and condition. This experiment uses an object recognition and 3-D manipulation task to evaluate the effect on task performance of the type of information provided within a virtual environment for visual feedback. The independent variables in this experiment are the presence of *binocular cues* and *viewpoint location.* The dependent variables in this investigation are measures of task performance, defined as the time for task completion and positional error measures. Task completion time was recorded as the subject's object *retrieval time* and *release time.* Task error measures are recorded as distances in x, y, and z coordinates to the correct release location. All other display parameters, such as *color, occlusion, shading,* and *frame rate,* are held constant in this investigation. All objects were rendered as semi-transparent and by a diffuse lighting model and single light source across all conditions.

The subjects were assigned to one of six conditions. The six conditions were defined by the presence or absence of stereoscopic cues, and by the viewpoint from which the stimuli was rendered. Three viewpoints were tested in this experiment: 0°, 45°, and 90° elevation. All conditions were presented at 0° azimuth, and at 20° field of view. The conditions were assigned as follows: Conditions 1, 2, and 3 are stereoscopic, and conditions 4, 5, and 6 are monoscopic. In conditions 1 and 4, the stimuli were presented at 0° elevation, conditions 2 and 5 at 45°, and conditions 3 and 6 at 90°. The 90° elevation angle is a top-down view, and the 0° angle is from "ground level."

Four of each of the three object types were presented in randomized order to the subjects to be manipulated. The subjects were assigned randomly to the six conditions.

Results

Figure 4 compares the subjects' object retrieval times. A major effect across the three viewpoint conditions is seen. In the 0° elevation (ground view) viewing angle conditions, the subjects required more time to accurately position the hook to retrieve the object. The effect of stereoscopic display presentation is also apparent. Retrieval times are consistently faster across all viewpoints for the stereoscopic display conditions.

Figure 5 compares the subjects' object release times. Although the subject was not required to satisfy a measure of accuracy to release the object as when retrieving the object, the release time data exhibit a similar relationship to the conditions as the retrieval time data. However, the difference between the data from the 45° stereoscopic and monoscopic presentations is not significant.

The release position errors for each condition are shown in figure 6. An error of 0.0 results if the subject releases the object at the height of the bin opening. The subjects' object positioning performance was most accurate in the 45° elevation conditions. The differences between stereoscopic and monoscopic release height errors were not significant.

No significant speed-accuracy tradeoff is apparent from a review of release time vs. positioning error scatterplots. The Y (height) error data show a significant trend around the 1.0 value, particularly at lower (quicker) release times.

Retrieval times across all subjects are shown for each condition in figure 7. Although release times did not significantly change over the course of the experimental trials, the retrieval times for each condition show a learning curve over the course of the experiment. There is no significant difference between conditions shown in the learning curve data.

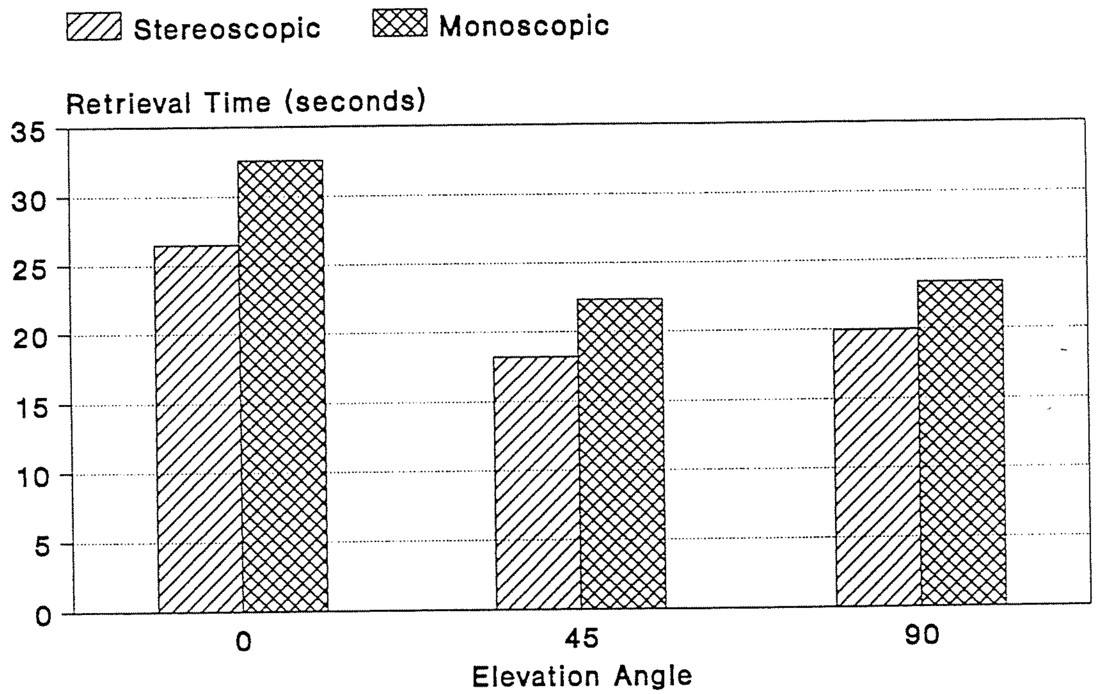

Figure 4. Object retrieval times. Retrieval times are consistently quicker across all viewpoints for the stereoscopic display conditions.

