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Visual perception of oriented map symobols

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VISUAL PERCEPTION OF ORIENTED MAP SYMBOLS

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ABSTRACT

VISUAL PERCEPTION OF ORIENTED MAP SYMBOLS

by Maureen Ann Kelley

The orientation visual variable for point symbols is used for specialized areas such as geologic mapping and can be employed for other types of spatial data as a result of the popularity of geographic information systems and scientific visualization. However, map users are generally not aware of their ability to accurately judge angular measurements. This study addresses how well map users judge angled symbols and if there are differences between experienced and inexperienced map users through experimentation using two types of maps. The results correspond to psychophysical research in orientation.

I would like to thank my colleagues and friends in the National Mapping Division of the United States Geological Survey, Menlo Park, California for their invaluable support during my internship. I would also like to thank my family: Mom, Marc, Annie, and most especially my brother Dan; without whose support and encouragement throughout the years, I would never have traveled so far.

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Introduction

Symbol design has been an integral part of the cartographic process since early humans first drew lines in the soil to show the natural landscape. Cartographers use primitive geometric shapes, such as points, lines, and polygons, to communicate the spatial relationships between real and derived phenomena. They have developed techniques for using these primitives that enable them to maximize the graphic relationship between the spatial phenomena and the connotative graphic symbol.

Bertin (1981/77) identified **visual variables** of the cartographic image. They are location, size, value (or **lightness**), "grain" (or texture), color (or **hue**), orientation, and shape (p. 187). The first three are classified as image variables, that is, they are the basic components for identifying graphic features on a map. The latter four are termed differential variables, that is, these variables can be used alone or in conjunction with other variables to differentiate between the many graphic symbols that appear on the map (p. 213).

Point symbols can vary in shape, hue, orientation, size, and lightness based the type of phenomena depicted. Difference in kind, or **nominal** point symbols, can employ different shapes, colors, or symbol orientations (*Figure 1* on the following page). An example of this is changing the hue of circles to distinguish gas from water wells on a map. Ranked, or **ordinal**, data can be shown by varying the shape, hue, size, or lightness. For example, symbol size can vary based on hierarchy of spatial phenomena. Numeric information, such as **interval** or **ratio** data, can vary based on orientation, size, and lightness. Characteristic of this technique is using graduated symbols to depict population size.

For the six visual variables depicted on the next page, not one variable is used for all scales of

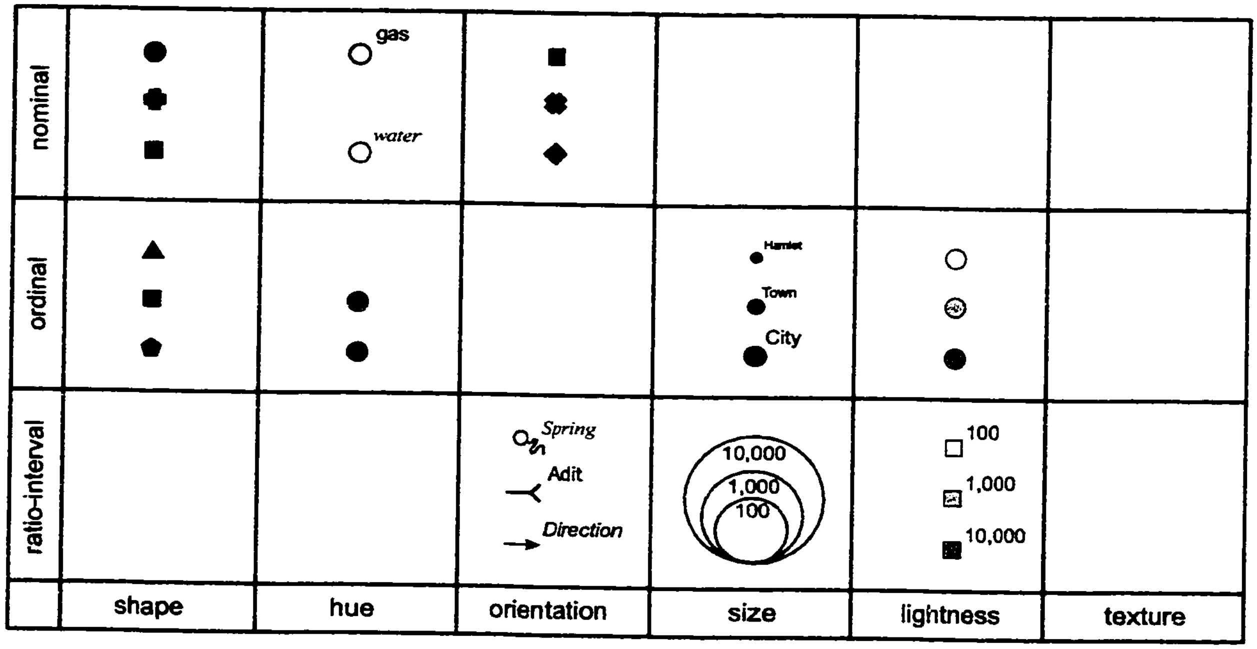


Figure 1. Chart showing visual variables and the scales of measurement used for point symbols. *Note*: Adapted from Bertin (1983/67) and Robinson et al. (1984).

measurement. Comparing the scales of measurement with the variables shows that most have either nominal-ordinal or ordinal-ratio-interval continuum scales. However, the orientation variable does not show this continuum.

The orientation variable is considered to be of primary importance when depicting nominal information (Bertin, 1983/67; Robinson et al., 1984) because changing the orientation of a square symbol 45° creates an apparently new symbol — a diamond. No symbols are suggested for the next scale of measurement level for orientation, perhaps due to direction not having a perceived starting or ending point. Yet orientation can and is used for the interval scale of measurement.

Map designers have used this visual variable guideline to design new symbols for the ever-increasing demand to depict derived spatial information due to the introduction of digital technologies such as **geographic information systems** (GIS) and **scientific visualization** (SciVis).

Traditionally, symbol design was limited to the capabilities of the reproduction technology of the day. Today computers allow the designer greater flexibility, more options, and greater efficiency to design symbols — not only the designer but the average person as well. But Castner (1983) cautioned that our map production technologies cannot be applied unquestioned to every design opportunity that presents itself (p. 92).

The role of the cartographer in the map making process is to minimize error during production beginning at the **compilation** stage and following through to the **prepress** phase. If the cartographer has minimized error on the production end, other sources of error may still exist because distortions of reality are held by the cartographer and **map user**. The methods in which the cartographer makes a map and the way the map user decodes information contribute to **map error**. The aim of **cartography** is to reduce the discrepancy between map maker and user (Robinson & Petchenik, 1976, p. 28).

Cartographic theory suggests that reducing the discrepancy is through better symbol design. Keates (1982) and Koláčný (1977) cautioned us that better designs created by cartographers may not be understood by map users. An assumption is that users will simply learn to work with any map cartographers make (Koláčný, 1977, p. 39). Discrepancies exist between what map makers intend to depict with better design and what map users understand. In fact, Downs (1981) noted that "cartographers know virtually nothing about the cognitive process of map reading and interpretation" (p. 157). Authors on cartographic theory agree that little is known about how we perceive and understand graphic symbols on maps. Robinson (1952) suggested that an objective look at cartographic methods should begin by looking at the limitations of human perception (MacEachren, 1995, p. 3).

Because the eye-mind perceptual system does not measure the way the ruler, the **planimeter**, the **densitometer**, and the **spectrometer** do, it is necessary to determine the appropriate human magnitude scales. The objectives of research having to do with quantitative symbolism are simple to relate the subjective magnitude responses to the stimulus magnitude . . . (Robinson, 1977, p. 168).

Robinson and Petchenik (1976) believed that in order for cartography to move forward, map makers need to have a deeper understanding of the processes and characteristics of what the map means to the maker and the user (p. xi). Questions such as what generalizations can be made about users' perceptual abilities (Keates, 1982, p. 59) and if there are fundamental differences among these capabilities (Robinson, 1977, p. 164) should be asked. Wood (1972) wrote the more that can be learned about how users perceive and interpret symbols on a map, the greater will be the opportunity to improve **cartographic communication** (p. 123). From Robinson's observations in the 1950s it appears as if no progress has been made in this area. Head (1991) used a geographical metaphor for the field's lack of progress in understanding **cognition** and understanding of the map user, "...the path is not clearly cut, the night is dark, we have no torch, and we have no map" (p. 237).

Beard (1989) advised that **map use errors**, such as symbol misperception, can carry significant penalties because any misapplication of design features could negate its potential benefits. Also, one case of misuse can potentially cancel all investment in **source** and **process error** reduction that was put into a project (p. 810). Failure to address this was excusable in the past but today is considerably more risky because with GIS more non-cartographers are designing symbols and using these geographic applications.

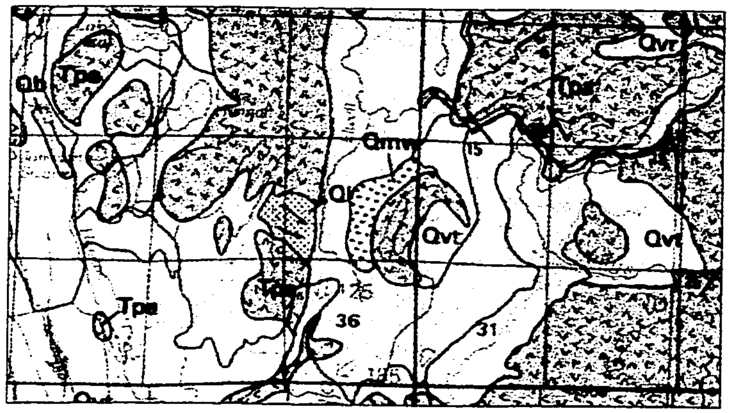


Figure 2. Sample of geologic symbols used for directional data. Elongated blue arrow (lower left) depicts Pleistocene ice flow direction, small double barbed arrows (center) show spillway direction, and small black bar and cross symbols (upper right) depict geologic formation directional trend ("strike and dip"). *Note:* From *Geologic Map of the Skykomish River 30- by 60-minute Quadrangle, Washington*, by R.W. Tabor, V.A. Frizzell, D.B. Booth, R.B. Waitt, J.T. Whetten, R.E. Zartman, 1993, USGS Miscellaneous Investigations I–1963, Washington, DC: USGPO.

The orientation variable used for directional data in mapping is such a case. Used in highly specialized mapping for depicting directional information, this variable can be easily employed by the designer to depict other derived data. Geological maps use oriented symbols to depict directional trends of rock formations and ice flows such as seen in *Figure 2*.

Oriented symbols are used in standard map series of which two can be seen in *Figure 3* on page 6. Topographic maps depict **adits** in their orientation to the hillside and meteorological charts employ oriented symbols to show wind direction. Carr, Olsen, and White (1992) introduced the positive design aspects and "numerous opportunities" **ray-glyphs** can be used for statistical mapping (*Figure 4* on page 7). MacEachren (1995) advanced the Exploratory Visualization System (**EXVIS**) used for multivariate spatial analyses. The underlying principle of this scientific visualization tool is that human vision is highly selective for orientation and allows cartographers to design symbols with greater precision than before (p. 387).

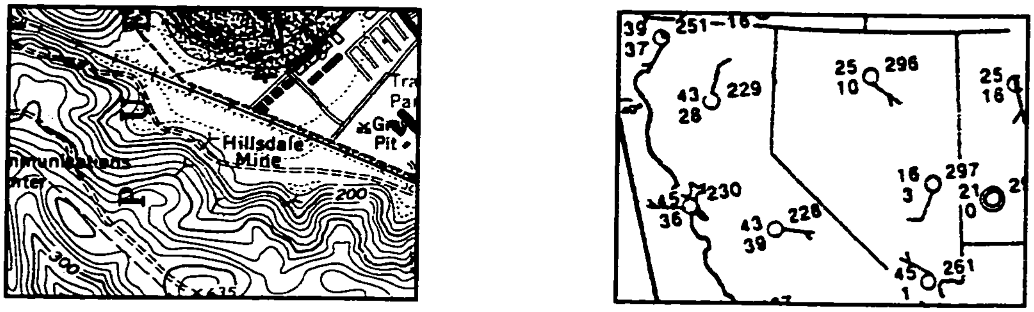


Figure 3. Mine symbols on San Jose West, CA (1982) 7.5′ USGS topographic map, left, wind direction symbols on *Daily Weather Map* — April 1, 1971 National Weather Service, right.

Map error can be minimized on the production end but what about the user end? Is human vision highly selective for orientation as Bertin (1983/67) and MacEachren (1995) advocate? How well can a map user judge the angular measurements of directional information on a map? Eastman and Castner (1983) noted that as long as cartographers are designing for "experienced" users, they should have greater design freedom because their users will come to map reading with more flexibility than inexperienced users (p. 137). But is this true? Are experienced users better at judging oriented symbols than inexperienced users?

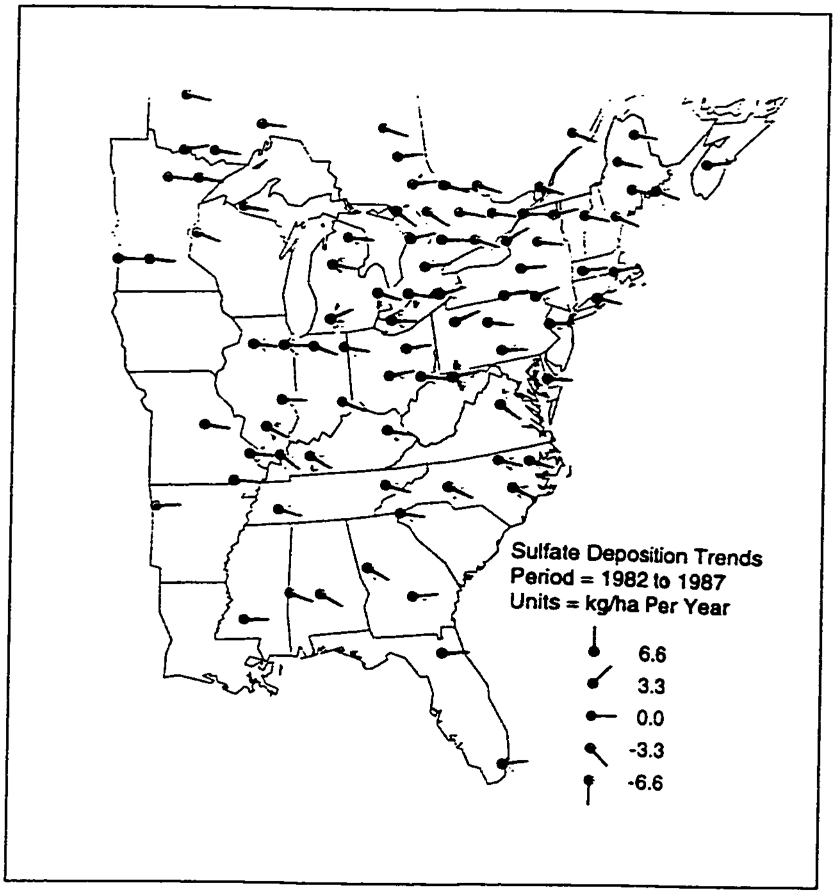


Figure 4. Ray-glyph map using orientation as primary visual variable. *Note*: From "Hexagon Mosaic Maps for Display of Univariate and Bivariate Geographical Data," by D. B. Carr, A. R. Olsen, and D. White, 1992, *Cartography and Geographic Information Systems, 19*, p. 233. Copyright 1992 *Cartography and Geographic Information Systems*.

Literature Review

Jacques Bertin in *Semiology of Graphics* (1983/67) suggested that the orientation variable is useful because "implantation by point" is comparable to hue and superior to shape implying that humans are highly sensitive to orientation (p. 223). However, he did not elaborate on how well humans are sensitive to orientation. Monmonier and Schnell (1988) noted that point symbols are very useful for portraying orientation such as winds, currents, and other directional phenomena (p. 30). However, they did not explain how users can effectively use the data. Robinson et al. (1984) admonished cartographers not to use orientation for point symbols at "higher scales of measurement" above nominal data (p. 280) — with no explanation. Dent (1999) did not mention the orientation variable for points at all in his book on cartographic design. Keates (1982) and Byrne (1982) speculated that little cartographic research regarding how well humans judge angles has been conducted. A review of the literature supported their assertions that little interest has been generated in research cartography.

Psychologists have been interested in our ability to judge angles since the nineteenth century (Jastrow, 1893). Gibson and Radner (1937) tested subjects' ability to adjust a line to a target line accurately. Rogers, Volkman, Reese, and Kaufman (1947) conducted tests for the U.S. Navy on how well personnel could estimate bearings of enemy targets. Smith (1962) conducted a study similar to Rogers et al. (1947) for the U.S. Air Force where he tested the differences between civilian and airmen abilities to judge angular positions of displayed vectors on a simulated display.

Other researchers investigated perceptual effects of line orientation because experimental results were showing that estimating angles at or near the cardinal axes were more precise than oblique angles. Rochlin (1955) studied the effects of line-tilt, line-length and inter-line distance of parallel lines. Andrews (1967) conducted similar studies to Rochlin's judgment error for oriented lines. Westheimer, Shimanura, and McKee (1976) and Westheimer (1990) studied the effects of visual interference on the detection of oriented lines.

Researchers interested in the connection between physical stimuli and biological processes investigated how oriented figures are perceived by animals (Hubel & Wiesel, 1962; Mansfield, 1974; Hubel, 1982) and humans (Campbell & Kulikowski, 1966). Other scientists examined how precisely humans can judge various orientations (Movshon & Blakemore, 1973; Thomas & Gille, 1979; Bradley, Skottun, Ohzawa, Sclar, & Freeman, 1987; Dick & Hochstein, 1989) and the areas within the brain responsible for the processing of orientation stimuli (Hubel & Wiesel, 1962; Andrews, Butcher, & Buckley, 1973; Leventhal & Hirsch, 1975; Aslin, 1981; Vogels & Orban, 1985, 1986; Blakemore, 1990; Gilbert & Wiesel, 1990).

Similar investigations such as this one have been conducted in the past. However, none addressed orientation in a mapping context. Rogers et al. (1947) test subjects were college women, average age 19 years, and high school boys, average age 18 years. The orientation variables ranged from -10° to 100°. Smith (1962) studied subjects' judgment of headings on a 360° radar screen. Psychophysical and experimental psychologists investigated oriented figures using angles in multiples of 20°, 30°, and 45°, not the 360° orientations that point symbols can be displayed in mapping. Could testing angled symbols in all possible orientations reveal the same information?

Ekman, Lindman, and William-Olsson (1961) had problems with their map experiment. Their subject pool was not familiar with sophisticated map symbolization. Would inexperienced map users be less able to judge oriented angles than experienced map users? If a mixed pool of map users were used, the issue of how well and who can judge oriented symbols can be addressed.

Methodology

Tests

A test was designed to measure how well people could judge angled symbols in map use. This was separated into two general sections — a pretest and the experiment. The pretest was developed to help the participants get used to working with angled symbols. The first section of the pretest consisted of 12 selected-response items prompting the subject to identify the line in question from a field of four (*Figure 38* and *Figure 39* on pages 89 and 90). The second section involved matching 18 angled lines to the correct numeric value (*Figure 40* and *Figure 41* on pages 91 and 92). The second part comprised two tests — Test "A" and "B". Both tests had 25 arrow symbols, 0.3 in. in length, randomly placed in a 6.5 in. by 7.5 in. graphic rectangle representing a map on a standard white 20 pound 8.5 in. by 11 in. sheet. Test "A" map graphic orientation was 6.5 in. wide by 7.5 in. high. Test "B" map graphic orientaion was 7.5 in. wide by 6.5 in high.

Test stimuli

The test stimuli were solid black arrow symbols from a symbol set, usgs.mrk, installed on the GIS Arc/Info conforming to the United States Geological Survey (USGS) cartographic standards for map symbols. The symbol's dimensions are 0.300 in. length, 0.005 in. shaft width, 0.100 in. arrow point length, 0.110 in. arrow point width, and 30° arrow point angle.

Figure 5. Test item stimuli. −48° (left), 0° (center), 90° (right).

Stimulus length was assumed to have no influence on test participants' ability to judge symbol orientation although length of a stimulus line may influence a user's **visual perception** of the line. Rochlin (1955) and Scobey (1982) noted that shorter line lengths contributed to greater variability when subjects judged line orientation. Orban, Vandenbussche, and Vogels (1984) found that there was a "strong oblique effect," a pull away from the nearest major axis, in long (18° **visual angle**) rather than short, 0.5° visual angle, stimuli (p. 124). Yet, Rogers et al. (1947) found that line length did not matter when measuring individual accuracy (p. 1). Because the test symbol is included in a standard symbol set and the main function of the current experiment addressed orientation, no adjustments were made on length or size of the target symbol.

Test construction

Twenty-two arrow symbols were randomly oriented with 0°, 90°, and −90° orientations added to make a set of 25 for each test. The angle values in degrees were −90, −75, −73, −69, −55, −50, −48, −35, −30, −13, −9, −1, 0, 7, 10, 23, 29, 32, 44, 46, 47, 67, 73, 80, and 90 for Test "A", see *Figure 6* on page 13. The angles were randomly assigned item values and numbered in an orderly progression from the top to the bottom of the map graphic in order to facilitate easier visual search. Test participants were required to estimate each test angle to the nearest whole degree. A secondary part of the test required subjects to rate their confidence level, on a three-step scale, for angle judgment. The ratings were *not confident*, *confident*, and *very confident* (see *Figure 40* on page 91).

