THE AFFECT OF PATTERN ON GRAY TONE AREA SYMBOLS:

A PSYCHOPHYSICAL EXPERIMENT

by

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THE AFFECT OF PATTERN ON GRAY TONE AREA SYMBOLS: A PSYCHOPHYSICAL EXPERIMENT

ABSTRACT: Equal value gray scales are frequently employed by cartographers to choose gray tone area symbols. Several researchers have tried to quantify perceived gray tone as a function of percent area inked or reflectance but results have varied. The influence of pattern and texture on gray tone perception is considered a major cause in the variation of results. This research details the affect of pattern on gray tone perception. In the experiment, a pyschophysical based design, test subjects completed a seven step equal interval gray tone progression between various non-black and white anchor points using one of four testing patterns. Algorithms describing the relationship of perceived values to percent area inked were derived, showing in each case a psychophysical based logarithmic function. The perception of the two major pattern types used, dots and cross-hatched patterns, yielded different perceptual results.

THE USE OF PATTERN AS GRAY TONE AREA SYMBOLS

The use of gray tones or tint patterns as area symbols has long been a valued technique in cartography. Historically, methods for creating these area symbols have changed as new technologies have evolved. Creation by hand has effectively been replaced with press-on monochromatic layer-tints, photographic tint screens, and computer driven line printers and graphic plotters. Although these methods of production and reproduction can produce highly consistent, visually continuous gray tones, they largely rely on the arrangement of fine patterns (i.e., dots, cross-hatching, etc.) to simulate continuous tone.

Many factors must be taken into account when a cartographer designs a map using gray tone area symbols. Foremost, a decision must be made whether to partition the data to be portrayed into a limited number of classes or to represent data in an unclassed or continuous form. Gray tones serve a different purpose when used for unclassed maps rather than for classed intervals. Unclassed values require the reader to discriminate between patterned areas on a map whereas classed intervals require the reader to identify the value and match it to one presented in a legend. Several studies have dealt with the subject of pattern in unclassed choropleth mapping (Tobler, 1973; Dobson, 1973; Lavin, 1979).

For classed data representation, adjacent gray tones must be distinguishable from one another to properly communicate classed information (Williamson, 1982). While small differences can be discriminated when adjacent, the map reader can not effectively identify classed information when many values are shown on the map. An upper limit of six to eight values including black and white has been suggested (Robinson, 1952). Of equal importance, the gray tones should be arranged in some graded series or tonal progression to properly portray the numeric value range of a single attribute. Finally, it is the appearance of these represented classed intervals or, more precisely, how they are perceived by the map reader that determines the amount of information communicated.

PSYCHOPHYSICAL STUDIES OF GRAY SCALE

The study of the equal value gray scale was first undertaken by psychologists during the mid-1700's in an attempt to provide evidence for general psychophysical laws, that is, those concerning stimulus and sensation (Kimerling, 1975). Two of the most notable works were those of G.T. Fechner (1859) and J.A.F. Plateau (1873). Fechner deduced that the relationship between tone and value was logarithmic based on his just noticeable difference (JND) testing. He formulated a general psychophysical law: $V = c * \log(R) + k$, where V is the perceived measure of magnitude of the stimulus, R is the physical magnitude and c and k are constants. Plateau's initial work was based on the mixing of black and white paints in a partitioning experiment. His experimental results produced a power function relationship; $V = kR^c$, where V is value, R the physical measure and c and k are constants. Plateau later experimented with expanding the number of partitions between black and white. The expanded partitioning scale resulted in better accordance with a logarithmic function, whereby with each doubling of the stimulus there is a constant increment to the sensation (Stevens,1975).