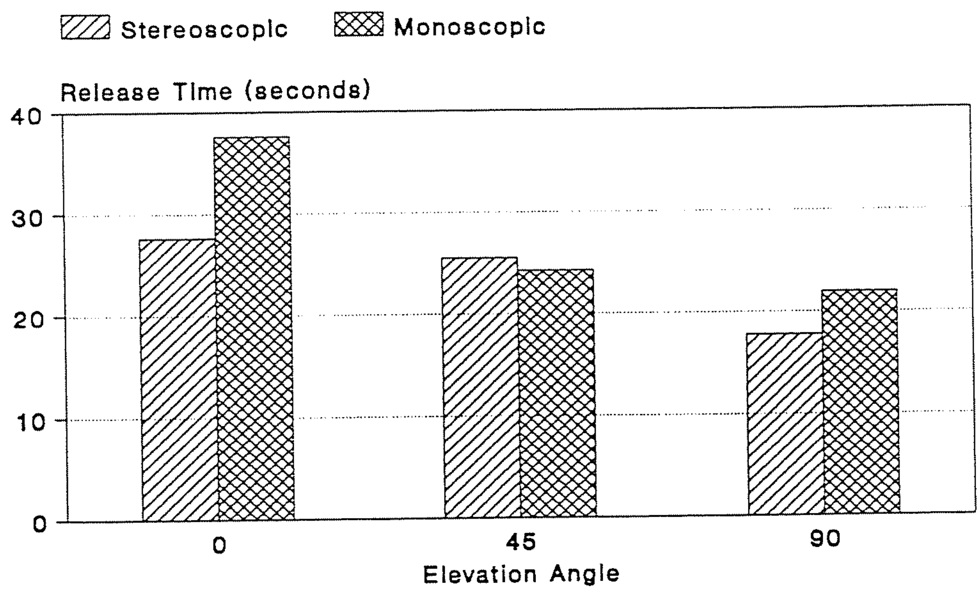

Figure 5. Object release times. The release time data exhibit a similar relationship to the conditions as the retrieval time data. The difference between the stereoscopic and monoscopic presentations is not significant in the 45 degree elevation condition.

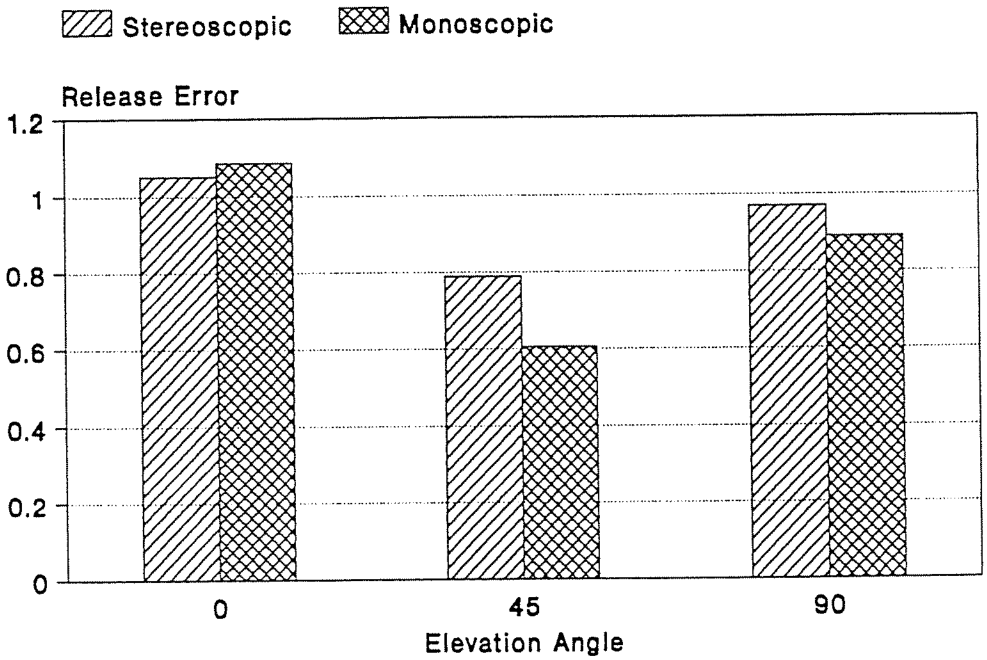

Figure 6. Release position errors. An error of 0.0 results if the subject releases the object at the height of the bin opening. The subjects' object positioning performance was most accurate in the 45° elevation conditions. The differences between stereoscopic and monoscopic release height errors were not significant.