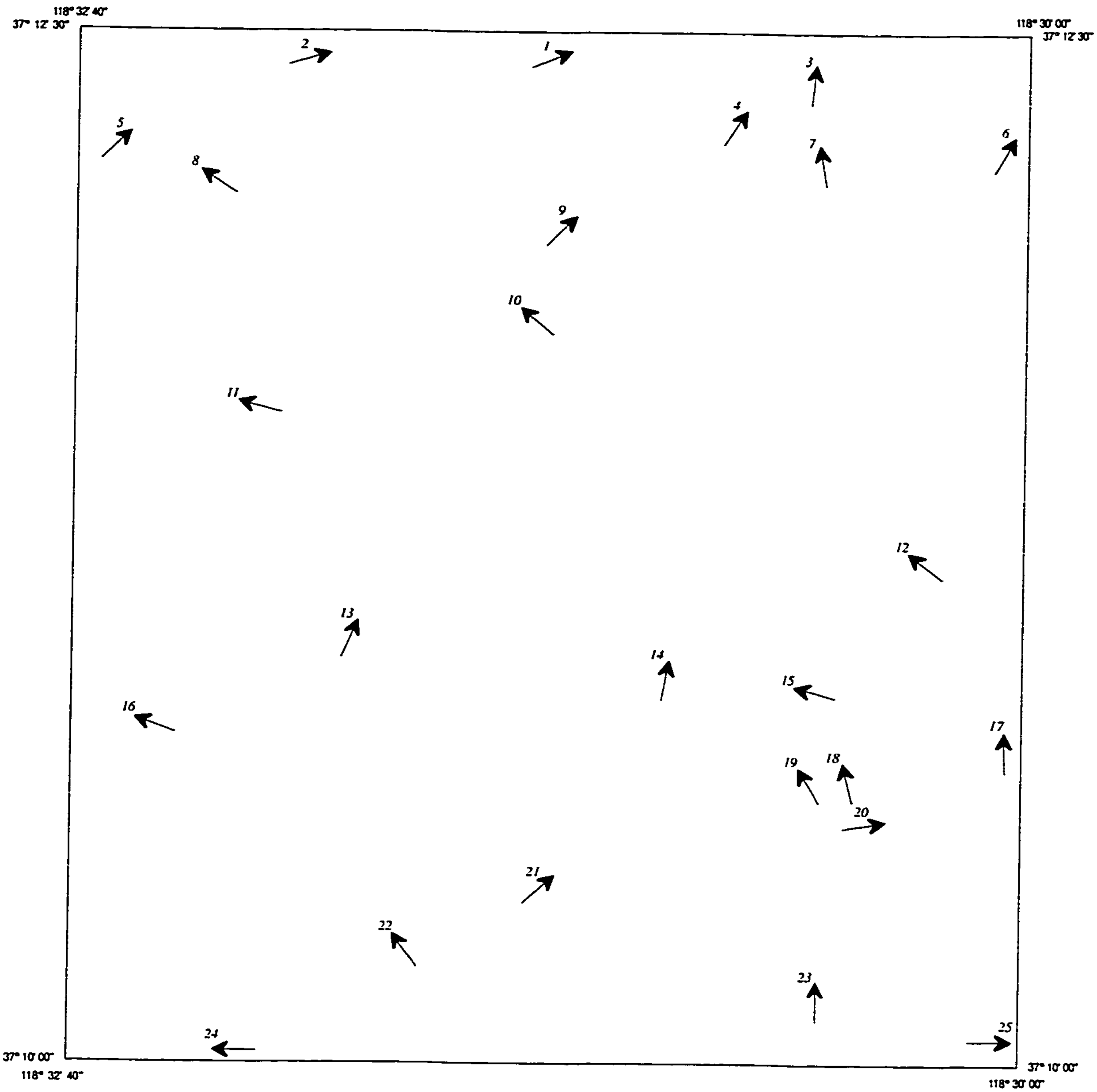
Test "B" was similar to "A" except a **topographic map** was included. The arrow symbols were randomly oriented, along with the three cardinal directions to complete the test set. The arrows were randomly placed, different from "A", and numbered in an orderly progression from top to bottom. The angle values in degrees were −90, −86, −86, −81, −80, −70, −54, −46, −45, −11, −3, 0, 0, 7, 15, 19, 28, 41, 48, 62, 64, 66, 84, and 90, see *Figure 7* on page 14.

The topographic base map was from a digital **raster image** of the Mt. Thompson, California 7.5′ USGS quadrangle. The topographic base included the **hypsography**, **hydrography**, **transportation**, and **cultural features** in black. Castner (1983) noted that using a real map instead of a controlled experimental map is valid because it closely resembles an actual map reading situation (p. 97).

The test questionnaire was used to gather information about each participant (*Figure 35* on page 86) such as map use experience, gender, handedness, college major and year, and vision impairment such as **astigmatism**. Astigmatism has been reported in the literature to affect an individual's ability to judge angles correctly even after optical correction (Appelle, 1972; Mansfield, 1974; Sekuler & Blake, 1994).

Map use experience was determined by a self-report method based on six criteria: "do not use," "street and **locator map**," "topographic," "**navigational** and/or **aeronautical**," "**thematic map** — geologic, meteorologic, etc.," and "use other." Test participants were classified inexperienced if they responded to any of the first three options. Subjects responding to most or all map types were classified experienced. The option "use other" allowed for a person to report any other type of maps not listed. If a person reported a map type that required some form of sophisticated map reading skill, such as reading **engineering plans**, the person was classified as experienced.

TEST A

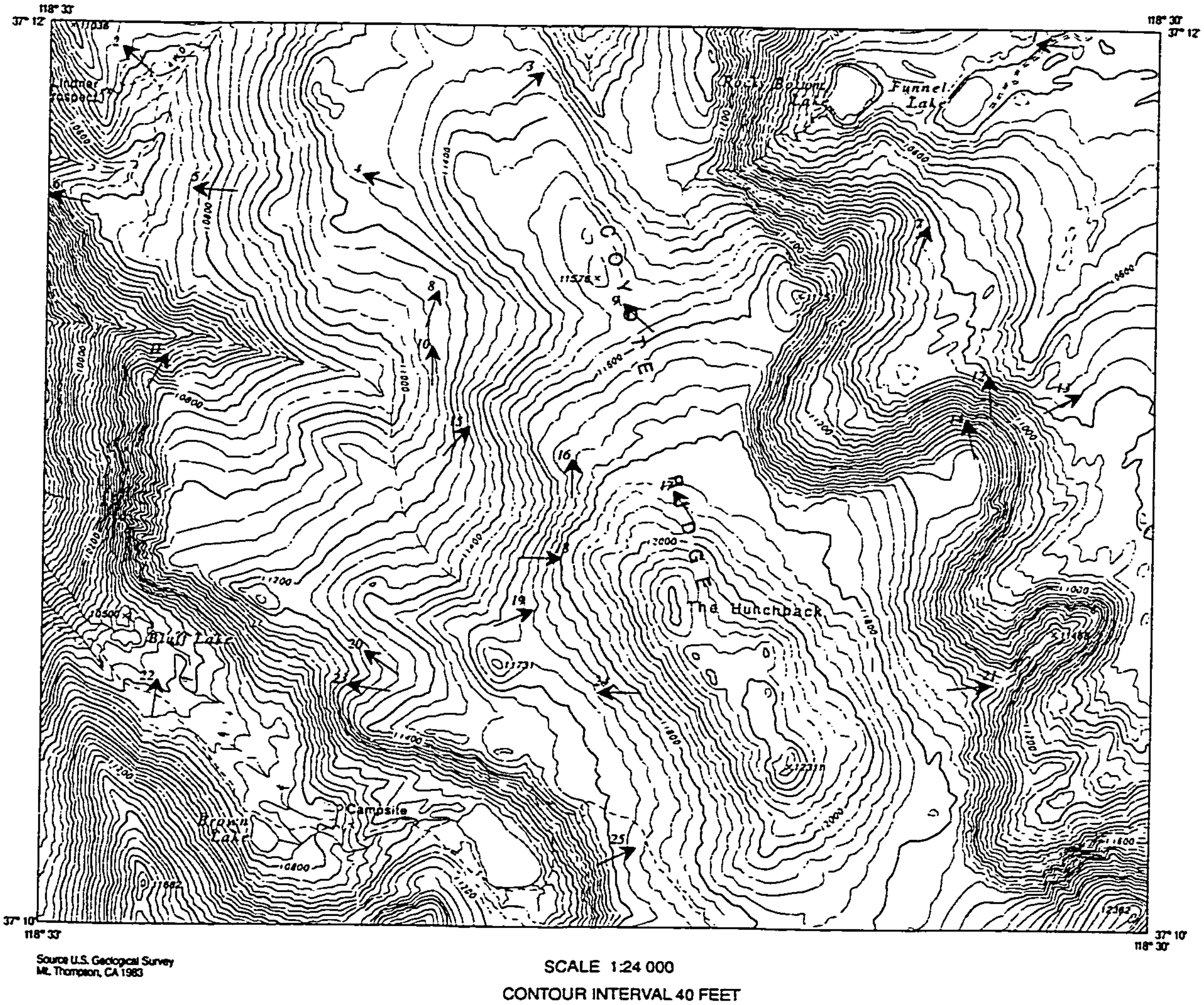


SCALE 1:24 000

20 ← Directional Arrows—Arrow head points toward direction; Number indicates test item.

Figure 6. Test "A" at reduced scale.

TEST B



20 ← Directional Arrows—Arrow head points toward direction; Number indicates test

Figure 7. Test "B" at reduced scale.

Procedures

The test was conducted as a group administered pen and paper test. Individuals answered questions in the provided test booklet. Although the test was not designed to be a timed trial, participants were allowed up to thirty minutes to complete the examination. A graphic aid was provided to use for the pretest only (*Figure 36* on page 87). This allowed the test participants to accustom themselves to recording the angles in the specified manner. Angles between ±90° were allowed for the purposes of this test. Zero degrees coincided with the vertical axis, −90° coincided with the left horizontal, and 90° coincided with the right horizontal. Participants were required to write down their responses in the test booklet.

Participants

Fifty-eight participants took part from various academic disciplines. Seventeen students were from earth sciences majors, 10 were from geography and environmental studies, 13 were from journalism and public relations, and the remainder from other disciplines (Table 1 on the next page). Students enrolled in a general education geography course received extra credit for their participation. Earth science majors, geography, and environmental studies students did not receive compensation for participating in the test. The sample does not assume to be representative of students from each of the academic disciplines, of the university, of college students, or of the general population.

Twenty-nine participants answered they used locator and or topographic maps, two answered they did not use maps. These thirty-one were classified as inexperienced. Twenty-four participants answered they were experienced with most of the map types and three answered they were

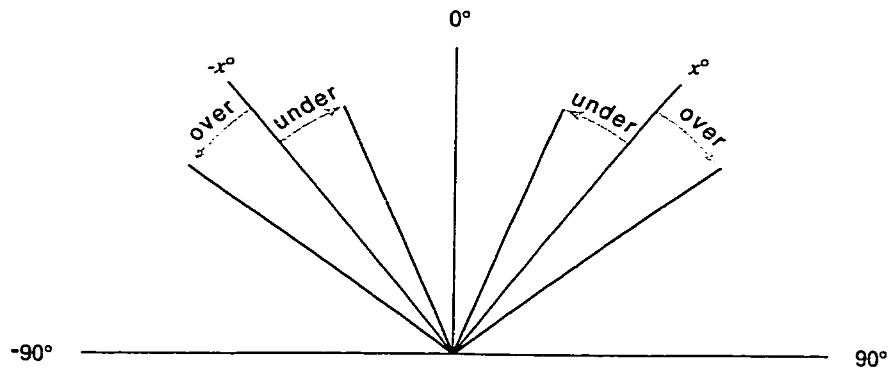
Table 1: Test participants by college major.

College Major	Number
Art	1
Business Administration	2
Computer Science	1
Environmental Earth Science	2
Environmental Studies	4
Geography	6
Geology	15
Graphic Design	1
History	3
Interior Design	1
International Business	1
Journalism	6
Liberal Studies	1
MIS	1
Music	1
Public Relations	7
Social Science	4
Undeclared	1
	58

experienced with all of the map types listed. These were classified as experienced. The youngest participant was 18 years and the oldest was 47 years. The average age was 26.5 years and the standard deviation was 5.5 years. Thirty females and 28 males participated. Nine participants identified themselves as "left handed" — three males and six females. Thirty responded they needed to wear corrective lenses and nine identified themselves as having had some form of astigmatism.

Score computations

Angle responses were computed to relative scores. Test participants' responses for Test "A" and "B" were computed to error scores. An error score was calculated by subtracting the absolute



$$\pm Error = |Observed| - |True|$$

Figure 8. Error score calculation graph.

value of the true angle from the absolute value of the observed angle, *Figure 8* above. A negative error score is considered an underestimation and a positive error score an overestimation of the true score.

Subject qualification

Participants not recording all judgments for both tests were disqualified. Table 2 on the following page lists disqualified participants and the reasons. Four participants did not record angle estimations — subjects 18, 20, 30, and 72 — for both tests. Three participants did not record values for "B", subjects 14, 28, and 31. Two participants did not record all test items for "A" and were disqualified, subjects 23 and 35.

The test with the background, "B", proved to be more problematic for the test groups. The "no response" rate in Test "B" (57 out of 1250 — 4.56%) was higher than the "no response" rate in Test "A" (2 out of 1450 — 0.14%). Participants not recording any test item from both tests were

Table 2: Participants not included in test sample.

Test A		Test B	
Subject	Reason	Subject	Reason
		14	no data
		17	missed items
18	no data	18	no data
20	no data	20	no data
		21	missed item
23	missed item	23	missed item
		24	missed items
		25	missed item
		26	missed item
		28	no data
30	no data	30	no data
		31	no data
35	missed item	35	missed items
		38	missed items
		40	missed cues
		41	missed items
46	misdirected[a]	46	misdirected[a]
48	missed cues	48	missed cues
51	misdirected[a]	51	misdirected[a]
		55	missed items
72	no data	72	no data
		73	missed item
75	misdirected[a]	75	misdirected[a]
79	misdirected[a]	79	misdirected[a]

[a] did not follow directions

not included in the sample set. Test item B17 was not included after tallying scores because many participants could not find it or commented that it was too difficult to see. This item was eliminated from the analysis.

Responses from the remaining participants were analyzed to ensure answers were in the correct relative judgment scheme as per test instructions. That is, all answers reflected the angle judgments with 0° as vertical, −90° as the negative horizontal, and +90° as the positive horizontal.

Subjects' response answers not conforming to this were disqualified. One subject's answers were recorded as ranges of values, 51. The scores of participants 75 and 79 were not included because their relative response judgments were different from what was required. They recorded their judgments using a 180° range instead of the ±90° range specified.

Angles corresponding to vertical and horizontal were used to detect a test subject's honesty because not all were compensated for their participation. These angles cues were selected because they are the easiest to detect and estimate (Jastrow, 1893; Gibson & Radner, 1937; Leibowitz, Myers, & Grant, 1955; Rochlin, 1955; Smith, 1962; Andrews, 1967; Orban et al., 1984; Dick & Hochstein, 1989). If the participant's responses for the majority of these angles were not within ±20° of the true angle then that participant was not included in the sample. Participant number 48 missed three out of three angle cues for Test "A" and three out of four for "B". Participant number 40 missed three out of four angle cues for Test "B".

Dropped sign analyses

Dropped sign analyses were performed to detect if response angles — participants' written angle estimations — were suspected of having the wrong sign associated with the number. A little leeway was allowed for all participants when it came to recording their estimations because imposing an arbitrary judgment scheme on test subjects can introduce more error in judgment (O'Toole & Wenderoth, 1977; Vogels & Orban, 1986; Dick & Hochstein, 1989).

If a suspected score was within ±20° of the true angle value and if other participants' error scores were the same as the proposed converted score, then the suspect response angle was converted. Approximately 1% and 2% were converted for Test "A" and "B", respectively.

Sample group

Data from 28 participants were collected for both tests. Fourteen were classified as inexperienced and 14 as experienced. The youngest participant was 20 years and the oldest was 42 years. The average age was 25.7 years and the standard deviation was 4.5 years. There were 13 females and 15 males. Five identified themselves as "left handed" — two males and three females. Sixteen responded they needed to wear corrective lenses, seven identified themselves as having some form of astigmatism.

Hypothesis testing

The null hypothesis assumes there is no difference between experienced and inexperienced subjects' error scores. That is, there is no difference between experienced and inexperienced map users when judging symbol orientation. The research hypothesis assumes there is a difference between experienced and inexperienced map users.

$$H_0 : \mu_1 - \mu_2 = 0$$

$$H_1 : \mu_1 - \mu_2 \neq 0$$

A related null hypothesis assumes there is no difference between both groups when judging angles between the two map formats, with a background or without. The research hypothesis assumes there is a difference when judging angles between the two formats.

Spearman r

Spearman rank correlation coefficient, r_s, values were calculated for subjects for Tests "A" and "B". Correlation statistics were generated for test and confidence ranks. Test ranks were calculated from subjects' average error score (*AES*) in comparison to other subjects' *AES* for each test. Confidence ranks from confidence scores, which were calculated as the sum of confidence ratings for each test item, were generated. The more confident subjects were for judging all angles, the higher the confidence scores.

$$H_0 : \rho = 0$$

$$H_1 : \rho < 0$$

The null hypothesis states that there is no correlation between *AES* and confidence ranks. The research hypothesis states that there is an inverse relationship between confidence scores and *AES*.

Results and Discussion

Test "A"

Ranked data

Spearman r_s values were calculated and graphed to determine if a correlation between confidence score and *AES* existed (*Figure 9* below). Twenty-one out of 28 scores for "A" were used because these participants responded to all items in the confidence section. Test "A" statistic was calculated to $r_s = .178$, $n = 21$ for the both groups. A one-tailed test at the .05 significance level was 0.371, therefore, the null hypothesis was accepted. Correlation statistics were $r_s\ inexp = -.217$, $n = 12$, and $r_s\ exp = .258$, $n = 9$, for each group, respectively.

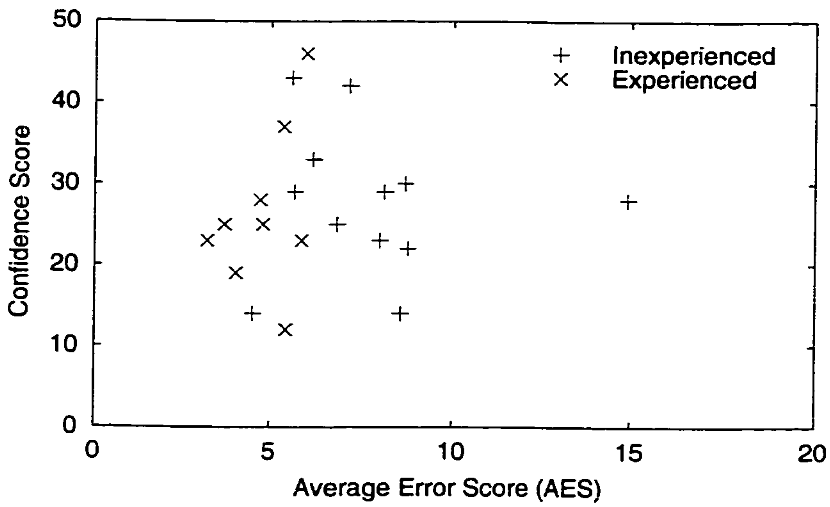


Figure 9. Test "A" scatterplot, $r_s = .178$

The current experiment shows there is a very weak positive correlation between average error scores and confidence scores. Comparing the two groups shows a weak inverse relationship for inexperienced participants; whereas, there is a weak positive correlation for the experienced group. Therefore, the null hypothesis is accepted for this test.

The experienced group appears to be more clustered near the *y*-axis than the inexperienced group. Differences in rank scores (*D*) revealed that the inexperienced group tended to be overconfident with their ability to judge angles than the experienced group.

Experimental results

Mean error and variances for each test item across all subjects were calculated and graphed. See *Figure 10* for mean error and *Figure 11* for error variances on page 24. Minimum average errors and variances were seen at or near ±90° and 0°. Maximum average errors of −7.00 ($SD^2 = 150.00$) and −7.32 ($SD^2 = 56.44$) were calculated at 67° and −30°, respectively. Variances greater than 0 can be seen for the moderate angles between ±80° and ±20° approaching maximum near ±60° with a maximum of 179.73 at 73°.

Angles within ±10° of vertical had mean errors of a few degrees with a mean error of 0.00 ($SD^2 = 1.78$) for 0°. The maximum overestimated error for these angles was 1.39 ($SD^2 = 0.80$) at −9°. However, most angles tended to be underestimated — in some instances greatly underestimated — than they were overestimated. Moderate angles tended to be underestimated greater than slight angles. Greater ranges of response values were seen for moderate angles compared to angles closer to the axes as well. Variances were greater for moderate angles compared to vertical and ±90°.

Both groups showed mean error and variances for the cardinal angles, ±90° as 0.00. That is, there were correct angle judgments and perfect agreement across all test subjects. The

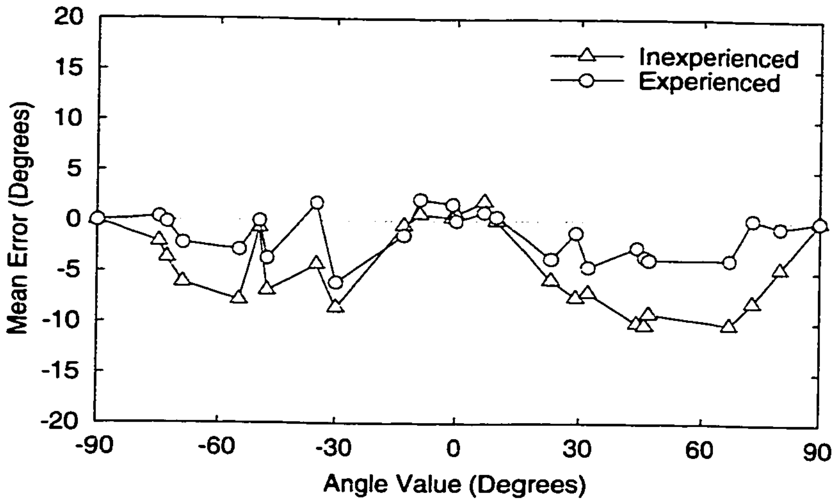


Figure 10. Test "A" mean error for inexperienced and experienced map users.