Additional psychophysical research on equal value gray scales include the studies of Munsell (1915) and Stevens (1957). Munsell, an artist and developer of the Munsell Color System, used a gray scale partitioning methodology to produce his gray scale that served as a basis for his color system. Munsell conducted two separate tests: a JND measurement and an equal interval partitioning test (Williamson, 1982). The JND experiment produced a category or interval scale while the partitioning experiment produced a power function relationship. Stevens (1957), a psychologist, utilized a magnitude estimation experiment with results described by a power function. Stevens believed that within psychophysics two class types of sensory continua exist. Prothetic continua, those concerning magnitude, universally exhibit a power function relationship where the sensation magnitude grows as a power function of the stimulus magnitude. Metathetic continua, in contrast, are concerned with more qualitative aspects of what and where. Therefore the type of sensory continua and the methodology used to measure sensation to a great degree will determine its functional relationship to stimulus (Stevens, 1975).

CARTOGRAPHIC STUDIES OF GRAY SCALE

Several cartographic studies have dealt with gray tone and associated pattern perception, notably the research of Williams (1958), Jenks and Knos (1961), Castner and Robinson (1969), Stoessel (1972), Peterson (1975), Kimerling (1975, 1985), and Williamson (1982). Williams (1958), the first cartographer to incorporate psychophysical principles in the study of the gray scale, used partitioning methods on coarse textured area symbols to produce his curve of the gray scale. The Williams scale, which appears to be a higher order polynomial function, has been widely used when maximizing contrast is important in choropleth mapping (Smith, 1987).

Jenks and Knos (1961) utilized preference testing techniques with commercially available dot patterns to determine which of several gray scales best produced a graded series of tones. They concluded the best gray scale was that of Williams, although the results of their testing have been considered suspect (Slocum and McMaster, 1986). Castner and Robinson's (1969) work focused on the effect of pattern and texture on value perception, which will be more thoroughly discussed in the following section.

Stoessel (1972) employed fine screened squares and asked test subjects to produce an equal stepped progression (Williamson, 1982). Stoessel's category scale appears to be the opposite of Munsell's, also a category scale. Stoessel's curve is neither logarithmic nor exponential, and, according to Kimerling (1975), "... is not based on current psychophysical theory."

Peterson (1979) employed a partitioning technique with coarse line plotter shades to produce a gray scale that is very similar to that of Munsell (Slocum and McMaster, 1986). Kimerling (1975) utilized a partitioning method with fine screened photographic samples to test the nature of the equal value scale for value-only screened areas and the influence of background to perception. Kimerling's results showed a marked similarity to those of Munsell.

COMPARING GRAY SCALES

Figure 1 shows several of the gray scale curves previously mentioned plotted against one another. The differences among the curves can be attributed to one or a combination of several variables. In his 1975 article, Kimerling showed that background differences can have a significant effect on gray scale perception. Other authors have reached similar conclusions (Cox, 1980). Methods of testing have also been shown to influence results, as has the stimulus continuum itself (Stevens, 1975). Size of symbol and complexity of data have also been shown to have some affect (Cole, 1981; Crawford, 1971). Even the method of reproduction chosen for gray tones has been shown to have an effect (Brown, 1982; Monmonier, 1980). But perhaps the best documented of the variables is the influence of pattern and texture upon value.

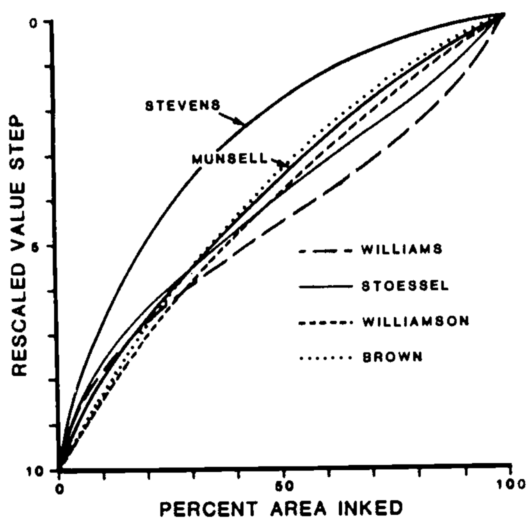


Figure 1. - Comparison of equal value gray scales. All physical measures were converted to percent area inked (From Kimerling, 1985).

