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EVALUATION OF ALTERNATIVE METHODS OF REPRESENTING THREE-DIMENSIONAL OBJECTS ON COMPUTER DISPLAYS

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Due to the increased use of 3D modeling software in the design and manufacture of products, careful evaluation needs to be made as to how the 3D model is represented on the computer display. The experiment's hypothesis is that both rate in which projections of a rotating object are presented and whether the object is rendered as a line drawing or shaded will effect the mental representation of the object. The experiment factorially crossed three levels of projection presentation rate with two levels of rendering (line drawing vs. shaded). All levels of both independent variables were between subjects. The subjects' score on a mental rotations test score was used as a covariant. The subjects each viewed 40 displays representing different rotating objects and identified the objects through a forced choice pair selection. RT and error rate were measured for each selection trial. Data on a total of 72 subjects was analyzed using the ANOVA procedure. The results of the experiment showed a significant main effect of the rate of presentation variable on RT. The results also showed a significant main effect of the rendering variable on error rate. No interaction was found between the two independent variables. The results indicate varying presentation rate can be an effective tool in allowing faster interpretations of an object. It is also recommended that the display technique be carefully matched to the complexity of the object being displayed and the capabilities of the computer being used to display it.

INTRODUCTION

The use of computer-aided design (CAD) tools by manufacturing industries is currently undergoing another stage towards complete integration into the design and manufacturing process. Initially, CAD tools were brought in to companies as electronic drafting tools. Geometric information about a product was represented as a series of orthographic projections. Originally these drawings were done by hand but increasingly have been transferred to paper from computer-based graphic information. More recently, many industries have moved to using CAD software capable of creating a 3D computer-based model of the product. This model can be evaluated directly by computer-based analysis tools, used to automatically extract orthographic views, or send 3D data directly to computer-aided manufacturing equipment.

Even with the design and manufacturing process further automated with 3-D modeling tools, there is still a need for designers, technicians, engineers, managers, and others to visually analyze the product. This experiment looks at some of the issues raised about the role of the current generation of computer graphics capabilities in the mental imaging of three-dimensional form. Research reviewed (e.g. Hochberg, 1964; Biederman, 1987) surmises the mind makes use of a singular, canonical form of three-dimensional objects that is independent of any specific projective view of the object. This internal representation can be formed by a stimulus of multiple projective views of an object and used to compare with other projective views to determine the similarity or difference between the internal model and the stimulus. There is, however, no agreement as to how this internal representation is formed or how it is used to evaluate novel forms. In addition, there is a paucity of research on the effects of varying 3-D display techniques on the formation of this internal representation. Though some research (Barfield, et al., 1990; Sanford, et al., 1987) addresses the issue of model rendering, none directly addresses the advantages of displaying multiple projective views in a serial or parallel format.

In this experiment, it is hypothesized that altering the method of displaying a 3-D object on a computer screen effects the formation of the internal mental representation of the object. More specifically, differing methods of graphically representing an object on a computer display will effect how quickly and accurately a person can choose the correct object from a forced choice pair of projections of two different objects. This experiment varied display methods for representing the rotation of a 3-D object on a computer screen. There are two computer display design principles of interest: the temporal dimension in which projections of the rotation are displayed and the method of representing the edges and faces of the object.