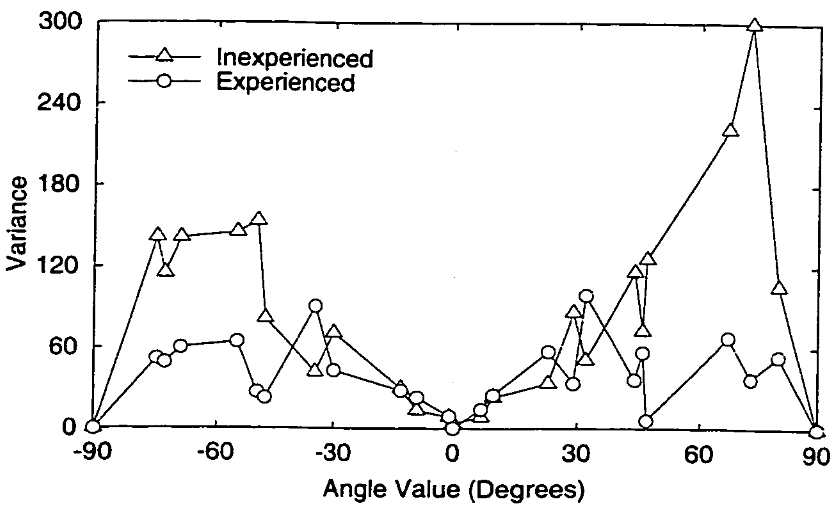


Figure 11. Test "A" error variances for inexperienced and experienced participants.

inexperienced subjects' mean errors for moderate angles tended to be greater than the experienced group. Whereas, the experienced participants' mean errors for slight angles tended to be greater than the inexperienced group overall. The experienced group tended to overestimate angles within $\pm 10^\circ$ of vertical and horizontal. This group's variability tended to be less than the inexperienced group for moderate angles as well. The average variability for the experienced group was 50 where the average variability for the inexperienced was near 150 with a maximum variance of 300.00 ($SD = 17.32$) at 73°.

Test "B"

Ranked data

Correlation statistics, Spearman r_s were calculated and graphed for both groups, *Figure 12* on page 26. Twenty-four out of twenty-eight scores were used. The scatterplot is similar to "A". Test "B" correlation statistic was calculated to $r_s = .036$, $n = 24$, one-tailed test at .05 level of significance was 0.337; therefore, the null hypothesis was accepted. Correlation statistics for each group were calculated as r_s *inexp* $= -.117$, $n = 13$, and r_s *exp* $= .148$, $n = 11$, respectively. The null hypothesis was accepted that is there is no statistical correlation between *AES* and confidence scores. Spearman r_s statistics were similar to Test "A".

No pattern was seen for pooled statistics except for the experienced group being clustered similar to that of Test "A". These clusters could be attributed to a smaller set from the original 58 test subjects. However, inexperienced participants' *AES* and confidence scores showed greater ranges in comparison to the experienced group. Inexperienced users tended to overestimate their abilities; whereas, more experienced users tended to underestimate their abilities. Kruger and

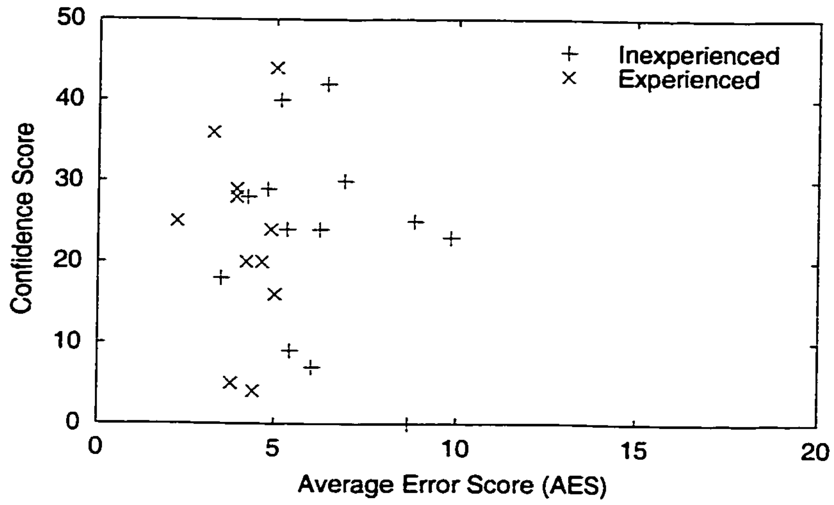


Figure 12. Test "B" scatterplot, $r_s = .036$

Dunning (1999) showed the same results in their experiments on humor, logical reasoning, and cognitive skills. They attributed the differences to the inability to recognize one's own deficiencies in the former group to the inability to recognize one's peers' deficiencies in the latter group.

Experimental results

Mean errors and variances for "B" were calculated and graphed for both groups (*Figure 13* and *Figure 14* page 28). The only angle that no error was calculated for was −90°. Mean errors and variances for 0° and +90° were comparable with an absolute average of 0.59. Two items' angle values were 0° — 0.57 mean error ($SD^2 = 4.33$) for B10 and −0.69 ($SD^2 = 4.21$) for B16. Maximum average errors were calculated as −9.64 ($SD^2 = 98.02$) at −45° and −9.93 ($SD^2 = 83.99$) at 41°. Maximum variance values were for moderate angles with the highest value of 156.22 at −70°. Angles for the cardinal directions have minimum mean errors and variances. Mean errors for the two 0° items were 0.93 ($SD^2 = 7.45$) and 0.00 ($SD^2 = 0.00$) and 0.21

($SD^2 = 1.26$) and -1.39 ($SD^2 = 3.85$) for inexperienced and experienced groups, respectively. Both groups' mean error scores for +90° were the same at -0.50 ($SD^2_{\text{inexp.}} = 1.96$, $SD^2_{\text{exp.}} = 1.81$).

Minimum errors were near the cardinal axes and maximum errors surrounded the moderate angles. Overestimations occurred near vertical and −90° with a maximum of 2.21 ($SD^2 = 18.64$) for the inexperienced group at −80° in comparison to 2.00 ($SD^2 = 4.00$) at −3° for the experienced group. The inexperienced group showed greater underestimations for most moderate angles than the experienced group. For example, a mean underestimation of -16.00 ($SD^2 = 42.31$) at 41° was recorded for the inexperienced group compared to a mean underestimation of -3.86 ($SD^2 = 52.75$) for the experienced group.

The negative non-cardinal angles of −86° to −54° showed similar values from both groups yet did not show the curve as for Test "A". The inexperienced and experienced mean errors showed oscillating values for −86°, B01 and B05, negative for −81°, and positive for −80° . Variances between the groups generally did not show the same trend as the first test. The variance curves showed minima for the cardinal directions and at −46°, $SD^2 = 2.26$, for the experienced group only. Maximum variance of 209.48 was calculated for 66° for the inexperienced group. One observable discrepancy between variance scores was seen for −86°, B01, were the experience group's score was 22.69 compared to 115.15 for the inexperienced group.

Similarities between mean and variance curves from both tests were noted as well as other unexpected results during the course of the experimental analysis. All mean error and variance graphs generally were sinusoidal curve types where maxima were near ±45° within a ±10° range and minima were at ±90° and 0°. Another unanticipated result was test participants' restricted judgments of most angles in multiples of 5°. The next section addresses these issues in reverse.

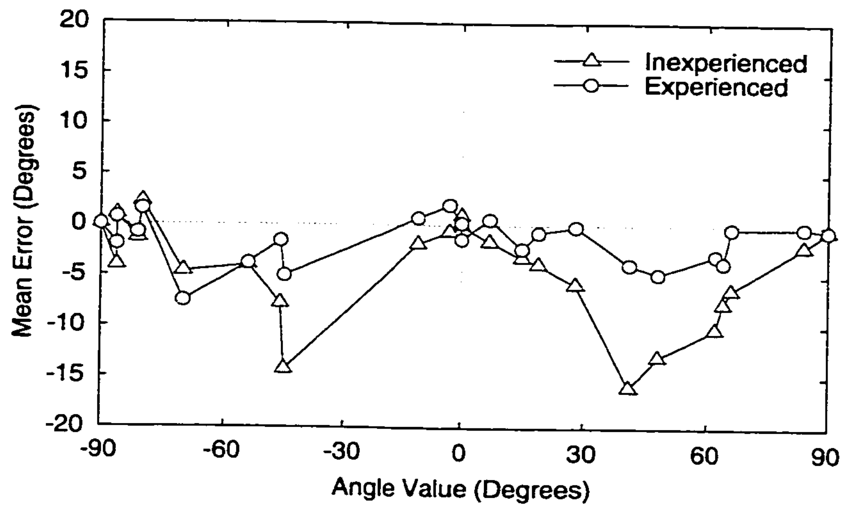


Figure 13. Test "B" mean error for inexperienced and experienced subjects.

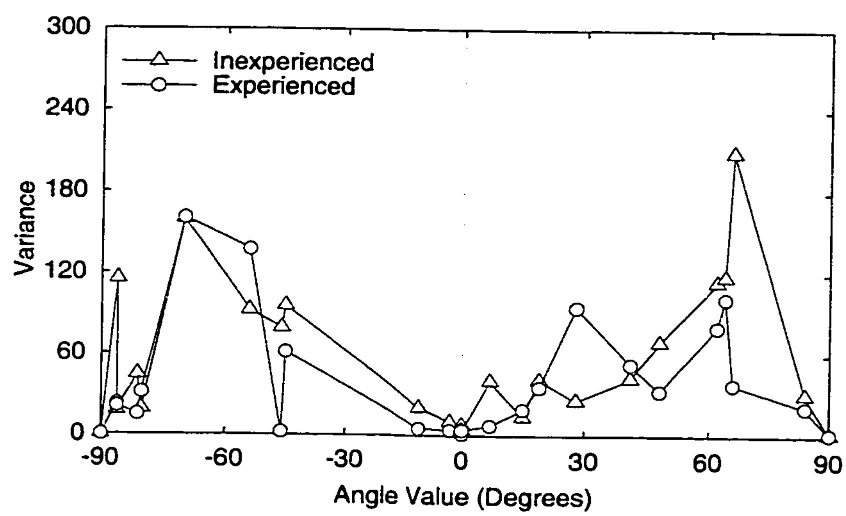


Figure 14. Test "B" error variances for inexperienced and experienced subjects.

Similarities to other studies

Response limitations

Test participants limited their estimations in 5° multiples for most angles despite instructions stating that each angle should be estimated to the nearest degree. A review of all participants' responses revealed that approximately 95% of all item responses were estimates in multiples of five for Tests "A" and "B" (Table 3). For the test items that were 0° and ±90°, 98% and 90% of item responses were estimates in multiples of five for each test, respectively.

Other studies have noted high response frequencies in 5° multiples as well (Rogers et al., 1947; Smith, 1962). Smith (1962) noted that 90% of the numerical responses were 5° multiples (p. 242). Rogers et al. (1947) surmised that the tendency to round numbers to the nearest 5° was because there was no "stabilizing influence" around the oblique angles such as the "natural ability" to judge vertical and horizontal angles (p. 13).

Current research showed similar limitations imposed by the participants. The **response limitation** percentages for the groups of angles not within 10° of an axis for each test were higher than Smith's 90% at 98% and 97% for "A" and "B", respectively. Response limitations for angles near vertical and horizontal showed lower frequencies than other angles at 90% and 87%; whereas, ±90° and 0° responses were 98% and 90% for "A" and "B", respectively.

Table 3: Response limitation estimations in multiples of 5°.

Angle Groups	Test A	Test B
cardinal axes	98	90
±10° near axes, inclusive	90	87
others not included above	98	97
all	96	93

Another source that might have caused high frequencies of 5° multiples could have come from the pretest. The second section of the pretest asked participants to "Match each line to the angle value" (see *Figure 40* on page 91). All 18 items in this section were 5° multiples. This could have cued participants to continue this scheme into the next phase of the experiment even though that was not the intent of the test design. One test participant commented that he assumed he needed to estimate angles to the nearest 5° because the previous section's answers were in 5° multiples (personal communication, December 1, 1997). Another participant wrote, "...I didn't feel confident at guessing an exact degree..." (see Appendix E on page 99). Revising the pretest to include angles not in 5° multiples may result in response limitation frequencies to agree with Smith (1962) and Rogers et al. (1947).

Rogers et al. (1947) and Smith (1962) did not use stimuli in a mapping context. The contours of the base map used in "B" may have interfered with test subjects' ability to correctly estimate angles that were near or at horizontal and vertical compared to "A" given the lower percentage of multiples of 5 for "B". This may imply that their conclusions about people's inability to judge moderate angles less than 5° level of precision does have merit.

Graphical representations from other orientation studies

Graphs generated from this test revealed the same generalized curves regardless of data presented. Means and variances for the two experience groups for each of the tests and gender all showed the same curve with minimum mean errors and variances near the cardinal axes and maximum mean error and variances near ±45° (*Figure 15* and *Figure 16* on page 31). Variance data showed females tended to show greater variability than the males for the first test than the second (*Figure 17* and *Figure 18* on page 32).

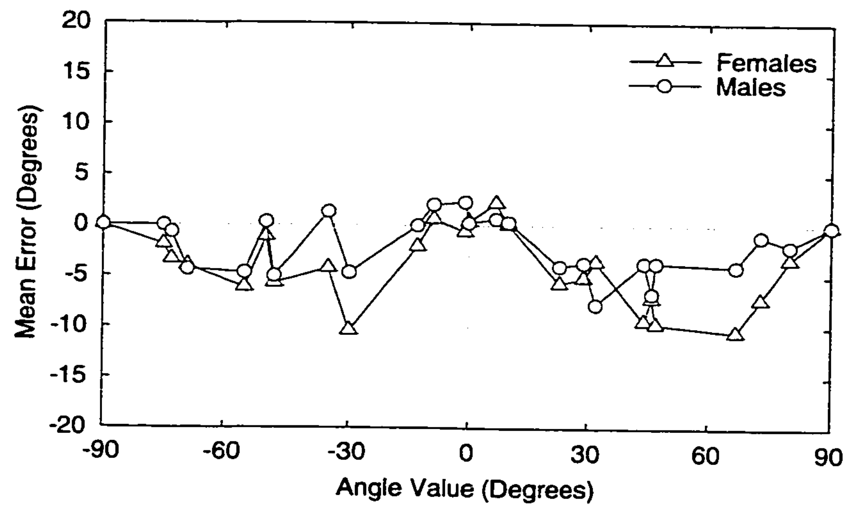


Figure 15. Test "A" mean error scores by gender.

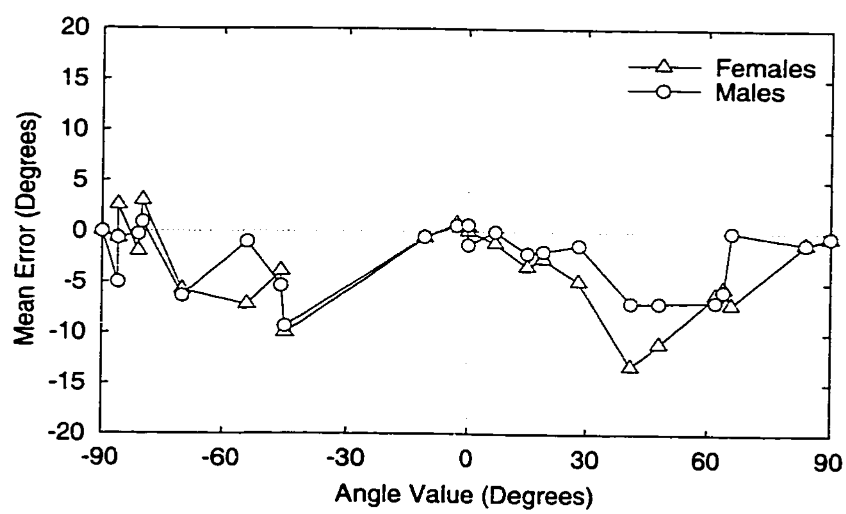


Figure 16. Test "B" mean error scores by gender.

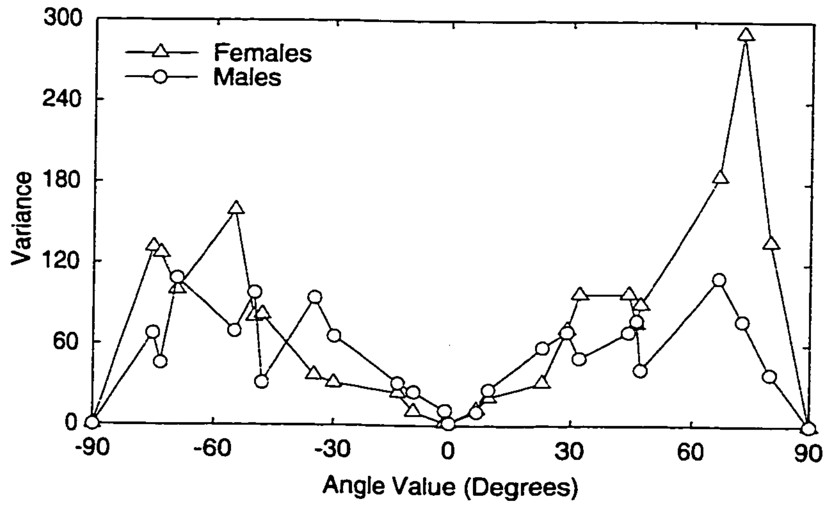


Figure 17. Test "A" error variances by gender.

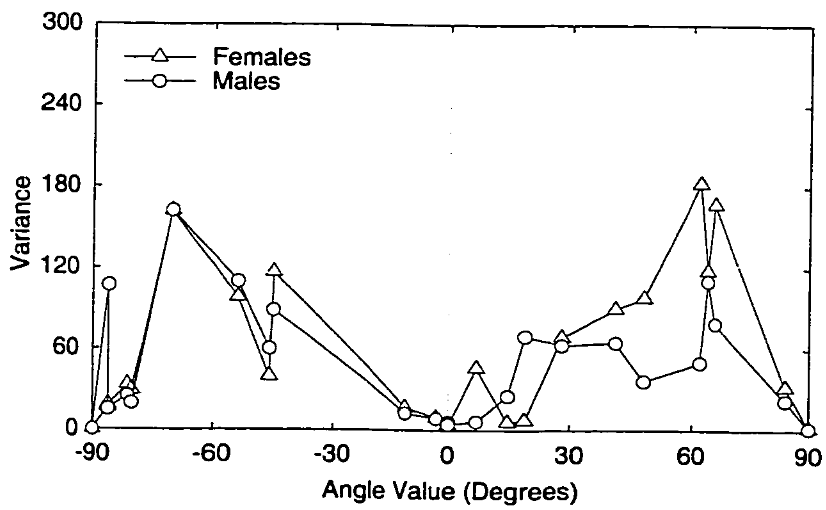


Figure 18. Test "B" error variances by gender.

One notable exception was from the participants identifying themselves as left-handed. Five identified themselves as left-handed and means and variances were graphed (*Figure 19* and *Figure 20* on page 34). Mean error curves for both tests tended to show more random errors but still underestimation for moderate angles and no error for cardinal angles. Variance curves showed the same general curve type for Test "A" and negative angles for Test "B". Test "A" showed two extreme outliers at 73° (item A02) at $SD^2 = 505.00$ and 80° (item A20) at $SD^2 = 257.50$. Test "B" results did not show greater variance than the first test. The graph section for positive angle variances for Test "B" showed oscillations between 0° and 90°. The reason for this could be a restricted sample set, although no other sample set showed this effect. No plausible explanation has been given from the literature.

Given the experimental data from the two experience groups (*Figure 10* and *Figure 13*) and other graphs shown (e.g. *Figure 15*), other researchers have noticed this general curve as well. Jastrow (1893) calculated the errors associated from subjects reproducing angled lines from memory. The average minimum errors were for 90° (no error) 135° (slight overestimation) and 30° (slight underestimation). The average maxima errors were for 75° (greater than 5° underestimation) and 105° (greater than 7.5° overestimation). Although Jastrow used angles from 15° to 165° in 30° steps, his graphs showed the same general trend as the current experiment.

Taylor (1963) compared three separate studies showing an "Index of Precision" based on the results of Rochlin (1955), Leibowitz et al. (1955), and Smith (1962). The graph compared angles, through 180° in 15° steps on the x-axis to the ability to assess orientation, ranging from .00 to 1.00 on the y-axis, where 1.00 corresponds to perfect ability for judgment. The curve showed a greater degree of precision for vertical and horizontal angles at a .75 level. The minima levels to .25 for

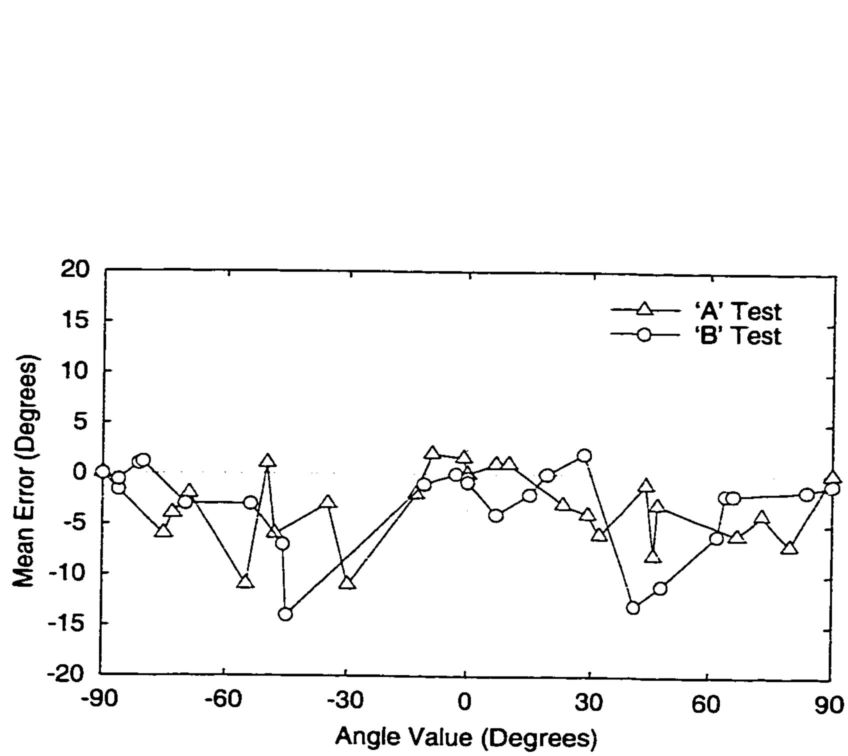


Figure 19. Mean error scores of participants that identified themselves as left-handed.

