Spatial Visualization Measurement: A Modification of the Purdue Spatial Visualization Test - Visualization of Rotations

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ABSTRACT

During the 1999 Fall semester at North Carolina State University, a study was conducted to determine the effectiveness of using trimetric pictorials instead of isometric pictorials on the Purdue Spatial Visualization Test - Visualization of Rotations (Guay, 1977). Undergraduate students enrolled in Graphic Communications courses completed computer versions of the PSVT and the Mental Rotations Test (Vandenberg & Kuse, 1978) during the first six weeks of classes. The instruments were used to record student responses and response times as well as information on gender, current major, and number of previous graphics courses completed. The control group completed the original version of the PSVT (isometric pictorials) and the MRT. The experimental group completed a revised version of the PSVT (trimetric pictorials) and the MRT. The researcher hypothesized that trimetric pictorials would be a more sensitive predictor of spatial visualization ability.

Introduction

There are many tests that claim to measure an individual's spatial ability. Research suggests these tests do not all measure the same spatial ability factor. The Purdue Spatial Visualization Test-Visualization of Rotations (Guay, 1977) and the Mental Rotations Test (Shepard & Metzler, 1971; Vandenberg & Kuse, 1978) appear to have high construct validity in the area of spatial visualization ability (Guay, 1980). The Revised Minnesota Paper Form Board Test (Likert & Quasha, 1970) appears to measure spatial orientation since it requires a high degree of analytical processing (Guay, McDaniel, & Angelo, 1978). Finally, there is evidence supporting the Spatial Ability section of the Differential Aptitude Test (Bennett, Seashore & Westman, 1981) as a measure of spatial orientation ability (Kovac, 1989; Juhel, 1991). Correlations among tests of spatial ability are variable and tend to be modest. This suggests that they are tapping different specific abilities or skills within the general spatial ability domain (Paivio, 1986). Since the types of activities that take place in technical graphics courses exercise and develop a person's spatial visualization ability, research suggests that the PSVT and the MRT are the best measures of this construct.

The researcher has conducted two studies involving the effects of coordinate axes on spatial visualization ability using the PSVT for assessment (Branoff, 1998 & Branoff, 1999). While conducting informal exit interviews for both studies, the researcher noted several individuals who interpreted objects as two-dimensional patterns rather than three-dimensional objects. This raised a concern regarding the validity of the PSVT for measuring spatial visualization ability.

The PSVT consists of 30 unfamiliar objects the observer is required to mentally rotate. Unfamiliar shapes can be perceived readily if they incorporate geometric regularities

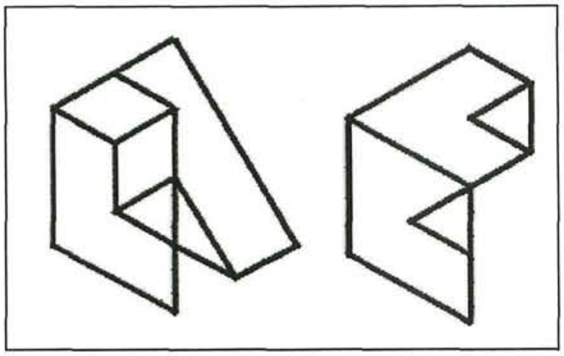

Figure 1 - 3-D objects or 2-D patterns?

like rectangularity and parallelism (Perkins, 1983). A problem occurs when perceived information can be interpreted in more than one way (Perkins, 1982). Lowe (1987) defined this as the detection condition. Perceived features must be constrained in a way such that accidental instances are unlikely to arise. One criticism of the PSVT is its use of isometric projections for the display of three-dimensional objects. In some cases, isometric projections of three-dimensional objects create accidental instances where the three-dimensional objects may be interpreted as two-dimensional patterns (*see Figure 1*). If an individual interprets the information being displayed as a two-dimensional pattern, the validity of the test must be questioned relative to assessing a person's ability to mentally manipulate the representation as a three-dimensional object. The researcher has concluded that a "missing piece" in research in this field is the testing of whether the use of trimetric projections of three-dimensional objects on the PSVT allow for a more accurate assessment of 3-D spatial visualization ability than isometric projections (*see Figure 2*).