For the purposes of this paper pattern is defined as the configuration or arrangement of inked areas (i.e., dots, lines, crosshatching, etc.). Texture refers to the number of lines of pattern elements per unit of measure (Smith, 1987). Value is the perceived lightness or darkness of a gray tone; it is scaled by the gray scale and is frequently quantified as a measured percent of area inked or percent reflectance.

Castner and Robinson (1969) dealt with many variables affecting perceived value, but focused on what they termed pattern-value. Stated simply, they tried to determine at how fine a texture a subject begins to see only a gray tone, without the pattern which makes up, the gray tone being apparent (Slocum and McMaster, 1986). Their research, and that of others (Williamson, 1982; Monmonier, 1980), indicates that subjects have difficulty perceiving coarse textured gray tones and tend to more readily see pattern only. Conversely, fine textures are perceived as value only without pattern. They conclude that for dot patterns a lower threshold of about 40 lines per inch exists. Below this threshold patterns will be perceived as simply a pattern of dots without any appreciable gray tone. An upper threshold of about 75 lines per inch is suggested as the point at which map readers will perceive dot patterns as particular gray tones without any pattern. The patterns between these texture thresholds, the area they call pattern-value, can have no single unit of measure as the map reader is influenced by both pattern and value.

To a great extent the variation in the gray scale curves and the functional relationships that define them are a result of differences in methodologies and materials used during testing (Smith, 1987; Stevens, 1975). Similar methods of testing tend to produce gray scale curves that are similar (Kimerling, 1975). Stevens (1975) contends that, in addition to methodology, the continuum itself dictates the type of curve that will result. Kimerling (1985) suggests only three equal value gray scales vary significantly, and each has an appropriate use. The Munsell scale appears suitable for screened gray tones on classed choropleth maps where the emphasis is to maximize class discrimination. Stevens' scale is suited to showing unclassed ratio level information. Williams' scale is more appropriate for coarse patterns used in a progression of equally stepped map classes (Kimerling, 1985).

In short, many factors are likely to effect the outcome of psychophysical testing. The effect of pattern texture on the perception of gray tone value has been shown to cause differences in resulting curves from those produced by evaluating gray tones without apparent pattern. A reasonable hypothesis for the differences, based primarily on the work of Castner and Robinson, is that low value shades are more difficult to discriminate as gray tones than high value shades because of texture.

THE EXPERIMENTAL DESIGN

Four distinct patterns were chosen for evaluation in the experiment. Two were dot patterns, with one containing dots of 0.2 mm in diameter and the other a dots of 0.4 mm diameter. The other patterns were cross-hatched, with line widths of 0.2 mm and 0.4 mm. These patterns represent those commonly used by Statistics Canada and other cartographic agencies. They are also regularly shaped and thus can more easily be evaluated quantitatively than can irregularly shaped patterns.

Each of the above patterns was acquired in graded series from Statistics Canada in film negative form. Each graded series ranged from 0.2 cm to 0.044 cm with increments of 0.002 or 0.001 cm in texture. The four graded series negatives were photographically printed onto Kodak rapid paper. Each pattern sheet was then scrutinized under a low magnification microscope and randomly measured with a micrometer to insure that dot shape, line consistency, relative darkness and overall clarity remained constant.

Six test packets were assembled from these pattern sheets and duplicated so that twelve packets could be administered for testing at once. Small rectangles (1/2" by 1") for each graded pattern were coded using a random alphabet code and placed into each packet. Test packet one contained 95 graded samples of dot patterns with a 0.2 mm dot diameter. Test packet two contained 95 graded dot pattern rectangles with a 0.4 mm dot diameter. Test packet three held 95 graded samples of cross-hatched patterns with a 0.2 mm line width. Test packet four had 95 graded rectangles with a 0.4 mm line width cross-hatch pattern. Test packet five contained 80 pattern rectangles, with 40 being 0.2 mm diameter dot patterns in graded series and 40 being 0.2 mm line width grades series cross-hatched. Test packet six also had 80 pattern rectangles, half 0.4 mm diameter dots in graded series and the other half 0.4 mm line width graded cross-hatched.