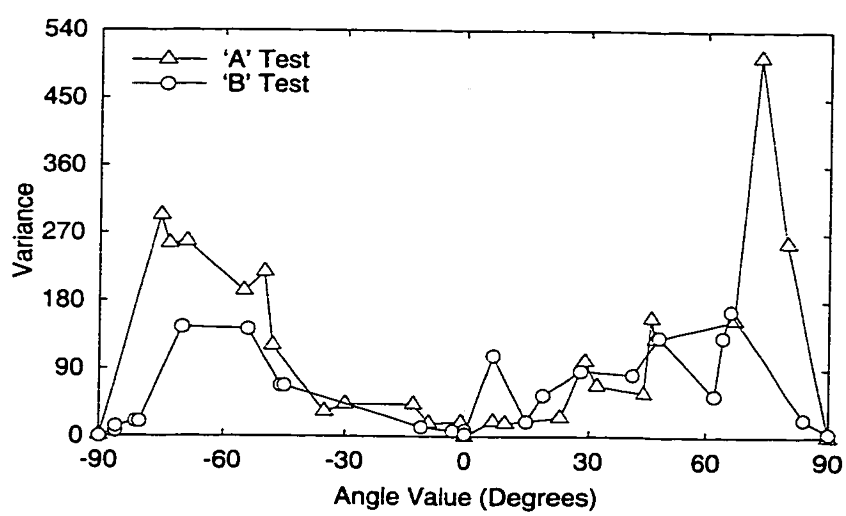


Figure 20. Error variances of participants that identified themselves as left-handed.

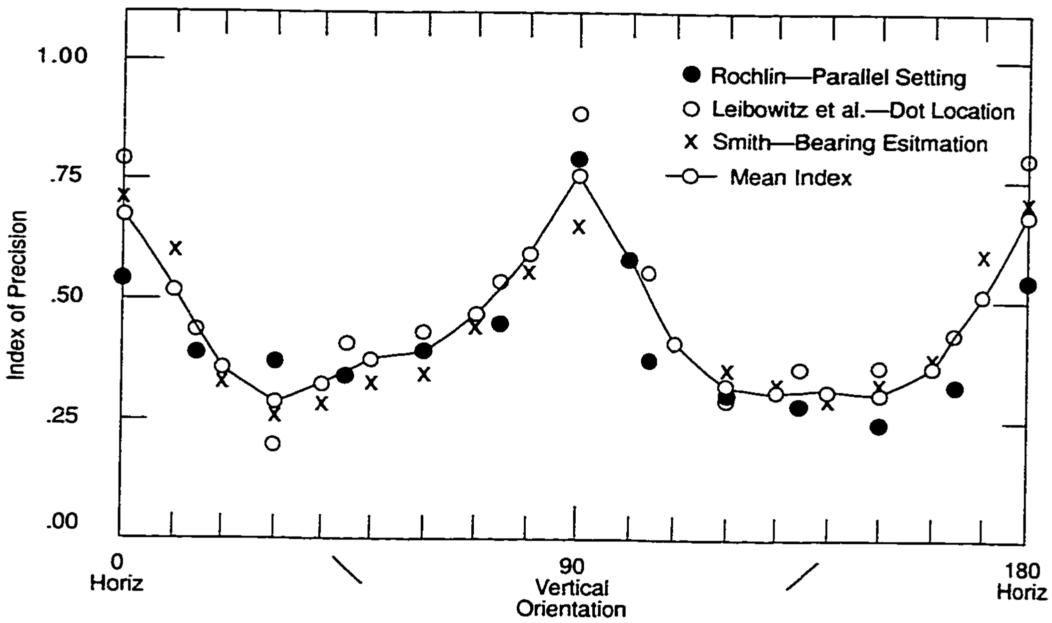


Figure 21. Ability to assess orientation expressed in terms of an index of precision. *Note*: From "Visual Discrimination and Orientation," by Maurice M. Taylor, 1963, *Journal of the Optical Society of America, 53*, p. 22.

angles near ±45°, *Figure 21* above.

Graphs from the current experiment show the generalized curves for mean errors as well, although the data are not as regular as Taylor's graphic. More oscillation can be observed for the negative angles than the positive angles for both experimental tests. Maxima and minima error for the current experiment are near ±45° and the axes as shown in the above graphic. Although Taylor's graphic was an attempt at normalizing data from separate experiments, the results from this experiment can be said to be comparable to Taylor's results. Howard (1982) noted that if researchers were seeing linear, rather than sinusoidal curves, the differences in orientations would be constant (p. 111). In order to understand why these occur one must investigate the mechanism that scientists believe is responsible for this phenomena, the **visual perception system**.

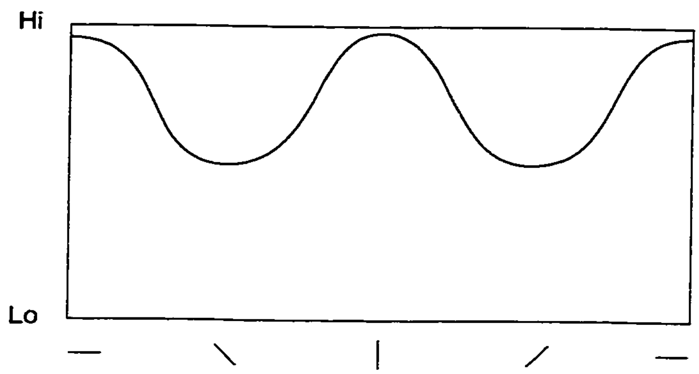


Figure 22. Generalized diagram of orientation sensitivity in the visual cortex of the cat. *Note*: From "Experiential Influences and Sensitive Period in Perceptual Development: A Unique Model," (p. 72) by Richard N. Aslin, 1981, in *The Visual System, Development of Perception, vol. 2*, Richard N. Aslin, Jeffrey R. Alberts, and Michael Petersen, eds., New York: Academic Press.

Visual perception and orientation

In the early 1960s a team of neuroscientists discovered within the visual cortex of one of their experimental cats an area of cells that detected line orientation (Hubel & Wiesel, 1962). Subsequent studies on other cats and monkeys (Hubel, 1982; Mansfield, 1974) revealed the area, known as the **primary visual cortex**, was highly organized. Campbell and Kulikowski (1966) found the human visual system appeared to have the same organization of the cat and monkey (*Figure 22* above).

After Hubel and Wiesel's experimentation on cats in the 1960s, it became evident to researchers that orientation is one of the attributes of basic visual information processing, along with motion, position, and color (Howard, 1982, p. 93). The visual perception area within the brain is located in the occipital lobe consisting of visual cortical fields. The primary visual cortex is responsible for processing primitive visual information such as shape, size, color, motion, and orientation (*Figure 23* on page 37).

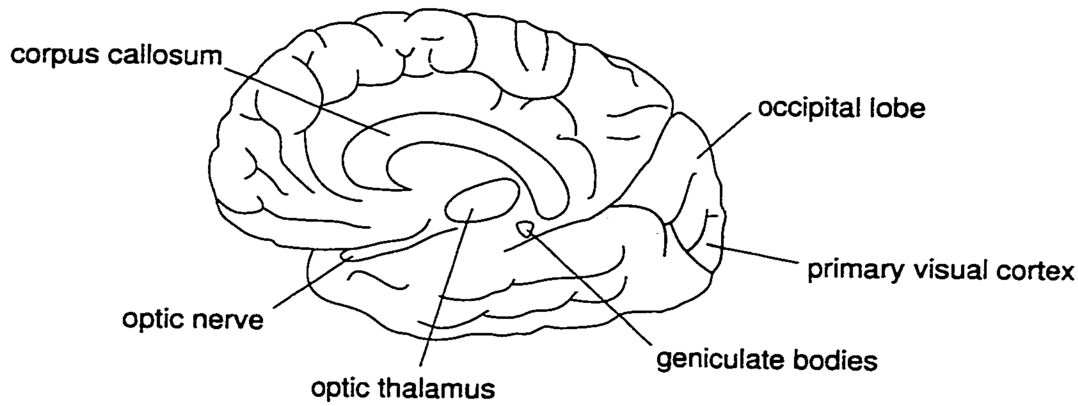


Figure 23. Cross section of the human brain showing areas associated with visual processing. *Note*: Adapted from *Encyclopaedia Britannica*, 15th ed., (vol. 24 p. 834), 1997, Chicago: Encyclopaedia Britannica. Reproduced by permission *Textbook of Anatomy and Physiology*, 12th ed., Catherine Parker Anthony and Gary A. Thibodeau, 1987, St. Louis: Times Mirror/Mosby College Publishing; adapted from "Feinere Anatomie des Grosshirns," by K. Brodmann, 1910, in *Handbuch der Neurologie*, Berlin: Springer-Verlag. Copyright 1997 by Encyclopaedia Britannica, Inc.

Since Hubel and Wiesel's discoveries, neurophysicists and psychophysicists have been conducting experiments to understand the primary visual cortex's role in orientation. Thomas and Gille (1979) surmised that a primary part of visual perception is orientation and that the ability to distinguish different orientations is a basic parameter of "visual capacity" (p. 652). Blakemore (1990) noted that when any part of the visual field is detected, this stimulates at least two columns of orientation cells and "the chance is very low that any particular orientation will be missed completely" (p. 272).

Many of these scientists have been investigating the cellular organization and function within the visual system. Ganz (1978) wrote that from studies of the **striate cortex** of cats and monkeys, scientists have discovered that there contains a group of **neurons** showing true orientation selectivity and **binocularity** and are arranged in a systematic fashion (p. 482), *Figure 24* on page 38.

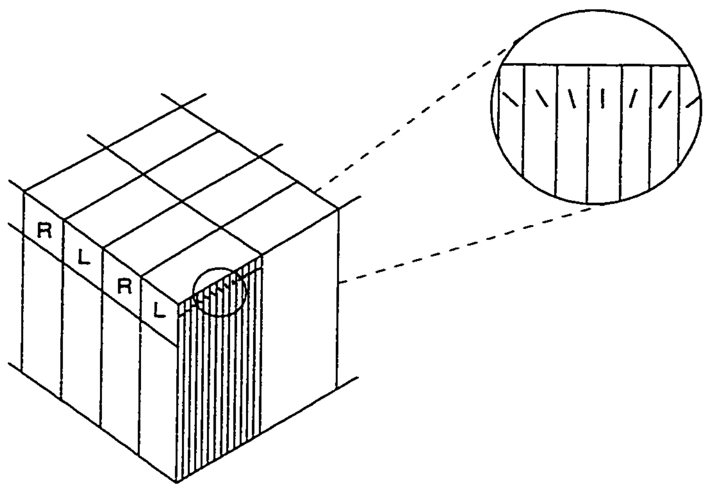


Figure 24. Enlarged view of orientation columns within the primary visual cortex showing binocularity and cellular organization. *Note*: From *A Vision of the Brain.* (p. 174), by Semir Zeki, 1993, Oxford: Blackwell Scientific.

Every cell has a preferred orientation (Sekuler & Blake, 1994, p. 118). However, no one cell is tuned to one orientation (Coren & Girgus, 1978, p. 110). That is, most cells are organized to detect a range of angles. Scientists call this a **tuning curve,** *Figure 25.* Orientation cells are highly selective to one angle and the interaction between separate cells creates an inhibitory effect called **lateral inhibition**. As a bar or **grating** is rotated away from the preferred orientation of a cell, there is a reduction of cellular responses (Movshon & Blakemore, 1973, p. 59). If an orientation

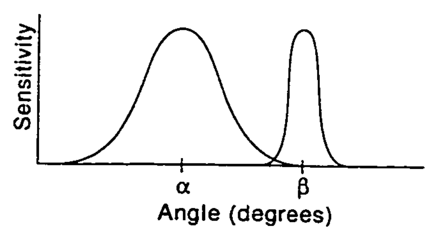


Figure 25. Proposed arrangement of tuning curves for orientation cells depicting wide curves for oblique angles (α) and narrow curves for horizontal and vertical angles (β). *Note*: Adapted from "Perceived Orientation of Isolated Line Segments," by H. Bouma and J. J. Andriessen, 1968, *Vision Research*, 8, p. 504.

cell can optimally detect one angle and, hypothetically, all orientations can be detected, then Howard (1982) could be correct in asserting that all error responses would be linear. However many researchers and the current experiment do not concur with this. All angles may not be treated the same within the primary visual cortex.

One theory describes the cellular organization between **simple cells** and **complex cells**. Simple cells are concerned with static, or slowly moving, patterns; whereas, complex cells are concerned with the perception of flicker and motion. Simple cells detect either horizontal or vertical angles and there are many more of these detectors in the visual cortex than complex cells. Complex cells detect a range of angles where no specific oblique orientation is detected (Howard, 1982, p. 101).

Leventhal and Hirsch (1975) speculated how cells tune to oblique angles. Cells that have a preference for diagonals may be "recruited" from other non-committal neurons, whose orientation specificity is affected by the animal's early visual experience (p. 904). Because cells have a preferred orientation, many of these can experience a 15° tilt away form the optimum and can negate the cells' response (Howard, 1982, p. 118). These cells detect only a narrow band of angles. Aslin (1981) estimated each cell may have a band width of 20–30° (p. 76).

The presence of more cells detecting horizontal and vertical than obliques would explain why mean errors and variances for cardinal angles showed no error, or less error, than oblique angles. If oblique angles were being detected by more complex cells that detect a range of angles, rather than "on" or "off" by the simple cells, then that could explain the lack of precision when judging these angles. Perkins (1983) argued that humans are not capable of detecting oblique angles at great **accuracy** and **precision** because it is not necessary from an evolutionary perspective (p. 343).

Perhaps this is why the majority of test participants limited their responses to the nearest 5° due to the inherent lack of precision at the cellular level.

How we process the cortical information to make an angular estimation is not understood. Hubel (1982) wrote that our perception of a line depends on a set of orientation cells and but how this information is assembled to become the perception of the line is still unknown (p. 519). Howard (1982) noted there are other factors that are likely to affect sensitivity to differences in orientation. These are the sensitivity of the orientation detectors, the width of their tuning curves, and the extent to which they inhibit each other (p. 112).

Howard (1982) noted that the **cardinal axes** are "...the fiducial lines; or norms, for judgments of orientation. We can judge when a line is vertical or horizontal to within a fraction of a degree, and this is not true for other angles" (p. 144). From the above information, it becomes evident that cellular organization and activity is geared toward detecting horizontal and vertical angles with greater precision and accuracy than oblique angles. Levine, Jankovic, and Palij (1982) wrote that there appears to be distortions of spatial perception for orientation; yet, spatial perception for direction, size, and shape show virtually no distortion (p. 158). The next section addresses spatial distortions concerning orientation more commonly known as optical illusions.

Visual illusions

The most important area of research into orientation perception is in the area of psychology concerned with the connection between physical stimuli, biological processes, and behavior — **psychophysics**. Psychophysicists research visual illusions to investigate how the visual system works. To the lay person these are just curious eye games. Coren and Girgus (1978) explained that

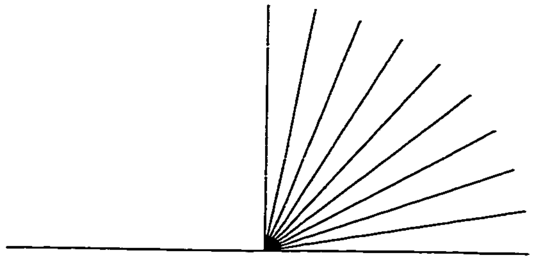


Figure 26. Jastrow-Lipps illusion. Right angle on left appears correct. Right angle on right appears to be greater because acute angles appear to sum greater than 90°.

not just one mechanism is responsible for visual illusions but that many factors such as visual blurring, retinal and cortical cells, and higher-level processing can have an effect on perception (p. 185). The following classes of visual illusions are associated with orientation perception at the cortical level.

Oblique Effect and Jastrow-Lipps. The ability to detect and identify vertical and horizontal lines better than oblique lines is called the **oblique effect** or the Jastrow-Lipps illusion (*Figure 26* above). Sekuler and Blake (1994) commented that before Mansfield (1974) studied the physiology of orientation effects, scientists interested in vision noted that horizontal and vertical lines were detected and identified more easily and rapidly than obliques (p. 121).

Essock (1980) hypothesized the effect is neural and may be based on sustained neurons (p. 37). Another hypothesis contended that stored "norms" of right angles act as residual stimuli on the orientation cells that "pull the perception of similar stimuli toward the stored "norm;" thus a type of averaging occurs (Coren & Girgus, 1978, p. 166). They attempted to classify the underlying mechanism for this type of illusion, along with the following illusion, and concluded that the possible mechanisms could be due to structural, or possibly optical aberrations, and lateral inhibition of orientation cells (p. 134).

Not all people are highly sensitive to the vertical and horizontal. Some people tend to judge oblique lines of another orientation better than the major axes. These people have some degree of astigmatism. The effect can lead to a "superiority" to the angle of astigmatism — even when the impairment is corrected with glasses (Sekuler & Blake, 1994, p. 122). Freeman, Mitchell, and Millodot (1972) proposed that this sensitivity to angles other than the cardinal axes is neural rather than optical (p. 1385).

Mean error curves and variances were plotted for all subjects who identified themselves as having some form of astigmatism, $n = 7$, four also indicated near-sightedness. The mean error and variance graphs for astigmatism (*Figure 27* and *Figure 28* on page 43) showed the same curves as cited above. This is explained by the fact that not all people experience astigmatism the same way. That is, the angle of astigmatism can vary by person and by individual eye such that when all subjects are pooled an averaging effect can occur. Only by investigating each subject's responses will one be able to ascertain whether an individual's astigmatism had any effect on angle judgment.

Howard (1982) noted that acute angles in the range of 5–60° appear to be larger or overestimated and angles between 60–90° tend to be smaller or underestimated (p. 156). An associated illusion deals with angles close to an axis. Stevens and Coupe (1978), citing earlier investigations by Bouma and Andriessen (1970), noted that angles near the vertical or horizontal axes tend to be perceived as distorted away from the nearest major axis, or a slight overestimation (p. 433). Within this group of illusions a phenomenon known as **tilt contrast**, or **acute angle expansion**, occurs when lines converge to form an acute angle and appear to repulse one another (Schiano & Tversky, 1992, p. 14).

The current experiment confirmed the existence of tilt contrast. Mean error graphs for both

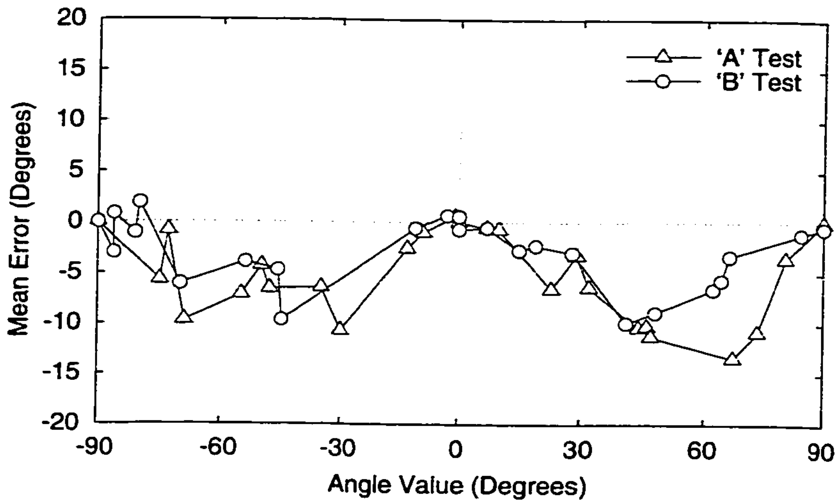


Figure 27. Mean error curves for participants that identified themselves as having astigmatism.

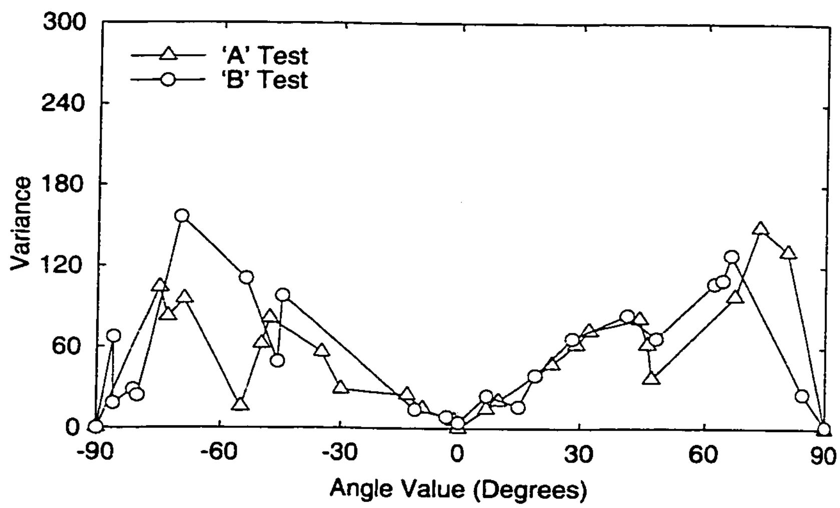


Figure 28. Error variances for all participants that identified themselves as having astigmatism.

Table 4: Comparison between sample angles from tests across both groups to demonstrate Jastrow-Lipps/oblique effect.

