Refereed Articles

Effects of Spatial Perception Level and Gender Using Two and Three Dimensional Graphics

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Abstract

Only a few studies have investigated the effects of two- and three-dimensional computer graphics on adult spatial ability. The purposes of this study were 1) to compare the effects of two- and three-dimensional computer graphics on spatial perception performance, 2) to determine if gender affects the outcome, and 3) to examine the role of spatial perception aptitude. Aproximately half of the participants used materials featuring two-dimensional graphics while the others used three-dimensional materials. The results indicated that women perform best on this spatial perception task when using a two-dimensional format rather than a three-dimensional format.

Introduction

An individual learns to navigate in three-dimensional space by conducting millions of tiny experiments in which s/he predicts the relationship between her/his movement through space and the resulting changes in the visual field (Allen, 1991). Our visual and tactile senses and our mental recollection of objects relies on the assumption that objects have dimensions of height, width, and depth (Duesbury, 1992). Our perception of two-dimensional graphics such as television images or photographs are interpreted mentally as representations of three-dimensional objects (Rock, 1984). Both our sensory perception and our mental representa-

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tion of the physical world are three-dimensional in nature (Duesbury, 1992).

Until recently computer graphics represented objects only two dimensionally. In the 1960s a new technological innovation permitted computer graphics to be created three dimensionally (Burns, 1986). A two-dimensional visual is created using an *x* axis for horizontal dimension and a *y* axis for vertical dimension. An additional *z* axis is utilized in three-dimensional graphics to add the dimension of depth. A three-dimensional computer image creates a more realistic visual representation as compared to a two-dimensional image (Jacobs, 1991). With three-dimensional computer graphics the scale and proportion of represented objects can be perceived, enabling the viewer to judge sizes and distances mentally (Winchip, 1991).

Visual images are more concrete than verbal information, and people remember visual information more easily (Collins, 1991). Objects represented in three-dimensional computer graphics are more closely associated with real-life experience (Zdepski & Goldman, 1988). Thus, a more concrete form of communication was born with the capability of representing visual images three- dimensionally.

Most research investigating the incorporation of visuals has focused on their impact regarding learning of prose (Rieber, 1994; Willows & Houghton, 1987). Rieber (1994) stresses the need for research investigating the use of graphics within non-prose contexts. This study investigated whether the use of three-dimensional computer graphics facilitated spatial perception skill in a non-prose context, thereby adding important empirical evidence to the discussion.

The purposes of this study were (1) to examine the effects of two- and three-dimensional computer graphics on spatial perception performance, (2) to determine if gender affects the outcome, and (3) to examine the role of spatial perception aptitude.

Research Questions

1. Is there a difference in achievement between subjects receiving the two instructional treatments (two-dimensional or three-dimensional)?
2. Is there a difference in achievement between subjects in the two treatment groups with respect to gender?
3. Is there a difference in achievement between subjects identified with high or low spatial perception ability receiving identical treatment?
4. Is there a difference in achievement between subjects identified as possessing high or low spatial perception ability?

5. Is there an interaction between the level of spatial perception ability and treatment type?

Definitions of Terms

Spatial ability is the skill of representing, transforming, generating, and remembering symbolic, nonlinguistic information (Linn & Petersen, 1985).

Spatial perception aptitude is the ability to determine spatial relationships with respect to the orientation of one's own body in the presence of distracting cues (Linn & Petersen, 1985).

A *mental rotation task* requires an object be rotated mentally to correspond to an external rotation of that object (Shepard & Cooper, 1982).

Linn and Petersen (1985) refer to *spatial visualization* tasks as ones involving "complicated, multistep manipulations of spatially presented information" (p. 1484).

Literature Review

A review of studies concerning gender differences and spatial ability is followed by a review of studies employing three-dimensional computer graphics and their effects on spatial ability.