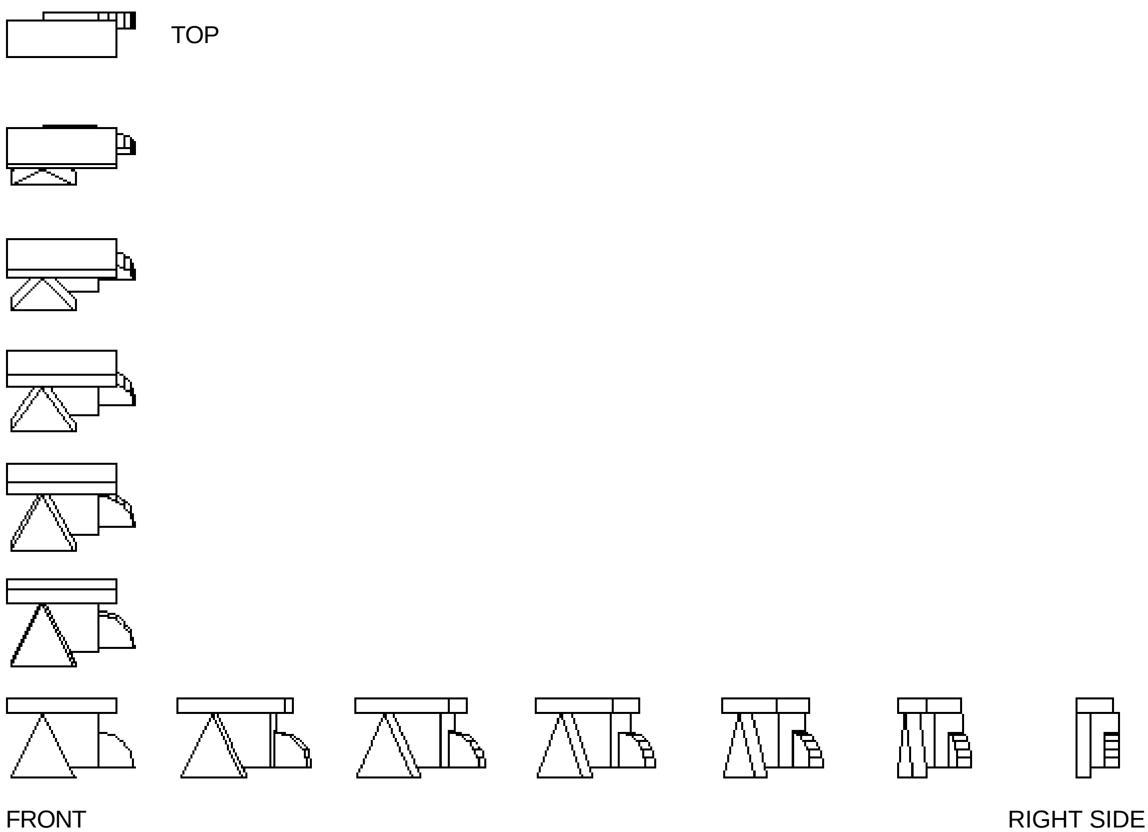

Figure 1. The Static/Line display design depicting all thirteen projections. (Principle Views Labeled for Illustration Only)

METHOD

Subjects

Subjects consisted of 72 university staff and students. No subjects had previously taken any technical or engineering graphics courses. In addition, the subjects were screened for normal visual acuity.

Design

The experiment employs a 3 x 2 full factorial design with three types of Format (Dynamic/Sequential/Static) and two types of Rendering (Line/Shaded) techniques. All levels of both independent variables were used between-subjects. Response time (RT) and accuracy (Error Rate) were the response measures. The subjects were assigned to one of six groups (12 per group) counterbalanced for gender.

Apparatus

An Apple Macintosh with a 16 inch monitor was used to display the experimental stimuli. The initial subject information, the instructions for responding to the stimuli, and the stimuli themselves were displayed and controlled through a script written in HyperCard 2.0. An external program, QuickTime, was used in conjunction with HyperCard to drive the image sequences seen in the Dynamic and Sequential formats.

Experimental Stimuli

Thirteen frames represented the object undergoing rotation in 15 degree increments about both the vertical and horizontal axes. This rotational sequence allowed for the display of the three primary orthographic views of the object (front, top, and right side) along with intermediate views at 15 degree intervals (see Figure 1).

The thirteen projections shown in parallel constitutes the Static display; the content of the display did not change during the entire exposure interval (see Figure 1). The second level of the Format variable (called Sequential) showed the projections in a serial manner: only one projection of the object was shown on the computer display at a time (see Figure 2). The projections were shown at a slow enough rate (1 sec/frame) to preclude apparent movement in depth as it underwent rotation. The third level of the Format variable (called Dynamic) was a serial presentation where the frames were shown at a fast enough rate (250 msec/frame) to induce apparent motion (Petersik, 1980). The object rotated back and forth between the right and front views three times (see Figure 3a) and then between the front and top views three times (see Figure 3b) producing a *rocking* motion. There was a pause at each of the standard (right, front, top) views before the rotation reversed direction.