Test "A"				Test "B"			
Item	Angle	*M*	*SEM*	Item	Angle	*M*	*SEM*
A24	−90	0.00	0.00	B24	−90	0.00	0.00
A16	−69	−4.18	1.90	B04	−70	−6.07	2.36
A08	−55	−5.36	1.96	B20	−54	−3.89	1.99
A10	−48	−5.32	1.37	B02	−46	−4.68	1.32
A18	−13	−0.96	1.00	B14	−11	−0.57	0.70
A17	−1	0.96	0.56	B12	−3	0.68	0.55
A23	0	0.32	0.25	B10	0	0.57	0.39
A03	7	1.39	0.63	B22	7	−0.53	0.93
A06	29	−4.36	1.56	B11	28	−3.00	1.54
A21	47	−6.46	1.59	B03	48	−8.89	1.54
A01	67	−7.00	2.31	B19	66	−3.32	2.14
A25	90	0.00	0.00	B18	90	−0.50	0.25

tests and the table, Table 4, showed angles corresponding to the axes, ±90° and 0° show little or no error. Cardinal direction values for Test "A" were judged with no error; whereas, these same values for "B" showed slight error for 90° and 0°. Angles near vertical generally showed the averages overestimated for "A". However, angles near vertical and 0° for "B" did not show the same trend as "A". This was due to the different test formats. Between angles, greater than ±11° to less than ±86°, showed greater error overall when compared with the groups above. These angles were generally underestimated for both tests.

Test "A" graph for both groups showed the mean error for angles within ±10° of vertical to be overestimated with a maximum of 2.14 ($SEM = 1.28$) for −9°, test item A07, for the experienced group. The inexperienced group's mean errors for Test "B", which did not show overestimation of angles near vertical; rather, the mean errors showed underestimations as compared to the experienced group. The experienced group's mean error scores showed slight overestimations in Test "B" with a maximum of 2.00 ($SEM = 0.53$) for −3°, test item B12.

Many factors could have contributed to the experimental tests not having a one-to-one correspondence with the theoretical data. The first could be from test design or experimental error. The second could have been from restricted sample set — only 28 of the original 56 subjects were used for the final analysis. Or one could argue that, with these factors besides, there were other factors contributing to the mean error responses when comparing the test with a background to one without. Test "B" used a map background to add visual clutter to the experiment. Whereas, Test "A" showed signs of the oblique effect for angles ±10° within vertical, Test "B" mean error responses from both groups did not.

An explanation of the interactions between background and figure may explain some of the test results. Two more visual illusions are presented that may explain some of the experimental results. These illusions can occur when lines are intersecting at acute angles or when an angled line lies within close proximity to a border or **neatline.**

Zöllner. This illusion occurs when the perceived orientation of a line is affected by another line in a different orientation such as when two lines intersect at an angle (Howard, 1982, p. 156). This is also referred to as tilt contrast. Many optical illusions work on this principle, one of which is the Zöllner illusion, *Figure 29* on page 46. Test "B" of the current experiment was used to detect this. Orientation symbols were randomly placed on a contour map to see if the underlying lines would affect the judgment of the angles.

The Zöllner illusion is based on the principal that a series of parallel lines intersecting main lines at angles causes perceptual distortions of the main lines. Jastrow (1893) cited Zöllner's conclusions about the illusion. Among them are that the illusion is greatest when angles are 30° to the vertical. Another is that the strength of the illusion varies with the inclination of the oblique

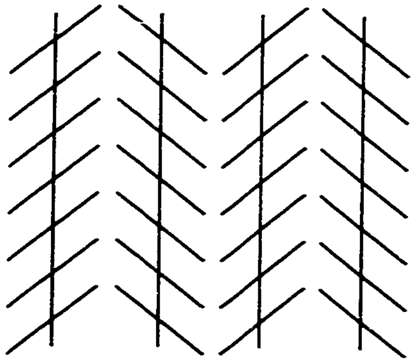


Figure 29. Zöllner illusion. Series of parallel lines do not appear to be such because of angular distortion created by intersecting lines.

lines but when viewed at a slight angle, the illusion disappears. As the intersecting angles approach perpendicular the illusion gets weaker and disappears (p. 390–391). Density may play a role as well. Wallace and Crampin (1969) showed that the greater background density of lines, the greater the illusion (p. 171). Westheimer (1990) wrote that when test lines and **induction lines** are not on the same plane, the **induction effect** on a test line, what he labeled "simultaneous orientation contrast," is stronger than when test and induction lines are on the same plane (p. 1916).

From a psychophysical perspective, Coren and Girgus (1978) argued when oblique lines are extremely tilted, they approximate the main lines. These angles could be close to the level of **cellular adaptation** that an averaging of the two angles can occur (p. 166). They classified this type of illusion and concluded that the orientation cells in the visual cortex are responsible. *Figure 30* on page 47 depicts the averaging effect when orientation cells detect lines intersecting at acute angles.

Given the randomization of stimuli placement on "B", most symbols did not have acute angle intersections (Table 5 on page 48). Four out of the twenty-five angle to contour intersections were less than 30°: B08, B10, B16, and B20. Test item B08 (19°, $\beta = 28°$) mean error score for the

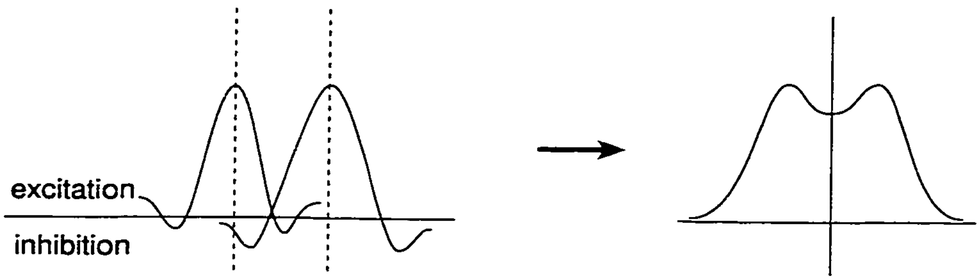


Figure 30. Example of the averaging effect of tilt contrast where an averaging occurs when lines intersect. Orientation cells detect two intersecting lines (left). Averaging effect occurs where higher frequency cellular responses becomes a range bounded by cellular responses of the intersecting lines (right). *Note*: From *Visual perception theory and practice* (p. 126), by Terry Caelli, 1981, Oxford: Pergamon Press.

inexperienced group was -3.86 ($SEM = 1.71$) compared to -0.71 ($SEM = 1.60$) for the experienced subjects. As compared to test item B16 (0°, $\beta = 28°$) mean error score for the inexperienced group was 0.00 ($SEM = 0.52$) to -1.39 ($SEM = 0.52$) for the experienced group. Test items B10 (0°, $\beta = 6°$) and B20 ($-54°$, $\beta = 14°$) mean error scores between both groups were closer at 0.93 ($SEM = 0.73$) and 0.21 ($SEM = 0.30$) and -4.00 ($SEM = 2.57$) to -3.78 ($SEM = 3.13$), for inexperienced and experienced groups, respectively.

Rod and Frame. This illusion occurs when a stimulus line, in close proximity to a border or frame, is pulled away from the direction of the border (*Figure 31* on page 49). This could be said to be caused by an averaging effect on the two lines. Another form is the "tilt illusion" as defined by Schiano and Tversky (1992). This occurs when the orientation of a test line is influenced by another line, or induction line, of a different orientation (p. 14). A variant of this effect is known as the **major axes hypothesis** where orientation illusions take place early in the perceptual organization process. The hypothesis predicts that a test line within a frame should appear to be tilted away from whichever of the frame's axis of symmetry is closest to the line (Schiano & Tversky, 1992, p. 15).

Table 5: Test "B" items and intersecting angles with map elements for possible Zöllner effects.

Item	α^1	β^2	Comments
B01	−86	47	intersecting trail symbol
B02	−46	87	trending contour lines
B03	48		no intersecting contours
B04	−70		no intersecting contours
B05	−86	78	trending contour lines
B06	−80	46	trending contour lines
B07	15	0	coincident angles
B08	19	28	trending contour lines
B09	−45	49	text label intersection
B10	0	6	trending contour lines
B11	28	90	intersecting index contour
B12	−3	64	intersecting index contour
B13	62	81	trending contour lines
B14	−11	64	trending contour lines
B15	41	44	intersecting index contour
B16	0	28	trending contour lines
B18	90	66	trending contour lines
B19	66	56	intersecting contour line
B20	−54	14	trending contour lines
B21	84	54	trending contour lines
B22	7	70	intersecting trail symbol
B23	−81	58	trending contour lines
B24	−90	53	intersecting index contour
B25	64	73	intersecting index contour

[1] test angle

[2] intersecting angle

Rather than compare experience groups as in the case of the illusion class above, comparisons were made with angles near the neatline with similar or identical angle values within the interior, Table 6 on the next page. Test items A05 (46°), A09 (44°), and A21 (47°) had mean error scores of −6.89 ($SEM = 1.63$), −6.32 ($SEM = 1.77$), and −6.46 ($SEM = 1.59$) for all subjects.

Thus the mean error scores were very similar and no Rod and Frame illusion effect could be attributed to the mean error scores. Test item A06 (29°) was compared with test item A04 (32°).

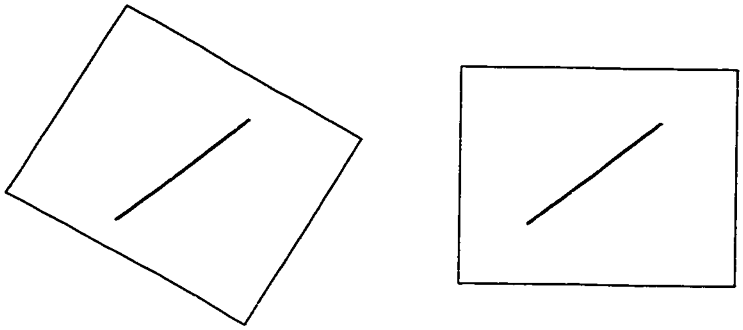


Figure 31. Rod and Frame effect. Centered lines in both figures do not appear to be parallel because of the perceptual influence of the enclosing boxes.

Mean error scores and *SEMs* were comparable at −4.36 ($SEM = 1.56$) and −5.78 ($SEM = 1.62$), respectively. Test items A17 (−1°) and A23 (0°) showed similar results with mean error at 0.96 ($SEM = 0.56$) and 0.32 ($SEM = 0.25$), respectively. Test items A24 (−90°) and A25 (90°) showed no error. All test subjects perceived the stimuli as being parallel to the frame.

However, test items B01 and B05 (−86°) showed considerable differences. Mean error scores for B01 and B05 were −3.00 ($SEM = 1.55$) and 0.82 ($SEM = 0.81$) for all subjects. This may

Table 6: Test items and angles values for possible anchoring effects for the Rod and Frame illusion. The table reflects items within close proximity to the neatline.

Item	α^1	$\asymp^2$	β^3	γ^4
A01	67	0.17	23	90
A02	73	0.18	17	90
A05	46	0.30	46	0
A06	29	0.13	29	0
A17	−1	0.12	9	0
A24	−90	0.08	0	90
A25	90	0.10	0	90
B01	−86	0.12	4	90

[1] item angle (degrees)

[2] proximity to frame (in.)

[3] anchor effect (degrees)

[4] frame orientation (degrees)

have been complicated by both items being in Test "B" which had background contours. Yet B01 and B05 angle intersections were calculated to 47° and 78°, respectively. This should have indicated that the intersecting angle for B05 had less of an influence on that angle than B01 as the Zöllner illusion suggested. Clearly something more was creating these discrepancies.

The inclusion of a contoured base map may have affected the participants' scores where they were not able to accurately judge angles because of possible visual illusion effects. Descriptive statistics revealed that there were differences between experience groups' mean error scores for moderate angles and little differences for cardinal axes. Other statistical results showed slight variations in mean error scores with comparable "A" and "B" angles.

A robust statistical analysis was needed to determine if there were significant differences between the two experience groups, stimuli orientations, and the two map types; most notably if the visual illusion effects were strong enough to influence angular judgment. The three main variables identified — experience, orientation, and map format — could not be treated as distinct and independent variables from each other. A statistical test was needed to analyze these variables en masse.

Analysis of variance

An analysis of variance model was designed to determine if there were statistically significant differences between experience groups, map formats, and angle judgments. Experience (identified as variable A) was determined to be random, given test subjects are assumed to be randomly sampled from a large population (Howell, 1987, p. 382). The other variables were identified as fixed, that is, variable levels were arbitrarily assigned by the investigator and did not vary in the

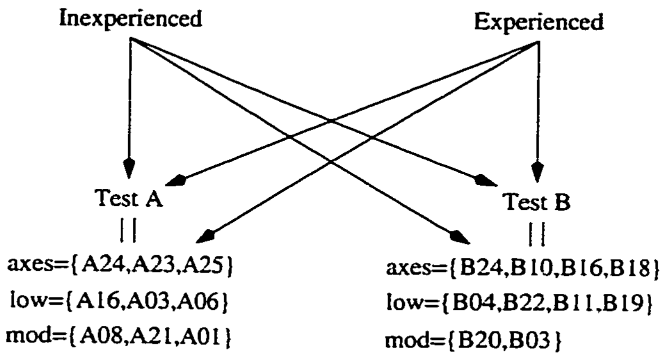


Figure 32. Analysis of variance factors and interactions.

experiment. These variables were map formats (*B*) and angle judgments (*C*).

The number of levels for each variable then were assigned. The experience variable *A* had two levels, inexperienced and experienced. Variable *B* corresponded to the two test formats. Variable *C* referred to orientation. Variable *C* had three levels: the first level was for ±90° and 0°, the second level was for angles within 30° of an axis, and the third level was for angles ±15° of ±45° (*Figure 32* above). Included with these three main variables were other variables defined as interactions as seen in Table 7.

The first interaction variable was whether experience level would influence test subjects' ability to deal with the two map formats, *A* interacting with *B* resulting in *AB*. The second interaction variable was whether experience level would influence test subjects' ability to

Table 7: Mixed effects ANOVA elements.

Main Effects	Interaction		Model
experience (*A*)	experience	format	
orientation (*C*)	experience	orientation	experience × orientation × format
format (*B*)	format	orientation	

Table 8: Angle pairings used for mixed effects ANOVA. Test hypothesis category is the assumption that experience groups were equal in judgment abilities.

Item Pair	Angle Pair	Class	Test Hypothesis
A24:B24	−90:−90	card[a]	no difference
A16:B04	−69:−70	low[b]	difference (Zöllner)
A08:B20	−55:−54	mod[c]	difference (Zöllner)
A23:B10	0:0	card[a]	no difference
A23:B16	0:0	card[a]	no difference
A03:B22	7:7	low[b]	no difference
A06:B11	29:28	low[b]	no difference
A21:B03	47:48	mod[c]	no difference
A01:B19	67:66	low[b]	no difference
A25:B18	90:90	card[a]	no difference

[a] cardinal direction: 0°, ±90°
[b] ±30° near a cardinal angle
[c] ±15° of ±45°

accurately judge angles, A interacting with C resulting in AC. The next interaction variable was whether map format would influence subjects' ability to accurately judge angles, B interacting with C resulting in BC. The last interaction variable was whether experience, map format, and angle type were influencing one another, A interacting with B interacting with C resulting in ABC.

Mixed ANOVA requires that all variables are matched pair-wise. However, given that both angle groups were randomly generated for each test type, not all angles were used in the analysis. Angles between both tests that were within one degree of one another were included in the analysis. The ability to detect whether the Jastrow-Lipps, Zöllner, or Rod and Frame illusions for all cases was limited given selecting angles by a randomization process. As a result, all angle pairs would detect for Jastrow-Lipps illusion. Only two angle pairings would have a possible Zöllner effect and none for the Rod and Frame (Table 8).

In order for an analysis to be performed a statistical linear model was built identifying the

Table 9: Mixed effects analysis of variance factors and terms.

Source	df	MS	E(MS)
Main effects of A (random)	$I-1$	MS_A	$\sigma_e^2 + nb\sigma_\alpha^2 + nc\sigma_\alpha^2$
Main effects of B (fixed)	$J-1$	MS_B	$\sigma_e^2 + n\sigma_{\alpha\beta}^2 + na\sigma_\beta^2$
Main effects of C (fixed)	$K-1$	MS_C	$\sigma_e^2 + n\sigma_{\alpha\gamma}^2 + nc\sigma_\gamma^2$
$A \times B$ interaction	$(K-1)(I-1)$	MS_{AB}	$\sigma_e^2 + n\sigma_{\alpha\beta}^2$
$A \times C$ interaction	$(K-1)(J-1)$	MS_{AC}	$\sigma_e^2 + n\sigma_{\alpha\gamma}^2$
$B \times C$ interaction	$(I-1)(J-1)$	MS_{BC}	$\sigma_e^2 + n\sigma_{\beta\gamma}^2$
$A \times B \times C$ interaction	$(K-1)(J-1)(I-1)$	MS_{EAF}	$\sigma_e^2 + n\sigma_{\alpha\beta\gamma}^2$
Error	$IJK(Q-1)$	MS_e	σ_e^2

variables, constants, and interactions. The ANOVA was to determine if there were interactions between experience (A), test formats (B), and angle orientation (C). That is, interactions between all variables. This resulted in the following model equation for the true cell means.

$$y_{ijkq} = \mu + a_i^A + \alpha_j^B + \alpha_k^C + a_{ij}^{AB} + a_{ik}^{AC} + \alpha_{jk}^{BC} + a_{ijk}^{ABC} + e_{ijkq}^{ABC}$$

Where μ and the αs are constants, the as are variables, and e_{ijkq}^{ABC} is assumed to be zero and independent of the cell means. Constants correspond to fixed effects and variables correspond to random effects. Interactions between fixed and random effects result in variables (Scheffé, 1959). Table 9 lists mixed effects ANOVA variables, degrees of freedom (df), mean squares (MS), and estimated mean squares (E(MS)) for the model.

The mixed effects hypotheses were

$$H_0 : \mu_{AB} = \mu_{AC} = \mu_{BC} = \mu_{ABC}$$

$$H_1 : \mu_{AB} \neq \mu_{AC} \neq \mu_{BC} \neq \mu_{ABC}$$

Table 10: Mixed effects ANOVA results.

Source	df	SS	MS	F
experience (A)	1	677.820	678.400	10.860
format (B)	1	6.147	6.362	0.162
orientation (C)	2	2816.300	1411.000	4.902
experience×format (AB)	1	38.602	38.600	0.725
experience×orientation (AC)	2	561.140	280.600	117.600**
format×orientation (BC)	2	14.366	7.183	3.066
experience×format×orientation (ABC)	2	4.686	2.343	0.041
Error	520	29592.000	56.910	
Total	531			

** $p < .01$.

The null hypothesis for the mixed model assumed there were no interactions between experience, test format, and orientation; whereas, the research hypothesis assumed there were.

ANOVA results

Interactions between format and orientation (BC), experience and format (AB), and experience, format, and orientation (ABC) were not significant, $F(2,531) = 3.066$, $MSE = 0.089$, $F(1,531) = 0.725$, $MSE = 0.412$,and $F(2,531) = 0.041$, $MSE = 0.010$, respectively. However, a significant interaction was seen between experience and angle orientation (AC), $F(2,531) = 117.600$, $MSE = 3.313$, $p < .01$. The likelihood of committing a Type I error at $\alpha = .05$ was 0.007.

The ANOVA results showed no significant interaction between map types and experience (AB) or map types and orientation (BC) yet significant interaction between experience and orientation (AC), Table 10. This experiment's results showed that both experience groups showed no difference in angular judgments when confronted with a blank background or a contoured background. Another result showed no noteworthy influence of a contoured map background on any of the angles. The results could help explain the stronger influence of the Jastrow-Lipps illusion compared to any illusion influenced by the Zöllner and Rod and Frame illusions. However other variables, such as gender, were graphed against the same angles and showed the same sinusoidal curve. This may indicate that experience, gender, and perhaps others, are proxy variables for the actual mechanisms determining visual orientation.

The information thus far is far from complete. More experimentation should be conducted to understand the implications of visual illusions on map use. Given that the current experiment relied on randomizing many angle orientations and angle placements, a new experiment should be designed to investigate angle intersections with systematic, or deliberate, angle interactions. Also, other experiments should be conducted to determine if orientation symbols or vectors on maps, such as wind or current information, can be judged accurately.

Implications for cartographic design

Three options come to mind when dealing with orientation symbol design. The first has traditionally been for the cartographer to modify the symbol. The second option is to modify the end user. The third option is to do nothing.

Specialized symbols such as oriented points used for directional data are entrenched in few areas such as geology and meteorology. It is very difficult to do away with a symbol these scientists are familiar with even though they may not be judging them with a higher level of precision than 5° for oblique angles. The prudent designer should be cautious in introducing this symbol variable for other fields. Oriented point symbols used for directional data can be useful with the knowledge that highly generalized levels of accuracy such as use with nominal information is best for mapping aimed at the general map reader.

Another option for the cartographer is to generalize to the point where, acknowledging that most people can judge horizontal and vertical angles, other angles are generalized. However, the cartographer must caution against this approach because this information applies to angular judgment or estimation only, not angular measurement. Many specialized fields rely on measuring data and it may be that the original level of field measurement precision would be less than the leeway allowed by the cartographer. This would go against the cartographers credo of not introducing error in the map production process.

A new field that may allow for the inclusion of directional point data at the possible sub-degree level of precision is GIS. The orientation value could be built in the attribute information for each point feature. Rather than the user judging the angular value, all he or she needs to do is query the feature and the attribute information is readily accessible. Yet once again, this may be the issue that although we have the technical capabilities to create these symbols, we still are forgetting the main factor when it comes to map production — the map user. We still have not addressed the fundamental visual perception limitations of humans, that is, we are not very good at accurately judging angles other than horizontal and vertical. If map users are poor at oblique angles, then can they be taught?

If people learn how to read and write (literacy) and learn to work with numbers (numeracy), then they should also be able to learn to work with graphic objects (graphicacy). Balchin (1976) used this term to refer to the intellectual skills required to read graphs and maps. The results of this experiment gives credence to this concept. There was a statistically significant difference between the experienced and inexperienced groups when judging angle regardless of map type. Map reading experience was correlated to orientation judgment accuracy. However, none of the test subjects judged angles with complete accuracy. Psychologists have addressed this issue in numerous studies.