Gender Differences in Spatial Skills

Gender differences in spatial abilities have been reported by a number of researchers (Kalichman, 1988; Liben & Golbeck, 1984). Thomas, Jamison, and Hummel (1975) found that adult males were more successful than adult females in determining the horizontality of liquid in a tilted bottle. McGee (1979) found that males scored higher than females on three tests measuring spatial skills. In 1985 Linn and Petersen found that males between the ages of 13 and 60+ years typically outperformed females on mental rotation tasks. Only a moderate gender difference favoring males from age 8 onward was reported for spatial perception tasks. However, they reported no gender differences for spatial visualization tasks.

Kalichman (1988) reviewed studies over a 20-year span involving adult spatial perception performance on water-level tasks. He found that men significantly outperform women on this spatial task. However, the findings of Liben and Golbeck (1980, 1984, 1986) suggest that experiential factors may play a role in spatial performance on water-level tasks. They found that when women were provided relevant information relating to the task, gender differences disappeared.

While this literature involves spatial perception skill, three-dimensional computer graphics were not employed in these studies. A review of recent research utilizing three-dimensional computer graphics follows.

Three-Dimensional Graphics Studies

Barsam and Simutis (1984) conducted a study using a computer-based training program of map reading skills for Army personnel. The instructional materials required the participants to relate two-dimensional images to three-dimensional representations. The results showed that high spatial-ability learners benefited from this instructional strategy. There was no effect for participants with low or average spatial ability.

In a recent study Duesbury (1992) found that greater net gains were achieved by subjects with low spatial ability. The purpose of the study was to determine if practice manipulating two- and three-dimensional wire-frame images would affect an individual's ability to visualize three-dimensional objects from standard multiview blueprints. Sixty adult males registered for a blueprint reading class participated in the study.

Trethewey (1990) explored whether computer-generated graphics improved visualization skills when adults worked alone or with a partner. For her study she used McGee's (1979) definition of spatial visualization. Spatial visualization is the "ability to mentally manipulate, rotate, twist, or invert pictorially presented visual stimuli" (McGee, 1979, p. 3). Tretheway's (1990) research indicated that women of low and high mental rotation aptitude scored significantly higher than women at the middle level after viewing objects transforming between two and three dimensions.

Another study conducted by Zavotka (1987) produced improvement in orthographic object identification skills, but not in mental rotation skills. Three groups viewed films of objects displayed two-dimensionally and three-dimensionally in wire-frame or solid form. Three objects were used in four animation sequences. The objects were a staircase against a wall, a house, and a kitchen cabinet group. Findings from this study indicated that the sequence in which the objects were viewed had a significant effect on the ability to identify orthographic views of it. The optimal sequence showed the object in its most natural, solid color, three-dimensional form, and then it changed to a two-dimensional form. Next, the object was displayed in a three-dimensional wire frame form followed by a transition to a flat, two-dimensional line drawing representation.

In the studies reviewed an improvement in spatial ability was produced through instructional strategies which included three-dimensional visuals.

Methodology

Participants

Female and male college level students enrolled in four Hotel, Restaurant and Institutional Management classes conducted during the summer 1995 session at The Pennsylvania State University were the research subjects. The study population included 52 females and 41 males for a total of 93 subjects. All subjects in the study volunteered to participate. Comparisons between specific ages or racial differences were not considered in this study. All subjects were adults, i.e., at least 18 years of age.

Testing Measures

Two evaluation measures were used in this study: Six-Item Water Level Task (Liben, 1992) and Restaurant Spatial Comparison.

Water-Level Task. A Six-Item Water Level Task (Liben, 1992) was used to measure general spatial perception aptitude. In this task subjects drew a line indicating where the water line would be in six pictures of tilted bottles, if the bottles were approximately half filled with water.