Methodology

Purpose of the Study

The purpose of the study was to determine whether the use of trimetric pictorials for items on the Purdue Spatial Visualization Test - Visualization of Rotations would be a more sensitive predictor of 3-D spatial visualization ability for students enrolled in technical graphics classes. Of key interest to the researcher were the concurrent validity and the reliability of the revised PSVT. Concurrent validity is the extent to which a person's score on a new measure corresponds to their score on an established measure of the same construct. Reliability is the extent to which a test yields the same results

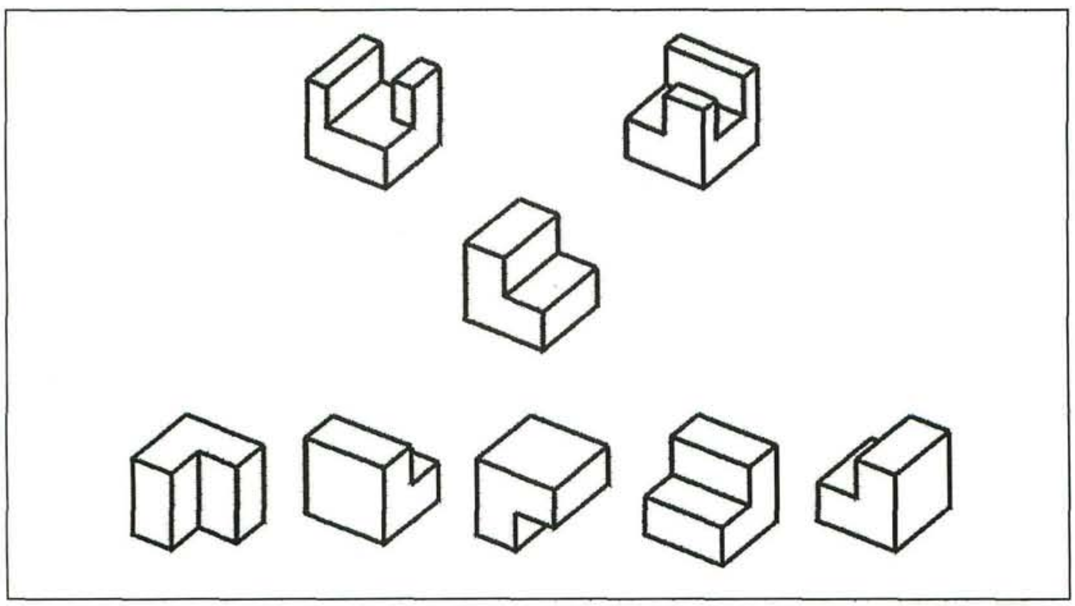

Figure 2 - Visualization of rotations test - revised with trimetric pictorials.

for the same individual over time (Gall, Borg, & Gall, 1996).

Sample
Students enrolled in graphic communications courses at North Carolina State University during the 1999 fall semester were required to participate in the study as part of the requirements for their course. Of the 380 students enrolled in GC101, GC120, GC210, GC211, GC250, GC350 and GC450, 277 students completed the study.

Research Design
The study was conducted to collect validity and reliability data on the revised PSVT. Students were randomly assigned to either the control group or the experimental group. The control group completed computer versions of the original PSVT and the MRT. The experimental group completed computer versions of the revised PSVT and the MRT (*see Table 1*).

Instrumentation
Since the main construct of interest for the study was spatial visualization ability, the Purdue Spatial Visualization Test - Visualization of Rotations (PSVT) and the Mental Rotations Test (MRT) were used to assess this construct. The PSVT consists of 30 items of increasing level of difficulty. It is a 20 minute timed test appropriate for individuals 13 and older (Guay, 1977). Initial items require a rotation of 90° on one axis followed by items requiring 180° rotation about one axis, rotation of 90° about two axes, and concluding with items requiring rotation of 90° about one axis and 180° about another axis. The MRT consists of 20 items in five sets of four items. Each item contains a criterion object, 2 correct alternatives, and 2 incorrect alternatives. The subject is asked to select the two alternatives that are like the criterion object (Vandenberg & Kuse, 1978).

Guay (1980) reports internal consistency coefficient results (KR-20) of .87, .89, and .92 from studies conducted on 217 university students, 51 skilled machinists, and 101 university students respectively. Sorby and Baartmans (1996) conducted a study involving 492 freshmen engineering students. They reported a KR-20 coefficient of .82. Battista, Wheatley and Talsma (1982) administered the PSVT to 82 preservice elementary teachers enrolled in an undergraduate geometry course. A KR-20 internal consistency coefficient of .80 was reported. For studies conducted at North Carolina State University during the 1997 fall semester on 81 undergraduate students and during the 1998 fall semester on 249 undergraduate students, an internal consistency coefficient of .82 was calculated for the computer-based PSVT (Branoff, 1998; Branoff, 1999).