Many psychophysical investigations were conducted to determine if people could learn to judge angles more accurately with practice. Some studies also tried to determine learning strategies for these tasks. The results were somewhat mixed but hopeful. However, when accounting for all learning strategies (Schoups, Vogels, & Orban, 1995; Karni & Sagi, 1993, 1991; Schiano & Jordan, 1990; Jolicoeur & Milliken, 1989; Tversky & Schiano, 1989; Vogels & Orban, 1985; Aslin, 1981; McGee, 1979; Gibson, 1953), cultural biases (Serpell, 1971), and linguistic pitfalls (Matin, Drivas, & Valle, 1982), the researchers found that people still could not judge most angles with no error — there still was something left — the cellular activity in the primary visual cortex. What was determined to be left over and could not be overcome were the orientation cells' method of detecting angles.

Which leads to the third option — do not change a thing. That is we should accept the fact that this is a part of how we function. As Coren and Girgus (1978) stated, visual illusions are not aberrations of the perceptual system but windows of opportunity to understand normal cortical activity. With our sophisticated modern technology for map production we have encountered the very limits of human visual perception.

Conclusion

This paper addressed the ability of map users to accurately judge angled point symbols on maps and whether users could accurately assess these abilities. Whether there was a correlation between overall confidence and average error has not been established with this experiment. One reason was the restricted samples used to calculate the correlation coefficient. Another reason could have been that not everyone was aware of their perceptual judgment skills. Some were overconfident where others were underconfident in their abilities as evidenced by the scatterplots. Further investigation is needed in this area to discover if there is a correlation between overall confidence and average angle error.

A statistically significant interaction was found between experience level and orientation type when judging angles. That is, a greater difference in error and variance was displayed for angles near $\pm 45^\circ$ than angles close to the cardinal axes where there were no difference between experienced and inexperienced users for $\pm 90^\circ$ and 0°. This was shown graphically by the mean error and variance line graphs for Test "A" and "B". The experimental results also give merit to the influence of cortical cells influencing the orientation variable. Orientation does not show visual constancy.

As cartographers, we are inclined to fix a graphic problem when it arises. We must ask ourselves "do symbols need to be perceptually or representationally accurate." If we take the route that symbols need to be perceptually accurate, in terms of the orientation variable, then angular representation cannot be faithful for the full 360°. Angles at and near the meridia can be judged with a high degree of accuracy and precision; but angles near $\pm 45n^\circ$ show to be as much as 10° underestimated — the precise figure is unknown. To create symbols that are perceptually "accurate" and not measure up to the protractor does not do justice to the spatial data.

The only alternative is representationally accurate oriented symbols and many fields will continue to use these. However, there must be a caveat attached. Humans cannot judge oblique angles with a high degree of accuracy. We can directly measure, we can attach labels, but we should not assume all map users can estimate oblique angles with any level of accuracy past the nearest 5°.

Accuracy may get better over time due to experience and learning. However, there are limitations to visual perception. Researchers have eliminated many factors and yet subjects still are not able to accurately judge oblique angles. The residuals were determined to be a function of neuronal activity — the area of the primary visual cortex responsible for orientation detection.

References

Andrews, D. P. (1967). Perception of contour orientation in the central fovea. Part I—Short lines. *Vision Research, 7*, 975–997.

Andrews, D. P., Butcher, A. K., & Buckley, B. R. (1973). Acuities for spatial arrangement in line figures: Human and ideal observers compared. *Vision Research, 13*, 599–620.

Appelle, S. (1972). Perception and discrimination as a function of stimulus orientation: The oblique effect in man and animals. *Psychological Bulletin, 78*, 266–278.

Aslin, R. N. (1981). Experiential influences and sensitive period in perceptual development: A unique model. In R. N. Aslin, J. R. Alberts, & M. Petersen (Eds.), *The visual system, development of perception* (Vol. 2, pp. 45–93). New York: Academic Press.

Balchin, W. G. V. (1976). Graphicacy. *The American Cartographer, 3*, 33–38.

Beard, K. (1989). Use error: The neglected error component. In *Auto-Carto 9* (pp. 808–817). Falls Church, VA, Baltimore, MD: ASPRS, ACSM.

Bertin, J. (1981/77). *Graphics and graphic information processing.* Berlin, New York: Walter de Gruyter. (Wm. J. Berg and P. Scott, trans. Original work published 1977)

Bertin, J. (1983/67). *Semiology of graphics.* Madison, WI: University of Wisconsin Press. (Wm. J. Berg, trans. Original work published 1967)

Blakemore, C. (1990). Understanding images in the brain. In H. Barlow, C. Blakemore, & M. Weston-Smith (Eds.), *Images and understanding* (pp. 257–283). Cambridge: Cambridge University Press.

Bouma, H., & Andriessen, J. J. (1970). Induced changes in the perceived orientation of line segments. *Vision Research, 10*, 333–349.

Bradley, A., Skottun, B. C., Ohzawa, I., Sclar, G., & Freeman, R. D. (1987). Visual orientation and spatial frequency discrimination: A comparison of single neurons and behavior. *Journal of Physiology, 57*, 755–772.

Byrne, R. W. (1982). Geographical knowledge and orientation. In A. W. Ellis (Ed.), *Pathology in cognitive functions* (pp. 239–264). London, New York: Academic Press.

Campbell, F. W., & Kulikowski, J. J. (1966). Orientation selectivity of the human visual system. *Journal of Physiology, 187*, 437–445.

Carr, D. B., Olsen, A. R., & White, D. (1992). Hexagon mosaic maps for display of univariate and bivariate geographical data. *Cartography and Geographic Information Systems, 19*, 228–236, 271.

Castner, H. (1983). Research questions and cartographic design. In D. R. F. Taylor (Ed.), *Communication and design in contemporary cartography* (Vol. 2, pp. 87–113). Chichester, England: John Wiley and Sons.

Coren, S., & Girgus, J. S. (1978). *Seeing is deceiving: The psychology of visual illusions.* Hillsdale, NJ: Lawrence Erlbaum.

Dent, B. T. (1999). *Cartography thematic map design* (5th ed.). WCB/McGraw-Hill.

Dick, M., & Hochstein, S. (1989). Visual orientation estimation. *Perception and Psychophysics, 46,* 227–234.

Downs, R. M. (1981). Maps and mapping as metaphors for spatial representation. In L. S. Liben, A. H. Patterson, & N. Newcombe (Eds.), *Spatial representation and behavior across the life span: Theory and application* (pp. 143–166). New York: Academic Press.

Eastman, J. R., & Castner, H. W. (1983). The meaning of experience in task-specific map reading. In D. R. F. Taylor (Ed.), *Communication and design in contemporary cartography* (Vol. 2, pp. 115–147). Chichester, England: John Wiley and Sons.

Ekman, G., Lindman, R., & William-Olsson, W. (1961). A psychophysical study of cartographic symbols. *Perceptual and Motor Skills, 13,* 355–368.

Essock, E. A. (1980). The oblique effect of stimulus identification considered with respect to two classes of oblique effects. *Perception, 9,* 37–46.

Freeman, R. D., Mitchell, D. E., & Millodot, M. (1972). A neural effect of partial visual deprivation in humans. *Science, 175,* 1384–1386.

Ganz, L. (1978). Innate and environmental factors in the development of visual form perception. In R. Held, H. W. Leibowitz, & H.-L. Teuber (Eds.), *Perception: Handbook of sensory physiology* (Vol. 8, pp. 437–488). Berlin, New York: Springer-Verlag.

Gibson, E. J. (1953). Improvement in perceptual judgments as a function of controlled practice or training. *Psychological Bulletin, 50,* 401–431.

Gibson, J. J., & Radner, M. (1937). Adaptation, after-effect and contrast in the perception of tilted lines. I Quantitative studies. *Journal of Experimental Psychology, 20,* 453–467.

Gilbert, C. D., & Wiesel, T. N. (1990). The influence of contextual stimuli on the orientation selectivity of the cat. *Vision Research, 30,* 1689–1701.

Head, C. G. (1991). Mapping as language or semiotic system: Review and comment. In D. M. Mark & A. U. Frank (Eds.), *Cognitive and linguistic aspects of geographic space* (pp. 237–262). Dordrecht, Netherlands: Kluwer Academic.

Howard, I. P. (1982). *Human visual orientation.* Chichester, England, New York: John Wiley and Sons.

Howell, D. C. (1987). *Statistical methods for psychology* (2nd ed.). Boston, MA: Duxbury Press.

Hubel, D. H. (1982). Exploration of the primary visual cortex. *Nature, 299,* 515–524.

Hubel, D. H., & Wiesel, T. N. (1962). Receptive fields, binocular interaction and functional architecture in the cat's visual cortex. *Journal of Physiology, 160,* 106–154.

Jastrow, J. (1893). On the judgment of angles and positions of lines. *American Journal of Psychology, 5,* 214–248.

Jolicoeur, P., & Milliken, B. (1989). Identification of disoriented objects: Effects of context of prior presentation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 200–210.

Karni, A., & Sagi, D. (1991). Where practice makes perfect in texture discrimination: Evidence for primary visual cortex plasticity. *National Academy of Sciences, U.S.A., 88,* 4966–4970.

Karni, A., & Sagi, D. (1993). The time course of learning a visual skill. *Nature, 365*, 250–252.

Keates, J. S. (1982). *Understanding maps.* New York: Halsted Press.

Koláčný, A. (1977). Cartographic information: A fundamental concept and term in modern cartography [Monograph]. In L. Guelke (Ed.), *The nature of cartographic communication* (Vol. 19, pp. 39–54). Toronto: University of Toronto Press.

Kruger, J., & Dunning, D. (1999). Unskilled and unaware of it: How difficulties in recognizing one's own incompetence lead to inflated self-assessments. *Journal of Personality and Social Psychology, 77*, 1121–1134.

Leibowitz, H. W., Myers, N. A., & Grant, D. A. (1955). Radial localization of a single stimulus as a function of luminance and duration of exposure. *Journal of the Optical Society of America, 45*, 76–78.

Leventhal, A. G., & Hirsch, H. V. B. (1975). Cortical effects of early selective exposure to diagonal lines. *Science, 190*, 902–904.

Levine, M., Jankovic, I. N., & Palij, M. (1982). Principles of spatial problem solving. *Journal of Experimental Psychology: General, 111*, 157–175.

MacEachren, A. M. (1995). *How maps work: Representation, visualization and design.* New York: Guilford Press.

Mansfield, R. J. W. (1974). Neural basis of orientation perception in primate vision. *Science, 186*, 1133–1135.

Matin, E., Drivas, A., & Valle, V. (1982). Conditioned tilt naming: A modified absolute judgment method is used to measure the oblique effect. *Perception and Psychophysics, 31*, 421–428.

McGee, M. G. (1979). *Human spatial abilities: Sources of sex differences.* New York: Praeger Publishers.

Monmonier, M., & Schnell, G. A. (1988). *Map appreciation.* Englewood Cliffs, NJ: Prentice-Hall.

Movshon, J. A., & Blakemore, C. (1973). Orientation specificity and spatial selectivity. *Perception, 2*, 53–60.

Orban, G. A., Vandenbussche, E., & Vogels, R. (1984). Human orientation discrimination tested with long stimuli. *Vision Research, 24*, 121–128.

O'Toole, B., & Wenderoth, P. (1977). The tilt illusion: Repulsion and attraction effects in the oblique meridian. *Vision Research, 17*, 367–374.

Perkins, D. N. (1983). Why the human perceiver is a bad machine. In J. Beck, B. Hope, & A. Rosenfeld (Eds.), *Human and machine vision: Proceedings of the Conference on Human and Machine Vision* (pp. 341–364). New York: Academic Press.

Robinson, A. H. (1952). *The look of maps.* Madison, WI: Wisconsin University Press.

Robinson, A. H. (1977). Research in cartographic design. *The American Cartographer, 4*, 163–169.

Robinson, A. H., & Petchenik, B. B. (1976). *The nature of maps: Essays toward understanding maps and mapping.* Chicago: University of Chicago Press.

Robinson, A. H., Sale, R. D., Morrison, J. L., & Muehrcke, P. C. (1984). *Elements of cartography* (5th ed.). New York: John Wiley and Sons.

Rochlin, A. M. (1955). The effect of tilt on the visual perception of parallelism. *American Journal of Psychology, 68*, 223–236.

Rogers, S., Volkman, J., Reese, T. W., & Kaufman, E. L. (1947). *Accuracy and variability of direct estimates of bearing from large display screens* (Tech. Rep.). South Hadley, MA: Mount Holyoke College. Psychophysical Research Unit. (Report 166–1–MHC)

Scheffé, H. (1959). *The analysis of variance.* New York: John Wiley and Sons.

Schiano, D. J., & Jordan, K. (1990). Mueller-Lyer decrement: practice or prolonged inspection? *Perception, 19*, 307–316.

Schiano, D. J., & Tversky, B. (1992). Structure and strategy in encoding simplified graphs. *Memory and Cognition, 20*, 12–20.

Schoups, A. A., Vogels, R., & Orban, G. A. (1995). Human perception learning in identifying the oblique orientation: Retinotopy, orientation specificity and monocularity. *Journal of Physiology, 483*, 797–810.

Scobey, R. P. (1982). Human visual orientation discrimination. *Journal of Neurophysiology, 48*, 18–26.

Sekuler, R., & Blake, R. (1994). *Perception* (3rd ed.). New York: McGraw-Hill.

Serpell, R. (1971). Discrimination of orientation by Zambian children. *Journal of Comparative and Physiological Psychology, 75*, 312–316.

Smith, S. L. (1962). Angular estimation. *Journal of Applied Psychology, 46*, 240–246.

Stevens, A., & Coupe, P. (1978). Distortions in judged spatial relations. *Cognitive Psychology, 422*, 422–437.

Taylor, M. M. (1963). Visual discrimination and orientation. *Journal of the Optical Society of America, 53*, 763–765.

Thomas, J. P., & Gille, J. (1979). Bandwidths of orientation channels in human vision. *Journal of the Optical Society of America, 69*, 652–660.

Tversky, B., & Schiano, D. J. (1989). Perceptual and conceptual factors in distortions in memory for graphs and maps. *Journal of Experimental Psychology: General, 118*, 387–398.

Vogels, R., & Orban, G. A. (1985). The effect of practice on the oblique effect in line orientation judgments. *Vision Research, 25*, 1679–1687.

Vogels, R., & Orban, G. A. (1986). Decision factors affecting line orientation judgments in the method of single stimuli. *Perception and Psychophysics, 40*, 74–84.

Wallace, G. K., & Crampin, D. J. (1969). The effect of background density on the Zöllner illusion. *Vision Research, 9*, 167–177.

Westheimer, G. (1990). Simultaneous orientation contrast for lines in the human fovea. *Vision Research, 30*, 1913–1921.

Westheimer, G., Shimanura, K., & McKee, S. P. (1976). Interference with line orientation sensitivity. *Journal of the Optical Society of America, 66*, 332–338.

Wood, M. (1972). Human factors in cartographic communication. *The Cartographic Journal, 4*, 123–132.

Appendices

Appendix A — Glossary

accuracy A degree to which a measurement approximates a known value or location (p. 39).

acute angle expansion When an induction line and test line converge to form an acute angle, the lines appear to repulse each other (p. 42).

adit A horizontal mine shaft (p. 5).

aeronautical chart Any scale map used for air navigation where typical methods include charting courses by use of compasses and directional bearings (p. 12).

astigmatism A corneal error causing refraction of light waves along various angles (p. 12).

binocularity Seeing with two eyes (p. 37).

cardinal axis Corresponding to vertical or horizontal; the x or y axes in the Cartesian coordinate system (p. 40).

cartographic communication The process of transmitting geographic relationships in abstract graphical means via maps, charts, etc. (p. 4).

cartography The production of maps (p. 3).

cellular adaptation Change in state or quantity of cellular activity in response to stimuli (p. 46).

cognition The act or process of knowing (p. 4).

compilation Map preparation or revision (p. 3).

complex cells Visual cortical cells not showing on and off regions in their receptive fields (p. 39).

cultural features Map information comprising all human made non-transportation objects and geographical names (p. 12).

densitometer An instrument used for measuring amount of light transmitted or reflected (p. 4).

engineering plan Any plan or map used for constructing or describing in detail engineered works (p. 12).

EXVIS The EXploratory VIsualization System, a scientific visualization computer application (p. 5).

geographic information system A computer software system comprising of a graphical computer assisted drafting module and a database management system integrated as one unit to compile, produce, and analyze geographic data (p. 3).

grating A target consisting of alternating light and dark bars (p. 38).

hue Analogous to color in the Hue-Lightness-Saturation (HLS) color model (p. 1) .

hydrography Surface waters (springs, streams, and lakes) (p. 12).

hypsography Topographical relief (contours and spot elevations) (p. 12).

induction effect The interaction between induction and test lines (p. 46).

induction line Non-test line or lines (p. 46).

interval A measurement scale based on difference in relative amount (p. 1).

lateral inhibition Antagonistic neural interaction between adjacent regions (p. 38).

lightness Part of the HLS color model and analogous to value in the Hue-Value-Saturation (HVS) color model (p. 1).

locator map A large scale map used for helping persons locate where they are ("You Are Here" maps) (p. 12).

major axes hypothesis A variant of the Rod and Frame effect in which a test line appears to be tilted away from the nearest frame (p. 47).

map error Any errors introduced in the cartographic communication from source error through process error to map use error (p. 3).

map use error Errors caused by the map user due to misinterpretation, misapplication, inexperience, and other causes (p. 4).

map user The end user who reads or interprets symbols on a map (p. 3).

navigational chart Any scale map used to navigate waters where typical methods include charting courses by the use of compasses and directional bearings (p. 12).

neatline A line separating the body of a map from the marginalia (p. 45).

neurons The nerve cells constituting nerve tissue (p. 37).

nominal A measurement scale based on difference in kind (p. 1).

oblique effect The tendency for lines oriented vertically or horizontally to be more visible than oblique lines (p. 41).

ordinal A measurement scale based on difference in order (p. 1).

planimeter An instrument used for measuring area (p. 4).

precision The degree to which a measurement can be repeated (p. 39).

prepress Map production before printing (p. 3).

primary visual cortex The portion of the brain located in the occipital lobe associated with visual processing (p. 36).

process error Errors propagated by the map maker and graphic technologies in the process of producing a map (p. 5).

psychophysics The branch of science concerned with quantifying relationships between behavior and physical stimuli (p. 40).

raster image An image produced by small picture elements (pixels) in a pattern of scanned lines (p. 12).

ratio A measurement scale based on difference in absolute amount (p. 1).

ray-glyph A graphic mark with vectors emanating from center (p. 5).

response limitation Self-imposed level of precision (p. 29).

scientific visualization Computer software system used to visually simulate or model complex scientific data (p. 3).

simple cells Visual cortical cells showing on and off regions in their receptive fields (p. 39).

source error Errors caused by the field surveyor or compiler due to omission or commission and other causes (p. 4).

spectrometer An instrument used for measuring wavelengths of light (p. 4).

striate cortex The primary visual cortex (p. 37).

thematic map Any scale map designed for a special purpose not associated with navigation or general purpose (p. 12).

tilt contrast The apparent orientation of a line is affected by another line in a different orientation (p. 42).

topographic map General purpose map showing surface relief by the use of lines of equal elevation (p. 11).

transportation Map information comprising all classes of surface roads (p. 12).

tuning curve Nearly Gaussian curve showing excitation frequency as a function of angular response where the mode corresponds to the cell's selectivity to an angle (p. 38).

visual angle The visual angle of an image on the retina can be measured by the angle subtended by an object outside the eye (p. 11).

visual perception The acquisition and processing information in order to see (p. 11).

visual perception system The eye-brain mechanisms responsible for perceiving, recognizing, and understanding visual phenomena (p. 35).

visual variable A basic component of a graphic symbol; Jacques Bertin identified seven visual variables: location (position), size, shape, color (or hue), value (or lightness), texture (grain), and orientation (p. 1).

Table 11: Subject cumulative rank score (Score), Average Error Score (*AES*), ranks and differences for Test "A".

Subj.	Grp	Score	*AES*	Ranks: *Score*	Ranks: *AES*	*D*	D^2
12	1	42	7.16	3	15	−12	144
13	2	25	3.72	13	2	10	100
15	2	46	6.00	1	12	−11	121
16	2	28	4.72	9	5	4.5	20.25
19	1	23	8.00	14	16	−1	1
27	1	22	8.76	17	20	−3	9
29	2	23	5.88	15	11	4	16
32	2	12	5.44	21	8	13	169
36	1	30	8.68	6	19	−13	169
39	1	29	8.12	8	17	−9.5	90.25
42	1	33	6.20	5	13	−8	64
44	1	14	4.52	20	4	15.5	240.25
49	1	14	8.56	19	18	1.5	2.25
56	2	19	4.04	18	3	15	225
65	2	37	5.36	4	7	−3	9
66	1	25	6.84	12	14	−2	4
67	2	25	4.80	11	6	6	36
69	1	28	14.92	10	21	−11.5	132.25
71	1	29	5.68	7	10	−2.5	6.25
74	1	43	5.60	2	9	−7	49
76	2	23	3.24	16	1	14	196
						0	1803.5

Note: $N = 21$

Table 12: Test "A" descriptive statistics for all test subjects sorted by angle value.

Item	Angle	*M*	SD^2	*SD*	*SEM*
A24	−90	0.00	0.00	0.00	0.00
A15	−75	−0.89	94.54	9.72	1.84
A11	−73	−1.93	82.14	9.06	1.71
A16	−69	−4.18	100.89	10.04	1.90
A08	−55	−5.36	107.27	10.36	1.96
A12	−50	−0.36	86.90	9.32	1.76
A10	−48	−5.32	52.74	7.26	1.37
A22	−35	−1.25	73.38	8.57	1.62
A19	−30	−7.32	56.45	7.51	1.42
A18	−13	−0.96	28.11	5.30	1.00
A07	−9	1.39	18.02	4.24	0.80
A17	−1	0.96	8.92	2.99	0.56
A23	0	0.32	1.78	1.33	0.25
A03	7	1.39	11.21	3.35	0.63
A14	10	0.21	23.14	4.81	0.91
A13	23	−4.78	44.84	6.70	1.26
A06	29	−4.36	68.38	8.27	1.56
A04	32	−5.78	73.88	8.59	1.62
A09	44	−6.32	87.93	9.38	1.77
A05	46	−6.89	74.17	8.61	1.63
A21	47	−6.46	71.00	8.42	1.59
A01	67	−7.00	150.00	12.25	2.31
A02	73	−3.89	179.73	13.40	2.53
A20	80	−2.61	81.06	9.00	1.70
A25	90	0.00	0.00	0.00	0.00

Note: $N = 28$

Table 13: Test "A" descriptive statistics for inexperienced subjects sorted by angle value.