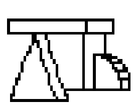

Figure 2. An single projection frame used in both the Sequential/Line and Dynamic/Line display design.

The second independent variable, Rendering, varied the representation of the edges and faces of the object. The first level of Rendering, called Line, represented the object's edges as black lines against a white background (see Figure 2). Any edges normally obscured from view were not shown. The other level of Rendering was called Shade. The Shade rendering applied a contrasting gray shading to the faces of the object (see Figure 4). This rendering technique simulates the effects of an infinite light source projected onto the surface of the object.

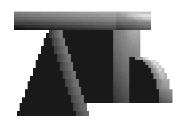

Figure 4. An single projection frame used in both the Sequential/Shaded and Dynamic/Shaded display design.

Procedure

Initially, the subjects were given the Mental Rotations paper test. The Mental Rotations test (Vandenberg & Kuse, 1978) is a 20 question paper test based on an experimental technique developed by Shepard & Metzler (1971). The subject's score on the Mental Rotations test was used as a covariant in the experimental data analysis.

The subject then viewed the experimental stimuli: an object represented by one of the six possible display designs for the specified time of 13 sec. After a screen blanking interval of 1 sec, a pair of different objects using the same rendering method was displayed side-by-side from the same projection (see Figure 5). The subjects responded to the forced choice pair by pressing either the right or left arrow key, indicating which object was the same as the one previously viewed. Immediately thereafter, they were asked whether they had high or low confidence in their response by choosing either the up or down arrow key.

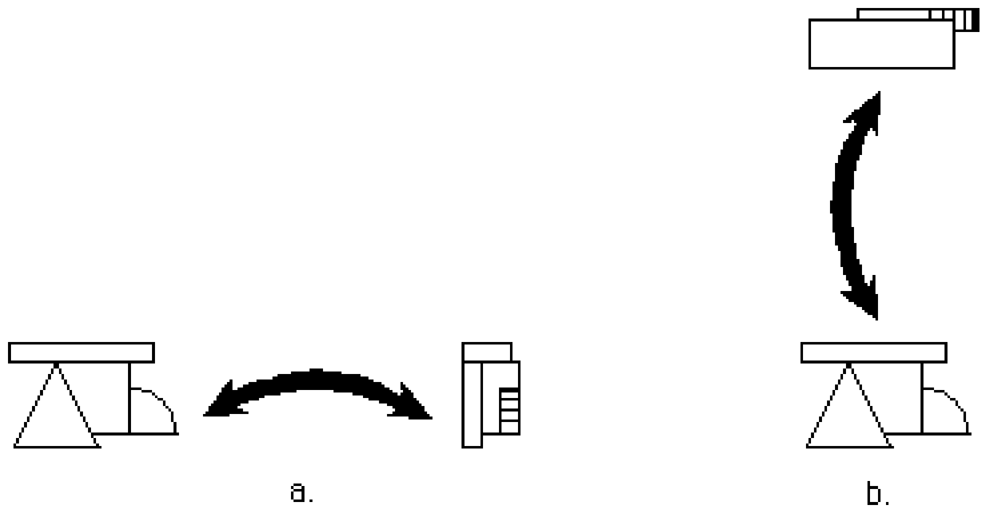

Figure 3. Projection frame sequence for the Dynamic/Line display design.

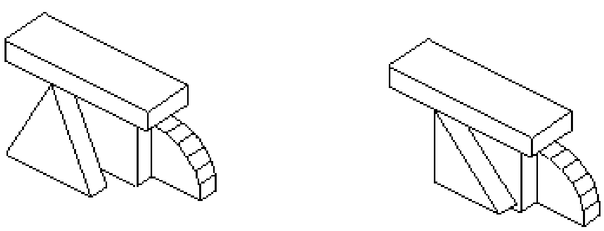

Figure 5. Forced choice pair of objects shown in isometric projection.