Scoring involved measuring how many degrees off the horizontal the lines were drawn (Liben, 1992). A pencil was used to extend the lines drawn by the subjects to the edge of the page. For each line, a protractor was placed on the page with the 90 degrees toward the center of the page and the middle bar lined up with the vertical edge of the paper. The center of the protractor was placed so that it was at the point where the extended line goes off the paper. The score for the item was determined by counting how many degrees off the 90 degrees the line was. Responses were scored as correct if the line was drawn within five degrees of the horizontal (Yekel, 1991). The total number correct within five degrees was used as the standard for this study.

One point was given for each correct response; consequently, scores could range from zero to six (Liben, 1992). A person is considered to have high spatial perception aptitude if her/his score is five or six correct responses. A score of zero, one, or two indicates low spatial perception ability. A score of three or four can indicate a moderate spatial perception aptitude or could indicate the subject guessed well on the test. Therefore, a middle score of three or four may not be a reliable measure of spatial perception aptitude for this test. For this reason, none of the middle scores were included in the data analysis.

Using the Kuder-Richardson formula 20, the reliability coefficient for the Six-Item Water Level Task (Liben, 1992) was 0.82 for this study.

Restaurant Spatial Comparison. The posttest instrument, Restaurant Spatial Comparison, was developed specifically for this research. This testing measure consisted of 30 multiple-choice spatial problems. Each problem was a printed computer graphic depicting a restaurant dining table and chair. Ten problems featured a table and chair in which the distance between them was excessive. Ten problems featured a table and chair in which the distance between them was insufficient. Ten problems featured a table and chair in which the distance between them was properly matched. For each problem, the participant determined whether the graphic depicted an appropriate table and chair height match.

Two versions of this test were used, a two-dimensional and a three-dimensional. Group 1 used the two-dimensional version while Group 2 used the three-dimensional version. Both groups indicated whether each graphic represented a properly-matched table and chair or one in which the chair seat was too low or too high in relation to the table top height. The determination of "appropriate" table and chair heights was based on data from the U.S. Public Health Service with a representative sample of 6672 adult males and females (Sanders & McCormick, 1987).

The heights of the table and chairs were determined by an associate professor of food systems management and included the standards presented by Sanders and McCormick (1987). The following factors were incorporated into the test instrument:

1. Various table heights were used in this study to provide a greater number of examples.
2. To provide a range of difficulty, the problems were not equal in their measurement differences.
3. Various types of furniture were used. Some problems featured bar stool, wheelchair, high-back chair, and low-back chair.

The Kuder-Richardson formula 20 was used to establish the reliability coefficients for the two versions of the Restaurant Spatial Comparison test used in this study. The two-dimensional version had a reliability of 0.74, while reliability for the three-dimensional version was 0.83.

Instructional Materials

Two versions of the instructional material, titled "Restaurant Dining Alternatives," were developed for this study. Group 1 used a two-dimensional version, and Group 2 used a three-dimensional version. Ten correctly matched dining table and chair computer graphics comprised the instructional material. These graphics were identical to the ten properly-matched table and chair graphics contained in the Restaurant Spatial Comparison test.

Procedure

Materials were distributed to the study participants in two parts. Part 1 consisted of Instructions, the Six-Item Water Level spatial aptitude test, and either the two- or three-dimensional version of Restaurant Dining Alternatives instructional material. After completing Part 1, participants raised their hands and were given Part 2. Part 2 consisted of either the two- or three-dimensional Restaurant Spatial Comparison and a questionnaire.

Findings

Five hypotheses were tested in this study. The data for all five hypotheses were separated into high and low groups for comparison. Using the scores from the Six-Item Water Level Task (Liben, 1992), high and low groups were selected based on the 27% rule (Anastasi, 1988). According to this rule, when data are to be separated into two groups, they are divided by finding the scores which represent the top and bottom 27%.

With this data set, the top 27% were those with a score of at least five and the bottom 27% were within a score of two. Subjects whose scores fell on the border were included. Thus, subjects with scores of five or six comprise the high spatial perception group while those with scores of zero, one, and two comprised the low spatial perception group. Subjects with scores of three and four were not included in the data that were analyzed statistically.