Procedures
During the spring and summer of 1999, computer versions of the PSVT (with trimetric pictorials) and the MRT were developed. The purpose of developing computer versions of the instruments was to provide accurate data on scores and response times. The researcher designed the tests so data was gathered in a spreadsheet format. The tests also collected data on gender, age, current major, the graphic communications course in which the subject was currently enrolled, and number of previous graphics courses taken.

Group	First Measure	Second Measure
Control Group	Original PSVT	MRT
Experimental Group	Revised PSVT	MRT

***Table 1** - Research design.*

During the first six weeks of classes in the 1999 Fall semester, students were randomly assigned to the control group or the experimental group. An equal number of males and females were assigned to each of the groups. The control group was administered the computer versions of the PSVT and the MRT. The experimental group was administered the computer versions of the revised PSVT (trimetric pictorials) and the MRT. Demographic questions were asked at the end of the test. All test data was written to a spreadsheet on a local server. The testing took place in a computer laboratory in Poe Hall on the campus of North Carolina State University.

Results

Demographic Data

Of the 381 students enrolled in graphic communications courses, 277 completed the study. *Table 2* shows information about treatment group, academic class, academic major, graphic communications course, and gender.

Treatment Group	Frequency	Percent
Control Group	139	50.2
Experimental Group	138	49.8
Total	**277**	**100.0**
Academic Class	**Frequency**	**Percent**
Freshman	25	9.0
Sophomore	174	62.8
Junior	39	14.1
Senior	35	12.6
Other	4	1.4
Total	**277**	**100.0**
Academic Major	**Frequency**	**Percent**
Design	2	0.7
Education	21	7.6
Bio. & Ag. Engineering	2	0.7
Civil Engineering	64	23.1
Electrical & Computer Engineering	4	1.4
Industrial Engineering	28	10.1
Mechanical & Aerospace Engineering	112	40.4
Textile Engineering	4	1.4
First Year College	14	5.1
Other	26	9.4
Total	**277**	**100.0**
Graphic Communications Course	**Frequency**	**Percent**
GC101	3	1.1
GC120	97	35.0
GC210	41	14.8
GC211	81	29.2
GC250	18	6.5
GC350	31	11.2
GC450	6	2.2
Total	**277**	**100.0**
Gender	**Frequency**	**Percent**
Female	42	15.2
Male	235	84.8
Total	**277**	**100.0**

***Table 2** - Demographic data.*

Category	N	Mean	SD
Control Group			
Score on PSVT	139	22.59	5.13
Score on MRT	139	14.91	4.39
Time on PSVT*	139	911.29 (15.19)	457.48 (7.62)
Time on MRT*	139	658.75 (10.98)	331.63 (5.53)
Age 139	20.41	3.42	
Experimental Group			
Score on PSVT	138	23.30	5.14
Score on MRT	138	15.09	4.65
Time on PSVT*	138	775.88 (12.93)	308.17 (5.14)
Time on MRT*	138	635.99 (10.60)	233.71 (3.90)
Age	138	19.91	2.17
*Times are listed in seconds. Times in parentheses are given in minutes.			

***Table 3** - Means and standard deviations by treatment group.*

Means and Standard Deviations

Table 3 displays the means and standard deviations for score and response time on the PSVT, score and response time on the MRT, and age for both the control and experimental groups.

Table 4 displays the means and standard deviations by gender for score and response time on the PSVT, score and response time on the MRT, and age for both the control and experimental groups.

Category	N	Mean	SD
Control Group			
Females			
Score on PSVT	21	21.43	5.29
Score on MRT	21	13.48	5.24
Time on PSVT*	21	1020.17 (17.00)	346.92 (5.78)
Time on MRT*	21	713.24 (11.89)	315.21 (5.25)
Males			
Score on PSVT	118	22.81	5.10
Score on MRT	118	15.17	4.20
Time on PSVT*	118	891.91 (14.87)	473.05 (7.88)
Time on MRT*	118	649.06 (10.82)	334.83 (5.58)
Experimental Group			
Females			
Score on PSVT	21	21.33	5.71
Score on MRT	21	13.43	5.46
Time on PSVT*	21	890.86 (14.85)	376.24 (6.27)
Time on MRT*	21	690.84 (11.51)	236.45 (3.94)
Males			
Score on PSVT	117	23.65	4.97
Score on MRT	117	15.39	4.45
Time on PSVT*	117	755.24 (12.59)	291.43 (4.86)
Time on MRT*	117	626.14 (10.44)	232.87 (3.88)
*Times are listed in seconds. Times in parentheses are given in minutes.			