Each group participated in one training block (10 objects) and one experimental block (30 objects). Both the training and experimental blocks used one of the six possible display combinations of Format and Rendering. Each group of subjects saw the same 40 objects in the same sequence.

RESULTS

Analysis

The Error Rate and RT data collected in this experiment were subjected to individual two-way analyses of variance (ANOVA). The independent variables of Format and Rendering were used in this analysis. For each subject, only the experimental block constituting the final thirty objects were used in the analysis. The Error Rate was calculated as the total number of incorrect responses and RT as the mean reaction time in the block. The ANOVA compared the Error Rate and RT for each combination of Format and Rendering. In the analysis, the subject's score on the Mental Rotations test was used as a covariant. The score was recorded as the number correct out of 20.

Response Time

The ANOVA performed on RT indicated there was no significant interaction between any of the variables. The analyses did, however, reveal a significant main effect for Format ($F(2,60)=6.71$, $p < .005$). A Newman-Keuls multiple range test was performed *post hoc* on the Format means. Subjects viewing the Dynamic format produced a significantly lower RT (M=1.903) than those viewing either the Sequential (M=2.662) or Static formats (M=2.332)). The Format variable accounted for 15.5% of the variability in RT.

The analyses indicated a significant effect on RT of the covariant, the Mental Rotations test score ($F(1,60) = 9.46$, $p < .005$).

Error Rate

The ANOVA performed on Error Rate indicated there was no significant interaction between any of the variables. The analyses did, however, reveal a significant main effect for Render ($F(1,60) = 13.53$, $p < .0005$). The Render variable accounted for 15.1% of the variability in Error Rate. A comparison of the two levels of the Render variable revealed that subjects viewing objects with their edges represented as black lines had a significantly lower Error Rate (M=1.472) than those viewing the shaded model (M=2.917). The analyses also indicated a significant effect of the covariant, Mental Rotations test score, on Error Rate ($F(1,60) = 8.29$, $p < .01$).

DISCUSSION

The results of this experiment show that manipulation of the independent variables had differing significant effects on the performance of identifying a 3-D object from a forced choice pair. Along the temporal dimension, the dynamic display of projections of an object rotating in space led to the fastest RT. The Dynamic format provided the apparent motion of rotation yet allowed for confirming the connectivity of edges by pausing at key, standard views. Combined, the standard views of top, front, and right side allowed a majority of the surfaces to be seen in their true size and shape.

Recent work by Sollenberger, et al. (1993) also found rotation to be an effective cue for tasks involving 3-D objects. Their study used organic, tree-like forms consisting exclusively of edges and no faces. The higher complexity of the forms and the lack of occlusion of edges farther in depth made their objects decidedly different than the ones used in the current study. This lends weight to a broader applicability of rotation as a performance enhancing technique.

Line rendering proved to give a lower error rate than Shaded rendering in the task. The indirect nature of representing edges with shading, the algorithms used to create the gradients on the faces, and the preponderance of planar faces on the objects used in this experiment are all possible explanations to the increased error rate for Shaded rendering. For example, an object consisting primarily of curved surfaces (unlike those used in this experiment) would have fewer edges which could be depicted in a line rendering whereas the shaded gradients would help depict the curvature of the surface. These types of curved objects might show a lower error rate shaded than as line renderings.

The results of this study suggests that tasks employing the projection of 3-D objects on 2-D computer displays need to be carefully matched to a display design. Both the complexity of the object and capability of the computer hardware may limit the speed in which projections of the object can be displayed. Depending on the task being performed, this may have a significant effect on performance. The use of line rather than shaded renderings may allow for faster calculation and presentation of projections. The results of this study seem to indicate that this will not be detrimental in object identification tasks. The use of shaded objects needs to be carefully evaluated. Depending on the shape of the object and the shading algorithm employed, there may be markedly different performance levels. Because an object shaded in one software package on one system may look considerably different on other software or systems, direct evaluation of the task and display pair may be necessary.

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