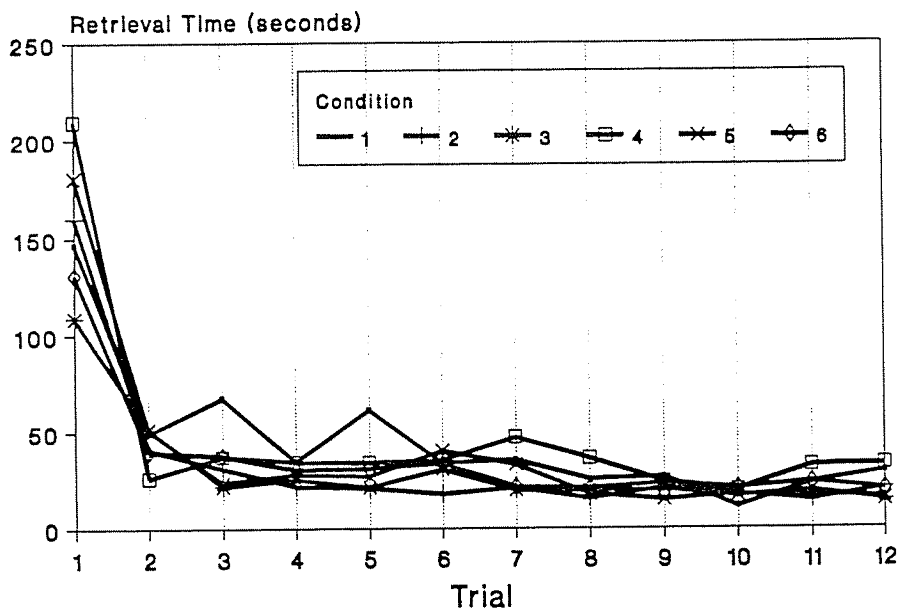

Figure 7. Although release times did not significantly change over the course of the experimental trials, the retrieval times for each condition show a learning curve over the course of the experiment. There is no significant difference between conditions shown in the learning curve data.

Discussion

Some subjects verbally noted difficulty in using the SpaceBall input device. The data shows, however, that they rapidly overcame any initial difficulties.

To retrieve the object, the subject was required to accurately position the hook of the crane near the object; therefore, the accuracy of the retrieval task was fixed. To release the object, the subject was free from any accuracy constraint. However, the data show that the retrieval and release times were of the same order. The subjects showed apparent mastery of the retrieval task by the second trial, but the data on release task showed no significant improvement in subject's accuracy or time of release over the course of the experiment. This is possibly due to feedback presentation. Feedback for accurate retrieval of the object is provided by the object becoming attached to the hook of the crane. No feedback (except visual inspection) was provided to the subject upon release of the object.

The data indicate that choice of viewpoint and the presence of stereoscopic depth cues are important to the performance of this task, as observed by Kim, et al. The data also confirm a consistent difference between the stereo and monoscopic conditions when positioning accuracy is fixed, as seen by Yeh and Silverstein.

The position error as a function of elevation angle confirms the findings of Kim, et al. For tasks of this nature, a viewpoint at 0° azimuth and 45° elevation produces increased performance. And as these findings suggest, the presence of stereoscopic cues may diminish the effect of viewpoint choice.

This study also revealed that some subjects were not sufficiently briefed on the functionality of the crane system. This was partly due to differences in a subject's prior exposure to crane terminology. A more complete briefing and sufficient practice trials would provide a more homogeneous sample of subjects.

In conditions 1 and 4 (0° elevation) a greater variability in X accuracy was observed. From this "ground view" perspective, the bins were partially occluded along the X direction.

Subjects assigned to this condition verbally noted difficulty in distinguishing between the three bins. Under all conditions, an error of 1.0 is predominant in Y (height). The subject were asked to align the top of the object with the top of the bin, producing an error value of 0.0. Most subjects, however, did not note this requirement, and placed the objects as far down as the software permitted, a value of 1.0 in screen units below the requested position. Feedback about the accuracy of the placement of the object would alert the subject to this error.

The need for practiced and briefed subjects suggests a within-subjects design for further studies. A significant percentage of the subject's time to perform this between-subjects experiment was required for briefing. Between-subjects variability was also significantly greater than the within-subjects variability, and also suggests a within-subjects experimental design for further studies.

The results of this investigation may be helpful in the design and use of virtual environment displays. The predominant findings of this experiment suggest that viewpoint considerations are not trivial, as suggested by Kim, et al. Other parameters of a virtual environment display, such as the presence of stereoscopic cues, can interact with the choice of viewpoint. Yeh and Silverstein's investigation of static displays seems to support the findings of this investigation of dynamic displays -- that the presence of stereoscopic cues can positively affect the performance of a task dependent on visual feedback. As Beaton warns, the presence of stereoscopic cues does not guarantee increased usability for all display tasks, but as this investigation confirms, stereoscopic cues can increase performance of complex interactive tasks, such as found in a virtual environments.

Acknowledgements

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