A t test was used to compare the means of the two posttest groups. The posttest for the control group consisted of visual problems displayed two-dimensionally (2D). The experimental group posttest featured the problems three-dimensionally (3D). The null hypothesis is not rejected since the p value equals 0.07 ($p > .05$). The data support the null hypothesis that there is no significant difference between the control group (2D) score mean and the experimental group (3D) score mean.

Table 1
Treatment (2D/3D) Results

Group	*n*	Mean	*SD*	*SE* Mean
2D	36	25.06	3.69	0.61
3D	34	23.24	4.42	0.76

$T = 1.86$; $p = .07$; $df = 64$

Hypothesis Two

There will be no significant differences in achievement between subjects in the two treatment groups with respect to gender. The data for this hypothesis are displayed in Table 2.

Females. A t test was used to evaluate the difference in means between the control group (2D) and experimental group (3D) posttest scores for females. Since the p value = 0.005, ($p < .05$), the null hypothesis is rejected. The data suggest that there is a significant difference between the control group (2D) and the experimental group (3D) scores for females. More specifically, the mean for females on the two-dimensional posttest is significantly different than the mean for females on the three-dimensional posttest.

Males. A t test was used to evaluate the difference in means between the control group (2D) and experimental group (3D) posttest scores for males. The null hypothesis is not rejected since the p value = 0.36 ($p > .05$). The data indicate there is no significant difference for males on the two-dimensional and three-dimensional posttests.

Hypothesis Three

There will be no significant differences in achievement between subjects identified with high or low spatial perception ability receiving identical treatment. The data for this hypothesis are displayed in Table 3.

Control Group (2D) Analysis. A *t* test was used to evaluate the difference in means for subjects with low and high spatial perception

Table 2
Comparing Gender to Treatment (2D/3D)

Group	*n*	Mean	*SD*	*SE* Mean
Females*				
2D	19	26.11	1.88	0.43
3D	21	23.90	2.72	0.59
Males**				
2D	18	24.11	4.75	1.10
3D	13	22.15	6.28	1.70

*$T = 3.00$; $p = 0.005$; $df = 35$, **$T = 0.94$; $p = 0.36$; $df = 21$

aptitude for the control group (2D) posttest. With a p value = 0.26 ($p > .05$), the null hypothesis is not rejected. The data indicate there is no significant difference between the two-dimensional posttest scores for subjects possessing high or low spatial perception aptitude.

Experimental Group (3D) Analysis. A *t* test was used to evaluate the difference in means for subjects with low and high spatial perception aptitude for the experimental group (3D) posttest. The null hypothesis is not rejected since the p value = 0.91 ($p > .05$). The data support the null hypothesis that there is no significant difference between the three-dimensional posttest scores for subjects possessing high or low spatial perception aptitude.

Table 3
High/Low Control Group (2D) and Experimental Group (3D) Posttest Results

Group	*n*	Mean	*SD*	*SE* Mean
Control Group*				
High	17	25.47	3.22	0.78
Low	19	24.68	4.11	0.94
Experimental Group**				
High	18	22.28	5.63	1.30
Low	16	24.31	2.18	0.55

*$T = 0.64$; $p = 0.26$; $df = 33$, **$T = -1.42$; $p = 0.91$; $df = 22$

Hypothesis Four

There will be insignificant differences in achievement between subjects identified as possessing high or low spatial perception ability. The data for this hypothesis are displayed in Table 4.

High Scores Analysis. A *t* test was used to evaluate the difference in means between the control group (2D) and experimental group (3D) posttest scores for subjects possessing high spatial perception ability. Since the *p* value = 0.048 ($p < .05$), the null hypothesis is rejected. The data indicate that there is a significant difference between the mean of the two-dimensional high spatial perception scores and the mean of the three-dimensional high spatial perception scores. Subjects possessing high spatial perception performed significantly different using the two-dimensional format rather than the three-dimensional format.