***Table 4**- Means and standard deviations by gender.*

Differences in Scores and Response Times
To check for differences between the original PSVT and the revised PSVT, an analysis of variance procedure was conducted for several different groups. *Table 5* displays the results of these analyses.

Correlations between the PSVT and the MRT
Since both the PSVT and the MRT claim to measure a person's 3-D spatial visualization ability, it is expected that a strong correlation exists between the two. *Table 6* displays the results of the correlations conducted.

Category	F	df	p
Analysis of Scores			
Is there a difference between the control group and the experimental group?	1.29	276	0.2575
Is there a difference between females in the control group and females in the experimental group?	0.00	41	0.9556
Is there a difference between males in the control group and males in the experimental group?	1.65	234	0.1998
Analysis of Response Times			
Is there a difference between the control group and the experimental group?	8.34	276	0.0042*
Is there a difference between females in the control group and females in the experimental group?	1.34	41	0.2538
Is there a difference between males in the control group and males in the experimental group?	7.10	234	0.0083*
*Significant at a=0.05.			

Table 5 *- Analysis of variance.*

Category	Pearson r	p
Correlation of Scores Between PSVT and MRT		
Control Group		
Overall Control Group	0.67	0.0001*
Females in Control Group	0.79	0.0001*
Males in Control Group	0.64	0.0001*
Experimantal Group		
Overall Experimental Group	0.65	0.0001*
Females in Experimental Group	0.77	0.0001*
Males in Experimental Group	0.60	0.0001*
Correlation of Response Times Between PSVT and MRT		
Control Group		
Overall Control Group	0.72	0.0001*
Females in Control Group	0.38	0.0922*
Males in Control Group	0.76	0.0001*
Experimantal Group		
Overall Experimental Group	0.62	0.0001*
Females in Experimental Group	0.66	0.0001*
Males in Experimental Group	0.61	0.0001*
*Significant at a=0.05.		

Table 6*- Pearson correlations between PSVT and MRT.*

Discussion

Concurrent Validity

The purpose of the study was to examine whether the revised PSVT was as good a measure of a person's 3-D spatial visualization ability as the original PSVT. Several analyses were performed to examine the effectiveness of the revised test. First, mean scores and response times were compared for both the revised PSVT and the original PSVT. No significant difference was found between the control group (original PSVT) and the experimental group (revised PSVT) when examining mean scores ($F=1.29$, $df=276$, $p=0.2575$). There was a significant difference between the control and experimental groups when mean response times were examined ($F=8.34$, $df=276$, $p=0.0042$). This difference seems to be attributed to the fact that males in the experimental group completed the revised PSVT in significantly less time (12.59 minutes) than the males in the control group completed the original PSVT (14.87 minutes). It is possible that the trimetric pictorials in the revised test made the initial interpretation of the objects easier. Exit interviews revealed that some students in the control group were confused with the last several items in the original PSVT. Based on these interviews, the researcher concluded that most of the confusion resulted from the accidental instances or coincidental edges that occurred with isometric pictorials.

In addition to the analysis of variance procedures between versions of the PSVT, analyses were conducted to examine how the revised PSVT correlated with another measure of spatial visualization ability. Previous research suggests that the PSVT and the MRT have high construct validity in the area of 3-D spatial visualization ability (Guay, 1980). Pearson correlation coefficients of 0.67 and 0.65 were calculated for the MRT and original PSVT and for the MRT and the revised PSVT respectively. These values suggest good relationships between the MRT and the two versions of the PSVT. Also, the values imply some consistency in measurement for both versions of the PSVT.

Reliability

In addition to examining the construct validity of the revised PSVT, the reliability of the instrument needed to be evaluated. Kuder-Richardson 20 coefficients were calculated for both the original PSVT and the revised PSVT. The KR-20 coefficient for the revised computer-based PSVT was 0.83. This value is consistent with previous research regarding KR-20 reliability and both paper and computer-based versions of the original PSVT (Battista, Wheatley and Talsma, 1982; Branoff, 1998 & 1999; Guay, 1980; & Sorby & Baartmans, 1996).