Item	Angle	*M*	SD^2	*SD*	*SEM*
A24	−90	0.00	0.00	0.00	0.00
A15	−75	−2.14	141.21	11.88	3.17
A11	−73	−3.71	114.83	10.71	2.86
A16	−69	−6.14	141.21	11.88	3.17
A08	−55	−7.86	145.05	12.04	3.22
A12	−50	−0.71	153.30	12.38	3.31
A10	−48	−6.93	81.45	9.02	2.41
A22	−35	−4.28	41.76	6.46	1.73
A19	−30	−8.57	70.88	8.42	2.25
A18	−13	−0.50	29.81	5.46	1.46
A07	−9	0.64	13.32	3.65	0.97
A17	−1	0.28	8.53	2.92	0.78
A23	0	0.64	3.48	1.86	0.50
A03	7	1.93	8.38	2.89	0.77
A14	10	0.00	23.08	4.80	1.28
A13	23	−5.86	33.52	5.79	1.55
A06	29	−7.57	86.26	9.29	2.48
A04	32	−7.07	50.84	7.13	1.90
A09	44	−10.07	116.07	10.77	2.88
A05	46	−10.28	72.53	8.51	2.27
A21	47	−9.14	125.82	11.22	3.00
A01	67	−10.21	221.56	14.88	3.98
A02	73	−8.00	300.00	17.32	4.63
A20	80	−4.64	105.63	10.28	2.75
A25	90	0.00	0.00	0.00	0.00

Note: $N = 14$

Table 14: Test "A" descriptive statistics for experienced subjects sorted by angle value.

Item	Angle	*M*	*SD*^{2}	*SD*	*SEM*
A24	−90	0.00	0.00	0.00	0.00
A15	−75	0.36	51.78	7.19	1.92
A11	−73	−0.14	48.90	6.99	1.87
A16	−69	−2.21	60.03	7.75	2.07
A08	−55	−2.86	64.28	8.02	2.14
A12	−50	0.00	26.92	5.19	1.39
A10	−48	−3.71	22.53	4.74	1.27
A22	−35	1.78	90.80	9.53	2.55
A19	−30	−6.07	42.99	6.56	1.75
A18	−13	−1.43	28.11	5.30	1.42
A07	−9	2.14	22.90	4.78	1.28
A17	−1	1.64	9.02	3.00	0.80
A23	0	0.00	0.00	0.00	0.00
A03	7	0.86	14.28	3.78	1.01
A14	10	0.43	24.88	4.99	1.33
A13	23	−3.71	57.14	7.56	2.02
A06	29	−1.14	33.52	5.79	1.55
A04	32	−4.50	99.04	9.95	2.66
A09	44	−2.57	36.26	6.02	1.61
A05	46	−3.50	56.73	7.53	2.01
A21	47	−3.78	6.18	2.48	0.66
A01	67	−3.78	67.72	8.23	2.20
A02	73	0.21	36.95	6.08	1.62
A20	80	−0.57	53.80	7.33	1.96
A25	90	0.00	0.00	0.00	0.00

Note: $N = 14$

Table 15: Subject cumulative rank score (Score), Average Error Score (*AES*), ranks and differences for Test "B".

				Ranks			
Subj.	Grp	Score	*AES*	*Score*	*AES*	*D*	D^2
12	1	40	5.13	15	3	12	144
13	2	28	3.88	5.5	8.5	−3	9
15	2	44	5.00	13.5	1	12.5	156.25
16	2	4	4.38	9	23	−14	196
27	1	24	6.25	19	13	6	36
29	2	24	4.88	12	13	−1	1
32	2	16	5.00	13.5	19	−5.5	30.25
33	2	29	3.88	5.5	6.5	−1	1
36	1	25	8.83	23	10.5	12.5	156.25
39	1	30	6.92	21	5	16	256
42	1	28	4.21	8	8.5	−0.5	0.25
43	1	0	8.67	22	24	−2	4
44	1	7	6.04	18	21	−3	9
49	1	9	5.42	17	20	−3	9
52	2	5	3.75	4	22	−18	324
56	2	20	4.17	7	16.5	−9.5	90.25
65	2	36	3.21	2	4	−2	4
66	1	24	5.33	16	13	3	9
67	2	20	4.63	10	16.5	−6.5	42.25
69	1	23	9.83	24	15	9	81
70	1	18	3.46	3	18	−15	225
71	1	29	4.79	11	6.5	4.5	20.25
74	1	42	6.42	20	2	18	324
77	2	25	2.17	1	10.5	−9.5	90.25
						0	2218

Note: $N = 24$

Table 16: Test "B" descriptive statistics for all test subjects sorted by angle value.

Item	Angle	*M*	SD^2	*SD*	*SEM*
B24	−90	0.00	0.00	0.00	0.00
B01	−86	−3.00	67.55	8.22	1.55
B05	−86	0.82	18.45	4.29	0.81
B23	−81	−1.07	28.51	5.34	1.01
B06	−80	1.89	24.17	4.92	0.93
B04	−70	−6.07	156.22	12.50	2.36
B20	−54	−3.89	110.69	10.52	1.99
B02	−46	−4.68	49.26	7.02	1.32
B09	−45	−9.64	98.01	9.90	1.87
B14	−11	−0.57	13.96	3.73	0.70
B12	−3	0.68	8.60	2.93	0.55
B10	0	0.57	4.33	2.08	0.39
B16	0	−0.70	4.21	2.05	0.39
B22	7	−0.53	24.18	4.92	0.93
B07	15	−2.75	16.19	4.02	0.76
B08	19	−2.28	39.54	6.29	1.19
B11	28	−3.00	66.67	8.16	1.54
B15	41	−9.93	83.99	9.16	1.73
B03	48	−8.89	66.76	8.17	1.54
B13	62	−6.57	107.36	10.36	1.96
B25	64	−5.68	110.00	10.49	1.98
B19	66	−3.32	128.67	11.34	2.14
B21	84	−1.14	25.76	5.07	0.96
B18	90	−0.50	1.81	1.35	0.25

Note: $N = 28$

Table 17: Test "B" descriptive statistics for inexperienced subjects sorted by angle value.

Item	Angle	*M*	SD^2	*SD*	*SEM*
B24	−90	0.00	0.00	0.00	0.00
B01	−86	−4.07	115.15	10.73	2.87
B05	−86	0.93	17.45	4.18	1.12
B23	−81	−1.36	44.09	6.64	1.77
B06	−80	2.21	18.64	4.32	1.15
B04	−70	−4.64	159.48	12.63	3.37
B20	−54	−4.00	92.31	9.61	2.57
B02	−46	−7.78	79.26	8.90	2.38
B09	−45	−14.28	95.60	9.78	2.61
B14	−11	−1.86	20.28	4.50	1.20
B12	−3	−0.64	10.09	3.18	0.85
B10	0	0.93	7.45	2.73	0.73
B16	0	0.00	3.84	1.96	0.52
B22	7	−1.64	40.25	6.34	1.69
B07	15	−3.21	13.87	3.72	0.99
B08	19	−3.86	41.05	6.41	1.71
B11	28	−5.86	25.82	5.08	1.36
B15	41	−16.00	42.31	6.50	1.74
B03	48	−13.00	69.23	8.32	2.22
B13	62	−10.21	113.87	10.67	2.85
B25	64	−7.71	117.76	10.85	2.90
B19	66	−6.36	209.48	14.47	3.87
B21	84	−2.07	30.53	5.52	1.48
B18	90	−0.50	1.96	1.40	0.37

Note: $N = 14$

Table 18: Test "B" descriptive statistics for experienced subjects sorted by angle value.

Item	Angle	*M*	SD^2	*SD*	*SEM*
B24	−90	0.00	0.00	0.00	0.00
B01	−86	−1.93	22.69	4.76	1.27
B05	−86	0.71	20.83	4.56	1.22
B23	−81	−0.78	14.95	3.87	1.03
B06	−80	1.57	31.34	5.60	1.49
B04	−70	−7.50	160.58	12.67	3.39
B20	−54	−3.78	137.56	11.73	3.13
B02	−46	−1.57	2.26	1.50	0.40
B09	−45	−5.00	61.54	7.84	2.10
B14	−11	0.71	5.14	2.27	0.60
B12	−3	2.00	4.00	2.00	0.53
B10	0	0.21	1.26	1.12	0.30
B16	0	−1.39	3.85	1.96	0.52
B22	7	0.57	7.34	2.71	0.72
B07	15	−2.28	19.30	4.39	1.17
B08	19	−0.71	35.76	5.98	1.60
B11	28	−0.14	95.05	9.75	2.60
B15	41	−3.86	52.75	7.26	1.94
B03	48	−4.78	33.10	5.75	1.54
B13	62	−2.93	80.53	8.97	2.40
B25	64	−3.64	101.78	10.09	2.69
B19	66	−0.28	37.91	6.16	1.64
B21	84	−0.21	21.10	4.59	1.23
B18	90	−0.50	1.81	1.34	0.36

Note: $N = 14$

Table 19: Test "A" descriptive statistics for females sorted by angle value.

Item	Angle	*M*	*SD*²	*SD*	*SEM*
A24	−90	0.00	0.00	0.00	0.00
A15	−75	−1.92	131.41	11.46	3.18
A11	−73	−3.38	126.92	11.26	3.12
A16	−69	−4.00	100.00	10.00	2.77
A08	−55	−6.15	158.97	12.61	3.50
A12	−50	−1.15	79.81	8.93	2.48
A10	−48	−5.69	81.73	9.04	2.51
A22	−35	−4.23	36.86	6.07	1.68
A19	−30	−10.38	31.09	5.57	1.55
A18	−13	−2.08	24.08	4.91	1.36
A07	−9	0.61	10.25	3.20	0.89
A17	−1	−0.61	1.92	1.39	0.38
A23	0	0.38	1.92	1.39	0.38
A03	7	2.23	11.86	3.44	0.95
A14	10	0.08	20.91	4.57	1.27
A13	23	−5.69	31.73	5.63	1.56
A06	29	−5.15	71.47	8.45	2.34
A04	32	−3.54	97.43	9.87	2.74
A09	44	−9.38	97.75	9.89	2.74
A05	46	−7.15	75.64	8.70	2.41
A21	47	−9.69	90.06	9.49	2.63
A01	67	−10.46	184.93	13.60	3.77
A02	73	−7.23	291.02	17.06	4.73
A20	80	−3.31	136.40	11.68	3.24
A25	90	0.00	0.00	0.00	0.00

Note: $N = 13$

Table 20: Test "A" descriptive statistics for males sorted by angle value.

Item	Angle	*M*	SD^2	*SD*	*SEM*
A24	−90	0.00	0.00	0.00	0.00
A15	−75	0.00	67.86	8.24	2.13
A11	−73	−0.67	45.95	6.78	1.75
A16	−69	−4.33	108.81	10.43	2.69
A08	−55	−4.67	69.52	8.34	2.15
A12	−50	0.33	98.09	9.90	2.56
A10	−48	−5.00	31.43	5.60	1.45
A22	−35	1.33	94.52	9.72	2.51
A19	−30	−4.67	65.95	8.12	2.10
A18	−13	0.00	31.43	5.60	1.45
A07	−9	2.07	24.92	4.99	1.29
A17	−1	2.30	11.24	3.35	0.86
A23	0	0.27	1.78	1.33	0.34
A03	7	0.67	10.23	3.20	0.82
A14	10	0.33	26.67	5.16	1.33
A13	23	−4.00	57.86	7.60	1.96
A06	29	−3.67	69.52	8.34	2.15
A04	32	−7.73	50.21	7.08	1.83
A09	44	−3.67	69.52	8.34	2.15
A05	46	−6.67	78.09	8.84	2.28
A21	47	−3.67	41.67	6.45	1.67
A01	67	−4.00	110.00	10.49	2.71
A02	73	−1.00	77.86	8.82	2.28
A20	80	−2.00	38.57	6.21	1.60
A25	90	0.00	0.00	0.00	0.00

Note: $N = 15$

Table 21: Test "B" descriptive statistics for females sorted by angle value.

Item	Angle	*M*	SD^2	*SD*	*SEM*
B24	−90	0.00	0.00	0.00	0.00
B01	−86	−0.69	16.40	4.05	1.12
B05	−86	2.54	17.93	4.23	1.17
B23	−81	−2.00	33.00	5.74	1.59
B06	−80	3.00	28.83	5.37	1.49
B04	−70	−5.77	161.86	12.72	3.53
B20	−54	−7.23	98.19	9.91	2.75
B02	−46	−3.92	39.41	6.28	1.74
B09	−45	−10.00	116.67	10.80	2.99
B14	−11	−0.61	16.75	4.09	1.13
B12	−3	0.77	9.19	3.03	0.84
B10	0	0.46	2.93	1.71	0.47
B16	0	0.00	3.50	1.87	0.52
B22	7	−1.15	46.14	6.79	1.88
B07	15	−3.46	5.77	2.40	0.66
B08	19	−2.69	7.23	2.69	0.74
B11	28	−4.92	68.91	8.30	2.30
B15	41	−13.31	90.06	9.49	2.63
B03	48	−11.08	98.08	9.90	2.75
B13	62	−6.23	182.69	13.51	3.75
B25	64	−5.54	118.27	10.87	3.01
B19	66	−7.15	167.31	12.93	3.59
B21	84	−1.15	31.97	5.65	1.57
B18	90	−0.54	2.10	1.45	0.40

Note: $N = 13$

Table 22: Test "B" descriptive statistics for males sorted by angle value.

Item	Angle	*M*	SD^2	*SD*	*SEM*
B24	−90	0.00	0.00	0.00	0.00
B01	−86	−5.00	107.00	10.34	2.67
B05	−86	−0.67	15.09	3.88	1.00
B23	−81	−0.67	25.21	5.02	1.29
B06	−80	0.93	19.78	4.45	1.15
B04	−70	−6.33	162.38	12.74	3.29
B20	−54	−1.00	110.00	10.49	2.71
B02	−46	−5.33	60.24	7.76	2.00
B09	−45	−9.33	88.81	9.42	2.43
B14	−11	−0.53	12.55	3.54	0.91
B12	−3	0.60	8.68	2.95	0.76
B10	0	0.67	5.81	2.41	0.62
B16	0	−1.30	4.28	2.07	0.53
B22	7	0.00	6.43	2.53	0.65
B07	15	−2.13	25.41	5.04	1.30
B08	19	−1.93	69.78	8.35	2.16
B11	28	−1.33	63.09	7.94	2.05
B15	41	−7.00	65.00	8.06	2.08
B03	48	−7.00	36.43	6.03	1.56
B13	62	−6.87	50.27	7.09	1.83
B25	64	−5.80	110.74	10.52	2.72
B19	66	0.00	79.28	8.90	2.30
B21	84	−1.13	22.27	4.72	1.22
B18	90	−0.47	1.69	1.30	0.33

Note: $N = 15$

Table 23: Test "A" descriptive statistics for participants that identified themselves as left-handed sorted by angle value.

Item	Angle	M	SD^2	SD	SEM
A24	−90	0.00	0.00	0.00	0.00
A15	−75	−6.00	292.50	17.10	7.65
A11	−73	−4.00	255.00	15.97	7.14
A16	−69	−2.00	257.50	16.05	7.18
A08	−55	−11.00	192.50	13.87	6.20
A12	−50	1.00	217.50	14.75	6.59
A10	−48	−6.00	120.00	10.95	4.90
A22	−35	−3.00	32.50	5.70	2.55
A19	−30	−11.00	42.50	6.52	2.91
A18	−13	−2.00	42.50	6.52	2.91
A07	−9	2.00	17.50	4.18	1.87
A17	−1	1.60	18.80	4.33	1.94
A23	0	0.00	0.00	0.00	0.00
A03	7	1.00	20.00	4.47	2.00
A14	10	1.00	17.50	4.18	1.87
A13	23	−3.00	25.00	5.00	2.23
A06	29	−4.00	100.00	10.00	4.47
A04	32	−6.00	67.50	8.21	3.67
A09	44	−1.00	57.50	7.58	3.39
A05	46	−8.00	157.50	12.55	5.61
A21	47	−3.00	130.00	11.40	5.10
A01	67	−6.00	155.00	12.45	5.57
A02	73	−4.00	505.00	22.47	10.05
A20	80	−7.00	257.50	16.05	7.17
A25	90	0.00	0.00	0.00	0.00

Note: $N = 5$

Table 24: Test "B" descriptive statistics for participants that indentified themselves as left-handed sorted by angle value.

Item	Angle	*M*	SD^2	*SD*	*SEM*
B24	−90	0.00	0.00	0.00	0.00
B01	−86	−1.60	6.80	2.61	1.16
B05	−86	−0.60	13.30	3.65	1.63
B23	−81	1.00	20.00	4.47	2.00
B06	−80	1.20	19.70	4.44	1.98
B04	−70	−3.00	145.00	12.04	5.38
B20	−54	−3.00	142.50	11.94	5.34
B02	−46	−7.00	67.50	8.21	3.67
B09	−45	−14.00	67.50	8.21	3.67
B14	−11	−1.00	12.50	3.53	1.58
B12	−3	0.00	7.50	2.74	1.22
B10	0	−0.40	8.30	2.88	1.29
B16	0	−0.80	3.20	1.79	0.80
B22	7	−4.00	107.50	10.37	4.64
B07	15	−2.00	20.00	4.47	2.00
B08	19	0.00	55.00	7.41	3.32
B11	28	2.00	87.50	9.35	4.18
B15	41	−13.00	82.50	9.08	4.06
B03	48	−11.00	132.50	11.51	5.15
B13	62	−6.00	55.00	7.41	3.32
B25	64	−2.00	132.50	11.51	5.15
B19	66	−2.00	167.50	12.94	5.79
B21	84	−1.60	23.80	4.88	2.18
B18	90	−1.00	5.00	2.23	1.00

Note: $N = 5$

Table 25: Test "A" descriptive statistics for participants that identified themselves as having astigmatism sorted by angle value.

Item	Angle	*M*	SD^2	*SD*	*SEM*
A24	−90	0.00	0.00	0.00	0.00
A15	−75	−5.71	103.57	10.18	3.85
A11	−73	−0.86	82.14	9.06	3.42
A16	−69	−9.71	95.24	9.76	3.69
A08	−55	−7.14	15.47	3.93	1.49
A12	−50	−4.28	61.90	7.87	2.97
A10	−48	−6.57	80.95	9.00	3.40
A22	−35	−6.43	55.95	7.48	2.83
A19	−30	−10.71	28.57	5.34	2.02
A18	−13	−2.57	24.62	4.96	1.87
A07	−9	−1.00	14.67	3.83	1.45
A17	−1	0.57	5.62	2.37	0.89
A23	0	0.00	0.00	0.00	0.00
A03	7	−0.57	14.28	3.78	1.43
A14	10	−0.71	20.24	4.50	1.70
A13	23	−6.57	47.62	6.90	2.61
A06	29	−3.28	61.90	7.87	2.97
A04	32	−6.43	72.28	8.50	3.21
A09	44	−10.43	80.95	9.00	3.40
A05	46	−10.28	61.94	7.87	2.97
A21	47	−11.28	36.90	6.07	2.29
A01	67	−13.43	97.62	9.88	3.73
A02	73	−10.86	148.81	12.20	4.61
A20	80	−3.57	130.95	11.44	4.32
A25	90	0.00	0.00	0.00	0.00

Note: $N = 8$

Table 26: Test "B" descriptive statistics for participants that identified themselves as having astigmatism sorted by angle value.

Item	Angle	*M*	*SD*^{2}	*SD*	*SEM*
B24	−90	0.00	0.00	0.00	0.00
B01	−86	−3.00	67.55	8.23	1.55
B05	−86	0.82	18.45	4.29	0.81
B23	−81	−1.07	28.51	5.34	1.01
B06	−80	1.89	24.17	4.92	0.93
B04	−70	−6.07	156.22	12.50	2.36
B20	−54	−3.89	110.69	10.52	1.99
B02	−46	−4.68	49.26	7.02	1.32
B09	−45	−9.64	98.01	9.90	1.87
B14	−11	−0.57	13.96	3.73	0.70
B12	−3	0.68	8.60	2.93	0.55
B10	0	0.57	4.33	2.08	0.39
B16	0	−0.69	4.21	2.05	0.39
B22	7	−0.53	24.18	4.92	0.93
B07	15	−2.75	16.19	4.02	0.76
B08	19	−2.28	39.54	6.29	1.19
B11	28	−3.00	66.67	8.16	1.54
B15	41	−9.93	84.00	9.16	1.73
B03	48	−8.89	66.76	8.17	1.54
B13	62	−6.57	107.36	10.36	1.96
B25	64	−5.68	110.00	10.49	1.98
B19	66	−3.32	128.67	11.34	2.14
B21	84	−1.14	25.76	5.07	0.96
B18	90	−0.50	1.81	1.35	0.25

Note: $N = 8$

Appendix C — Approval Letter

San José State
UNIVERSITY

Office of the Academic Vice President

Associate Vice President Graduate Studies and Research

One Washington Square
San Jose, CA 95192-0025
Voice: 408-924-2480
Fax: 408-924-2477
E-mail: gstudies@wahoo.sjsu.edu
http://www.sjsu.edu

TO: Maureen Kelley
P.O. Box 720621
San Jose, CA 95172-0621

FROM: Serena W. Stanford *Serena W. Stanford*
AAVP, Graduate Studies & Research

DATE: November 21, 1997

The Human Subjects-Institutional Review Board has approved your request to use human subjects in the study entitled:

"Effectiveness of Oriented Points for Large Scale Mapping"

This approval is contingent upon the subjects participating in your research project being appropriately protected from risk. This includes the protection of the anonymity of the subjects' identity when they participate in your research project, and with regard to any and all data that may be collected from the subjects. The Board's approval includes continued monitoring of your research by the Board to assure that the subjects are being adequately and properly protected from such risks. If at any time a subject becomes injured or complains of injury, you must notify Serena Stanford, Ph.D., immediately. Injury includes but is not limited to bodily harm, psychological trauma and release of potentially damaging personal information.