Low Scores Analysis. A *t* test was used to evaluate the difference in means between the control group (2D) and experimental group (3D) posttest scores for subjects possessing low spatial perception ability. With a *p* value = 0.74 ($p > .05$), the null hypothesis is not rejected. The data support the null hypothesis that there is no significant difference between the two- and three-dimensional posttest scores for subjects possessing low spatial perception aptitude.

Table 4
Low and High Spatial Perception Treatment (2D/3D) Results

Group	*n*	Mean	*SD*	*SE* Mean
High Spatial Perception*				
2D	17	25.47	3.22	0.78
3D	18	22.28	5.63	1.30
Low Spatial Perception**				
2D	19	24.68	4.11	0.94
3D	16	24.31	2.18	0.55

*$T = 2.07$; $p = 0.048$; $df = 27$
**$T = 0.34$; $p = 0.74$; $df = 28$

Hypothesis Five

There will be an insignificant interaction between the level of spatial perception ability and treatment type. The data for this hypothesis are displayed in Table 5.

A 2 x 2 factorial two-way analysis of variance (ANOVA) was used to determine whether there was an interaction between spatial perception (high or low) and treatment type (2D or 3D).

The null hypothesis is not rejected since the F statistic is less than the critical value ($F = 2.1109 < 3.989$). The data indicate that there is no interaction between spatial perception ability (high or low) and treatment type (two- or three-dimensional).

Table 5
*Interaction Results: Spatial Perception (High/Low) with Treatment Type (2D/3D)**

Source	Sum of Squares	Degrees of Freedom	Mean Square Error
Spatial Perception	6.8322	1	6.8322
Treatment Type	55.3517	1	55.3517
Interaction	34.5848	1	34.5848
Error	1,081.3892	66	16.3841

*F = 2.1109, Critical value = 3.989.

Discussion and Application of Findings

Adults with high spatial perception aptitude performed significantly differently, favoring the two- rather than the three-dimensional visual graphic display. However, further analysis did not show improved performance when level of spatial perception ability and visual graphic display dimensionality were compared. The results indicate that there is no relationship between spatial perception level and visual graphic display dimensionality. Evidence from this research also indicates that adult men with low or high spatial perception aptitude perform as well on a spatial task whether they use two- or three-dimensional computer graphics. There were significant differences between adult women who received the two- and three-dimensional instructional treatments with women receiving the two-dimensional format performing better.

Findings by Dwyer (1978) indicate that two-dimensional line drawings of the human heart were more conducive to learning than more realistic three-dimensional forms. Dwyer concludes that the more realistic visuals provide too much information to the learner and distracts their attention away from relevant information.

Research conducted by Liben and Golbeck (1980, 1984, 1986) supports Dwyer's findings. From their research on spatial perception skills, Liben and Golbeck (1980, 1984, 1986) note that women generally have developed mature spatial coordinate systems but do not attend to relevant learning cues. Further, they found that women's performance improved after receiving instruction on the relevant information needed to perform the task successfully. They reported no significant differences between women and men when women received task-relevant information cues.

It may be that, in this study, the three-dimensional computer graphics provided too much information just as in Dwyer's (1978) research. Perhaps the added realistic element of depth present in the three-dimensional visuals distracted females from the relevant learning cues involved in spatial perception tasks.

The empirical findings from this research are valuable to educators, performance technologists, instructional designers, and others involved in adult learning. The results of this research provide additional information for individuals using visual graphic displays for adult spatial perception tasks. The results of this research suggest that less development-intensive and less costly two-dimensional visual graphic displays are as effective for spatial perception tasks as three-dimensional visual graphic displays.

In many learning scenarios only a distinguishing of objects is needed, i.e., a comparison in spatial relationship. In these instances the third dimension is only additive and could actually interfere with learning for some adults. Most computer-assisted instruction is effective in a two-dimensional format. The same holds true for one-way or two-way video applications in distance learning environments.