Conclusions

Conclusions Regarding the Revised PSVT

Based on the statistical analyses, it appears that the revised PSVT is as good a measure of spatial visualization ability as the original PSVT. Based on exit interviews with some of the students, the trimetric pictorials used in the revised PSVT seemed to eliminate confusion on the last several items that typically occurred with the isometric pictorials. If the instrument is suppose to evaluate a person's ability to mentally rotate objects, other tasks that hinder a person's ability to do this (i.e. trying to determine the object's shape when confused by accidental or coincidental edges) only call into question the validity of the test. The differences in response times between the original and revised versions of the PSVT suggest that students took more time with the isometric pictorials than with the trimetric pictorials.

Recommendations for Further Research

This study examined the effectiveness of trimetric pictorials in a test measuring spatial visualization ability. The conclusions reached by the researcher suggest several areas of further research.

1. The study needs to be conducted using other measures of spatial visualization

ability. Relationships between the revised PSVT and the spatial ability section of the Differential Aptitude Test, the Purdue Spatial Visualization Test - Visualization of Views, and the Purdue Spatial Visualization Test - Visualization of Developments need to be examined.

2. The study needs to be replicated at other universities with similar populations to verify the generalizations made regarding the effectiveness of trimetric pictorials.
3 The study needs to be replicated with a different target population to verify the effectiveness of the revised PSVT. Trimetric pictorials may influence scores and response times differently for high schools students or undergraduate, non-engineering students.

References

Battista, M. T., Wheatley, G. H., & Talsma, G. (1982). The importance of spatial visualization and cognitive development for geometry learning in preservice elementary teachers. *Journal for Research in Mathematics Education*, 13 (5), 332-340.

Bennett, G. K., Seashore, H. G., & Westman, A. G. (1981). *The Differential Aptitude Test*. San Antonio, Texas: Psychological Corporation.

Branoff, T. J. (1998). The effects of adding coordinate axes to a mental rotations task in measuring spatial visualization ability in introductory undergraduate technical graphics courses. *The Engineering Design Graphics Journal*, 62 (2), 16-34.

Branoff, T. J. (In Press). Coordinate axes and mental rotation tasks: A Solomon four group design. *The Engineering Design Graphics Journal*, 63 (3), 4-13.

Gall, M. D., Borg, W. R., & Gall, J. P. (1996). *Educational research*. (6th ed.). White Plains, NY: Longman.

Guay, R. (1977). Purdue Spatial Visualization Test - Visualization of Rotations. W. Lafayette, IN. Purdue Research Foundation.

Guay, R. B. (1980). *Spatial ability measurement: A critique and an alternative*. A paper presented at the 1980 Annual Meeting of the American Educational Research Association, April, Boston, MA. (ERIC Document Reproduction Service No. ED189166).

Guay, R., McDaniel, E., & Angelo, S. (1978). *Analytic factor confounding spatial ability measurement*. Paper presented at the annual meeting of the American Psychological Association, Toronto, August, 1978.

Juhel, J. (1991). Spatial abilities and individual differences in visual information processing. *Intelligence*, 15 117-137.

Kovac, R. J. (1989). The validation of selected spatial ability tests via correlational assessment and analysis of user-processing strategy. *Educational Research Quarterly*, 13 (2), 26-34.

Likert, R. & Quasha, W. H. (1970). *Manual for the revised Minnesota paper form board test*, New York: The Psychological Corporation.

Lowe, D. G. (1987). Three-dimensional object recognition from single two-dimensional images. *Artificial Intelligence*, 31, 355-395.

Paivio, A. (1986). *Mental representations: A dual coding approach*. New York: Oxford University Press.

Perkins, D. N. (1982).The perceiver as organizer and geometer. In J. Beck (Ed.), *Organization and representation in perception*, (pp. 73-93). Hillsdale, NJ: Erlbaum.

Perkins, D. N. (1983). Why the human perceiver is a bad machine. In J. Beck & et al.

(Ed.), *Human and machine vision*, (pp. 341-364). Hillsdale, NJ: Erlbaum.

Shepard, R. & Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science*, 171, 701-703.

Sorby, S. A. & Baartmans, B. J. (1996). A course for the development of 3-D spatial visualization skills. *Engineering Design Graphics Journal*, 60 (1), 13-20.

Vandenberg, S. G & Kuse, A. R. (1978). Mental rotations, a group test of three-dimensional spatial visualization. *Perceptual and Motor Skills*, 47, 599-604.