Please also be advised that all subjects need to be fully informed and aware that their participation in your research project is voluntary, and that he or she may withdraw from the project at any time. Further, a subject's participation, refusal to participate, or withdrawal will not affect any services the subject is receiving or will receive at the institution in which the research is being conducted.

If you have any questions, please contact me at (408) 924-2480.

The California State University:
Chancellor's Office
Bakersfield, Chico, Dominguez Hills,
Fresno, Fullerton, Hayward, Humboldt,
Long Beach, Los Angeles, Maritime Academy,
Monterey Bay, Northridge, Pomona,
Sacramento, San Bernardino, San Diego,
San Francisco, San Jose, San Luis Obispo,
San Marcos, Sonoma, Stanislaus

Figure 33. Human Subjects/Institutional Review Board letter of acceptance.

Appendix D — Test Materials

Responsible Investigator: Maureen Kelley
Title of Protocol: Visual Perception Study on Estimating Angular Symbols for Large Scale Mapping.

Agreement to Participate in Research:

1. I __________________________________have been asked to participate in a research study investigating
   (Please Print Name)
   how well humans judge angled map symbols conducted by Maureen Kelley, graduate student in the Department of Geography, College of Social Sciences, San Jose State University.
2. I have been asked to write down, in the test booklet provided to me by the researcher, my best estimation of the orientation of angled symbols. I will also be asked how confident I was estimating these angles on a three-step scale. I will participate in (please circle one):
   a. Geography 101 class BC 212, 2 & 3 December 1997
   b. Geology Club meeting, DH 318, 8 December 1997
   c. Geography Department Seminar Room, WSQ 111, 2 & 3 December, 1997
3. I understand that there may be some slight eye strain from undertaking this test; otherwise, there are no other risks anticipated.
4. I understand there may be some benefit such that I will have an understanding of how well I can estimate angles.
5. I understand that the results of this study may be published but no information that could identify me will be included.
6. a. I understand that I will receive extra credit for my participation in this study (Geography 101 students only).
   b. I understand that I will not receive any compensation for my participation in this study (Geography and Geology majors only).
7. I understand that if I have any questions about the research, I am to contact Maureen Kelley, (408)971–6651. If I have any complaints about the research, I can direct them to Dr. David Helgren, Geography Department chair, (408)924–5475. If I have any questions or complaints about subjects' rights or research-related injury, I can direct them to Serena Stanford, Ph.D., Associate Academic Vice President for Graduate Studies and Research, (408)924–2480.
8. I understand that no service of any kind, to which I am otherwise entitled, will be lost or jeopardized if I choose not to participate in this study.
9. I consent to participate in this study voluntarily without undue influence or coercion by other persons. I understand that I am free to withdraw anytime without prejudice to my relations with San Jose State University.
10. I understand I will receive a signed and dated copy of this consent form before I begin the test.

- **The signature of the subject on this document indicates agreement to participate in this study.**
- **The signature of the researcher on this document indicates agreement to include the below named subject. The subject has been fully informed of his or her rights.**

______________________________ ____________________
Subject's Signature Today's Date

______________________________ ____________________
Investigator's Signature Today's Date

Figure 34. Consent form.

1. First Initial, Last Initial:______________ 2. Age:______________

3. Major:______________ 4. Year (please circle): FR SO JR SR GR

5. Gender: M F 6. Handedness: R L

7. Do you wear corrective lenses? (circle one): Y N

8. If you answered "no" to 7, then please continue to 9; otherwise, please circle what applies to you:

nearsighted b. farsighted c. astigmatism d. other

9. What type of maps do you use? Please circle what applies to you:

a. I do not use maps

b. street and locator maps

c. topographic maps

d. navigational and/or aeronautical charts

e. thematic maps—geological, meteorological, engineering, etc.

f. other;

please specify:____________________________________

10. Would you like your results mailed to you? Y N

11. If you answered "no" then please wait for further instructions; otherwise fill in below:

Name:____

Address:____Apt. No.:_________

City:________________________ State:_________ Zip:_____________

Figure 35. Questionnaire.

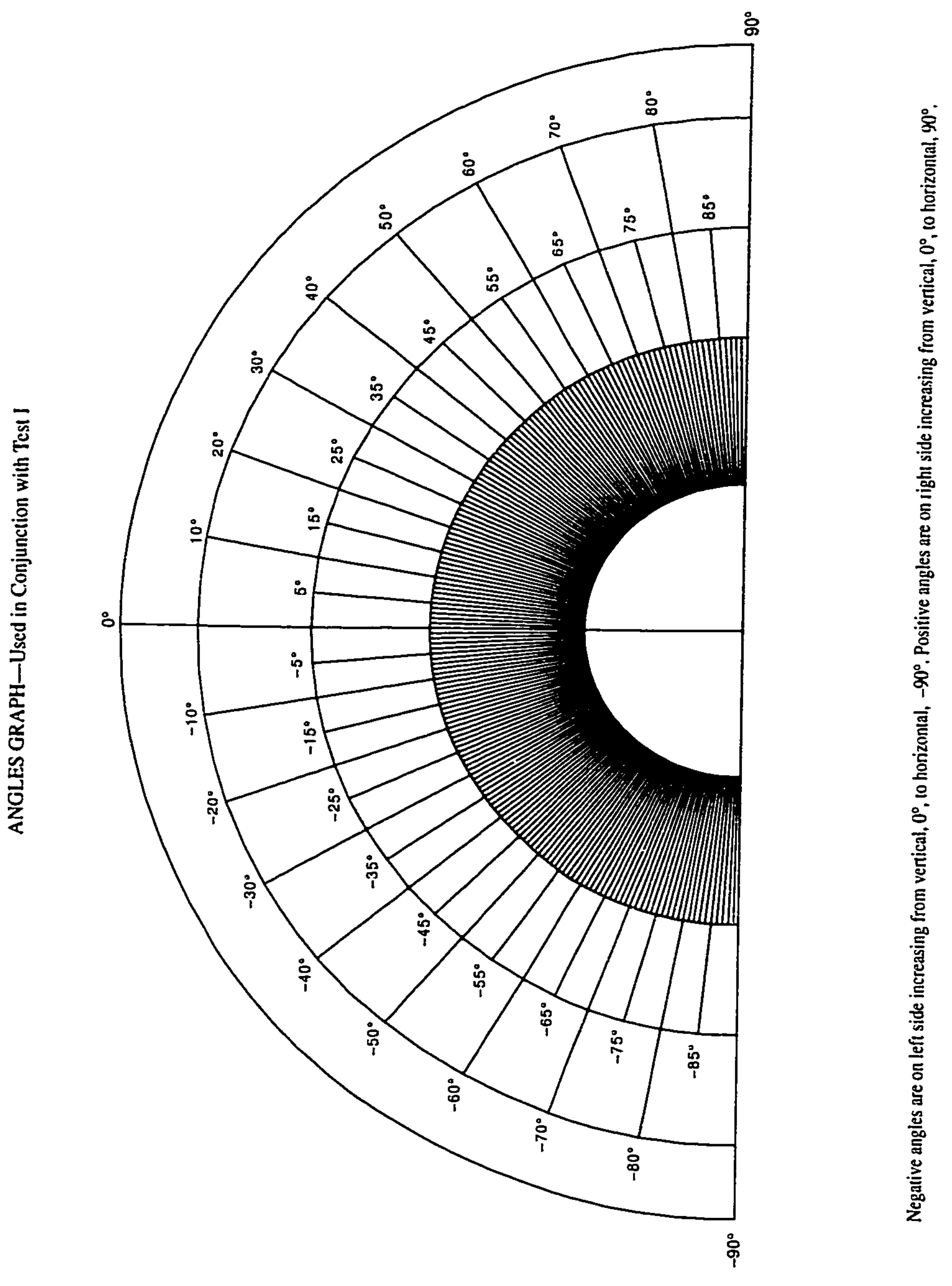


Figure 36. Sample protractor used for Test I.

TEST I

Please wait for instructions before beginning the test.

Turn the page only when instructed to do so................................

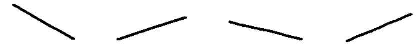
Figure 37. Beginning test instructions.

Circle the line that applies:

1. The line rotated more toward horizontal.

2. The line rotated more toward vertical.

3: The line rotated more toward horizontal.



4. The line rotated more toward vertical.

5. The line rotated more toward horizontal.

6. The line rotated more toward vertical.

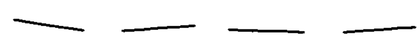


Figure 38. Test I Page 1.

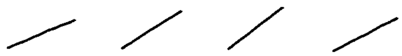
Circle the line that applies:

7. The vertical line.

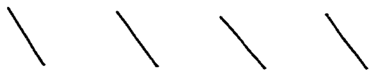
8. The horizontal line.

9. The line 45° from vertical.

10. The line 60° from vertical.



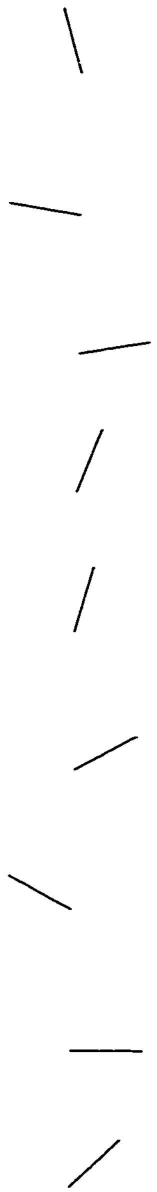
11. The line 30° from vertical.



12. The line 20° from vertical.

Figure 39. Test I Page 2.

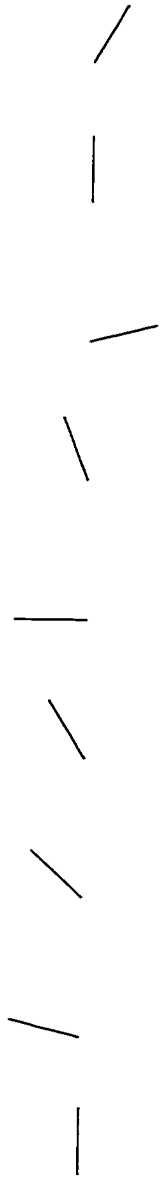
Match each line to the angle value:



13.	–80°
14.	–60°
15.	–15°
16.	15°
17.	20°
18.	45°
19.	60°
20.	80°
21.	90°

Figure 40. Test I Page 3.

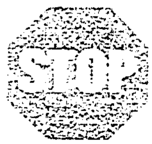
Match each line to the angle value:



22.	–90°
23.	–75°
24.	–45°
25.	–30°
26.	–20°
27.	0°
28.	0°
29.	30°
30.	75°

Figure 41. Test I Page 4.

END TEST I



The next part of the test requires that you do not use the Angles Graph. Please turn the paper over (written side down) before beginning the next part of the test.

Figure 42. Test I end.

TEST II

Turn the page to begin next test..................................

Figure 43. Test II beginning instructions.

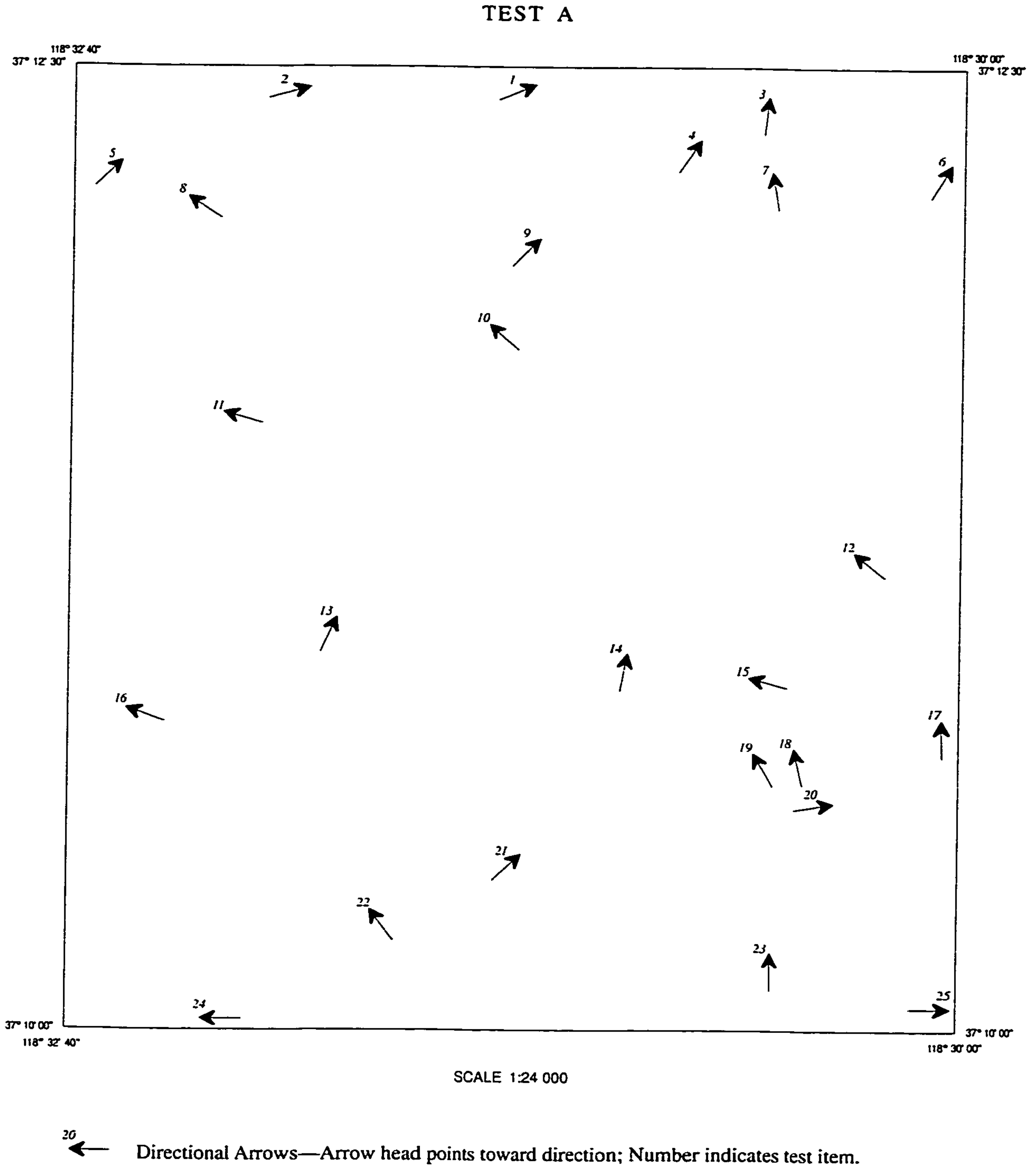
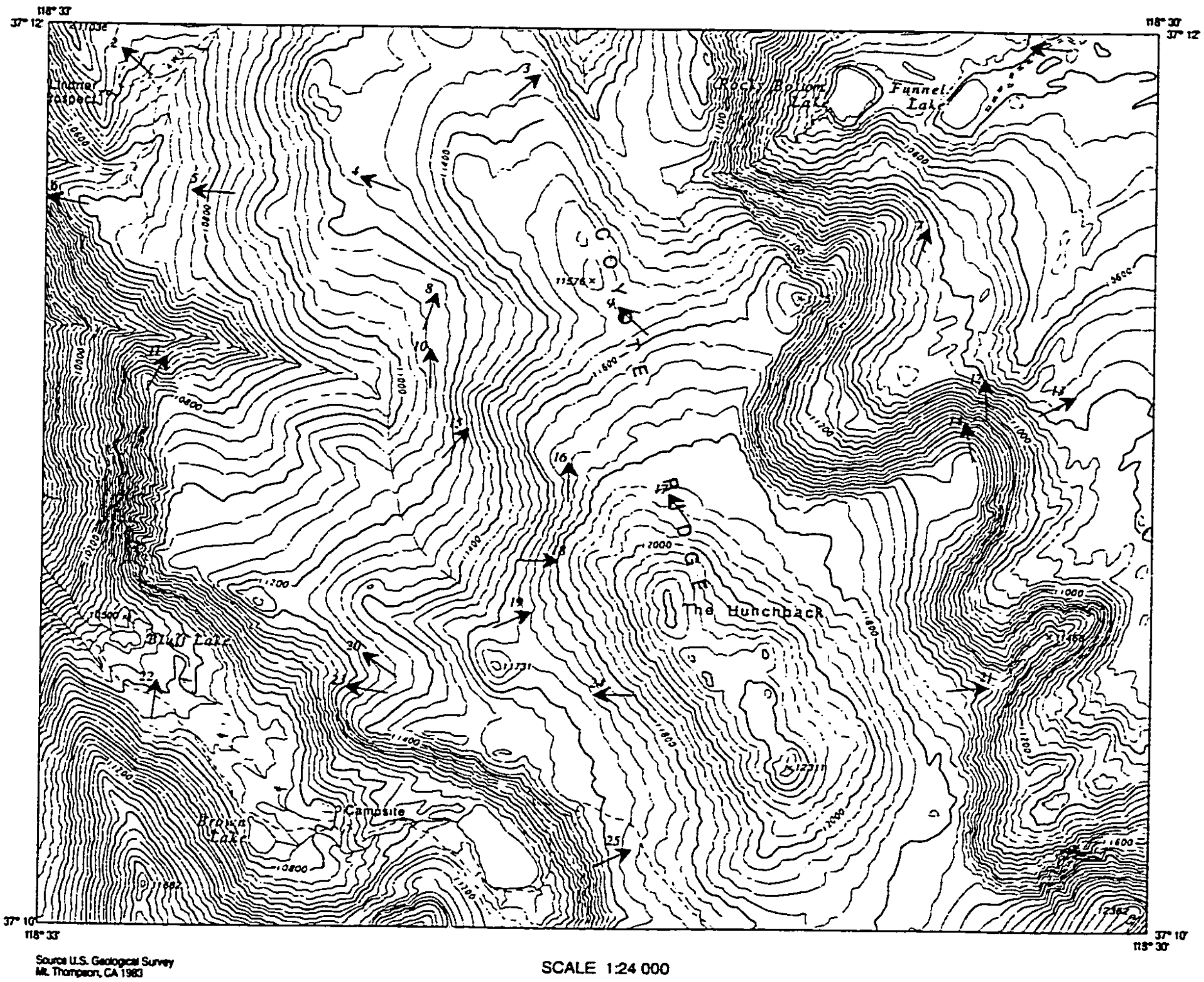


Figure 44. Test II Test "A".

TEST B



SCALE 1:24 000

CONTOUR INTERVAL 40 FEET

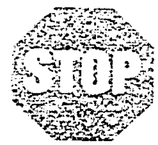
20 ← Directional Arrows—Arrow head points toward direction; Number indicates test

Figure 45. Test II Test "B".

Estimate each angle on the map to the nearest degree:	Circle the letter describing your confidence estimating angle n:	not confident	confident	very confident
1.	1.	a	b	c
2.	2.	a	b	c
3.	3.	a	b	c
4.	4.	a	b	c
5.	5.	a	b	c
6.	6.	a	b	c
7.	7.	a	b	c
8.	8.	a	b	c
9.	9.	a	b	c
10.	10.	a	b	c
11.	11.	a	b	c
12.	12.	a	b	c
13.	13.	a	b	c
14.	14.	a	b	c
15.	15.	a	b	c
16.	16.	a	b	c
17.	17.	a	b	c
18.	18.	a	b	c
19.	19.	a	b	c
20.	20.	a	b	c
21.	21.	a	b	c
22.	22.	a	b	c
23.	23.	a	b	c
24.	24.	a	b	c
25.	25.	a	b	c

Figure 46. Answer sheet for Test II Test "A" and "B".

END TEST II



A comments page is included in this packet. Please write down any comments you have regarding this test.
Please put all test materials into the folder provided.
Keep your consent copy for your records.
Remain seated for further instructions or until time is called.

Thank you for your participation in this study.

Figure 47. Test II ending instructions.

- Good Test, some difficult parts. I wonder how good or bad I did.
- Make numbers clearer on Test B second map.
- Too much of a strain on my eyes ... Could not continue ... I do not have my glasses
- Last map — it is difficult to find the number & arrows; perhaps larger type or something.
- This is too difficult and I applaud you for doing this. Can't do B because I can't think any further.
- The numbers on Test B should be darker, larger, easier to locate!
- It was a real shocker when the protractor was gone, I didn't feel confident at guessing an exact degree. I would have been more confident if I would have known it was approximate. My eyes felt irritated
- It gave me a headache
- Map on Test B is very hard to see arrows — make different color
- I couldn't find number 17 on Test B. Also, asking for a person's sex it's actually a better way of gather info that you need than gender. Gender can be ambiguous.
- Test B was more difficult than Test A. First of all, it was a little difficult to read the arrows. Second, estimating the angle was a bit harder due to this clarity problem.
- I never thought about how I estimate angles after having done it for so long. This was a good exercise to see how we visually perceive symbols we (as geologists) take for granted.
- Fun
- Interesting, much easier on blank map — although should be close to accurate on both, confidence goes way down on topo map. Extra lines make it more difficult.
- It gave me a headache
- Interesting study. much different than using a compass.
- In test 1 some lines seemed equally inclined vertically or horizontally & I wasn't sure if I could circle 2. Test 2, part 2 seemed easier. Question is if results show it?
- Time too long. When you say this is a timed test — implication is to hurry — but-after finished. This is the longest timed test I have taken-and one of the few I have had extra time.
- Should include topographic location questions
- In part 2 of the test, angles were easier for me to recognize if they were closer to 0° and if they were closer to plus or minus 90. I didn't use the angle diagram in Part 1 except to know where + or − was relative to 0°
- I used the angle method described in part 1, and part 2, but wasn't sure if I should have used it in part 2.
- Confusing