Other specific examples where a two-dimensional format is appropriate include (a) graphic display of furniture placement to ascertain how much furniture a room can accommodate or discern optimal seating arrangement and (b) graphic display of various landscape architecture schemes. Adults benefit from technology when it is used effectively in learning applications.

References

Allen, B. S. (1991). Virtualities. *Educational Media and Technology Yearbook, 17,* 47-53.

Anastasi, A. (1988). *Psychological testing* (6th ed.). New York: Macmillan.

Barsam, H. F., & Simutis, Z. M. (1984). Computer-based graphics for terrain visualization training. *Human Factors, 26*(6), 659-665.

Burns, W. E. (1986). Computer-aided design (CAD). *Industrial Education, 75*(6), 10-11.

Collins, A. (1991). The role of computer technology in restructuring schools. *Phi Delta Kappan, 73*(1), 28-36.

Duesbury, R. T. (1992). *The effect of practice in a three dimensional CAD environment on a learner's ability to visualize objects from orthographic projections.* Unpublished doctoral disseration, University of Southern California, Los Angeles.

Dwyer, F. M. (1978). *Strategies for improving visual learning.* State College, PA: Learning Services.

Jacobs, S. P. (1991). *The CAD design studio.* New York: McGraw-Hill.

Kalichman, S. C. (1988). Individual differences in water-level task performance: A component-skills analysis. *Developmental Review, 8,* 273-295.

Liben, L. S. (1992). *Six-item water level task.* State College, PA: The Pennsylvania State University.

Liben, L. S., & Golbeck, S. L. (1980). Sex differences in performance on Piagetian spatial tasks: Differences in competence or performance? *Child Development, 51,* 594-597.

Liben, L. S., & Golbeck, S. L. (1984). Performance on Piagetian horizontality and verticality tasks: Sex-related differences in knowledge of relevant physical phenomena. *Developmental Psychology, 20,* 595-606.

Liben, L. S., & Golbeck, S. L. (1986). Adults' demonstration of underlying Euclidean concepts in relation to task context. *Developmental Psychology, 22,* 487-490.

Linn, M. C., & Petersen, A. C. (1985). Emergence and characterization of sex differences in spatial ability: A meta-analysis. *Child Development, 56,* 1479-1498.

McGee, M. G. (1979). *Human spatial abilities.* New York: Praeger.

Rieber, L. P. (1994). *Computers, graphics, & learning.* Dubuque, IA: Brown & Benchmark.

Rock, I. (1984). *Perception.* New York: Scientific American Library.

Sanders, M. S., & McCormick, E. J. (1987). *Human factors in engineering and design.* New York: McGraw Hill.

Shepard, R. N., & Cooper, L. A. (1982). *Mental images and their transformations.* Cambridge: Massachusetts Institute of Technology.

Thomas, H., Jamison, W., & Hummel, D. D. (1975). Observation is insufficient for discovering that the surface of still water is invariantly horzontal. *Science, 181,* 173-174.

Trethewey, S. O. (1990). *Effects of computer-based two and three dimensional visualization training for male and female engineering graphics students with low, middle, and high levels of visualization skill as measured by mental rotation and hidden figures tasks.* Unpublished doctoral dissertation, The Ohio State University, Columbus.

Willows, D. M., & Houghton, H. A. (Eds.). (1987). *The psychology of illustration* (Vols. 1 & 2). New York: Springer-Verlag.

Winchip, S. M. (1991). Computer applications in interior design. *Journal of Home Economics, 83*(3), 31-35.

Zavotka, S. L. (1987). Three-dimensional computer animated graphics: A tool for spatial skill instruction. *Educational Communication and Technology Journal, 35*(3), 133-144.

Zdepski, M. S., & Goldman, G. (1988). Computers: Beyond working drawings. *Architectural Record, 176*(1), 127-129.