An instruction sheet accompanied each test packet, outlining the task required of the test subjects (see Appendix A for instruction sheet). Each test participant was assigned a packet at random and asked to arrange the rectangle patterns in an equal interval progression between the initial endpoints. A starting pattern of 0.2 cm texture (center to center ink spacing) and an ending pattern of 0.044 cm texture was identified for each packet. All testing materials were placed on white unlined paper and all tests were administered in the same room to insure lighting differences and background contrast would not vary.

Each test participant was asked to complete a seven step progression between his/her starting and ending pattern using the equal interval partitioning method. Thus, they would chose a pattern visually "half way" between the starting and ending patterns, then half way between the start and middle patterns and middle and end patterns, and so on until a nine step equal interval progression was made. The participants were allowed to change any of their responses at any time. At the completion of the partitioning process, each subject was given a post-test questionnaire (see Appendix B) and the time of completion as well as responses were recorded.

The tests were administered primarily to students enrolled in an undergraduate Geography class at Oregon State University. The participants were predominantly non-Geography major undergraduates between 18 and 20 years of age, although 46 tests were administered to Geography graduate students and faculty who ranging in age from 22 to 54 years old.

TESTING GOALS

Perceptual curves for each of the four single pattern tests could be identified and quantified by determining the means of each of the seven steps in the tests. The equations derived could then be compared to those derived from previous research to assess the influence of pattern on gray scale perception. Given the proper sample size, the mixed pattern tests should yield not only perceptual curves for the specified pattern combinations, but also indicate how texture influences perceived value between the dot and cross-hatched patterns. It was also determined that non-parametric statistics could be applied to the test subject data gathered on the post-test questionnaire versus the difference between the interval means and the subjects' responses. Therefore, the hypothesis that personal characteristics such as age and gender significantly affect value perception could be tested for acceptance or rejection.

ANALYSIS PROCEDURES

All recorded data were entered digitally on an IBM PC. Six files were created, one for each test. Statistics such as means, standard deviations, coefficient of variation, standard error and total range of response at each interval were calculated using the Number Cruncher Statistical System (NCSS) software. Non-parametric correlation options in NCSS were used to test subjects age, gender, time of completion and relative experience level versus responses. The mean at each interval was used to form a data base which contained nine interval means for each test. This file was used to define equations for curves of best fit for each test using SAS. Finally, the percentage of area inked was calculated for each mean interval using formulas published by Castner and Robinson (1969, pp. 23) and Monmonier (1982, pp. 103).

TEST RESULTS

PACKET ONE (0.2 mm diameter dot pattern)

Test packet one was administered to 48 subjects. Percent area inked of the patterns ranged from 1% to

18.7% for this test. Figure 2A shows a distribution of the means bracketed by 95% confidence intervals, with texture increments in mm shown on the Y axis. Figure 2B shows the calculated curves overlayed with the nine interval means, with percentage of area inked on the X axis. Table 1 gives a statistical summary by interval. The power and log function models derived for the mean data set are as follows, with values in parentheses beneath the equations representing the standard error of the intercept and slope respectively:

Log Function: $y = 1.0218 + 6.030 * \log(x)$
(0.1294) (0.1647)

RMSE = 0.2109
R^2 = 0.9948
n = 9

Power Function: $\log(y) = 0.1756 + 0.6703 * \log(x)$
(0.0482) (0.0613)

RMSE = 0.0785
R^2 = 0.9447
n = 9

PACKET TWO (0.4 mm diameter dot pattern)

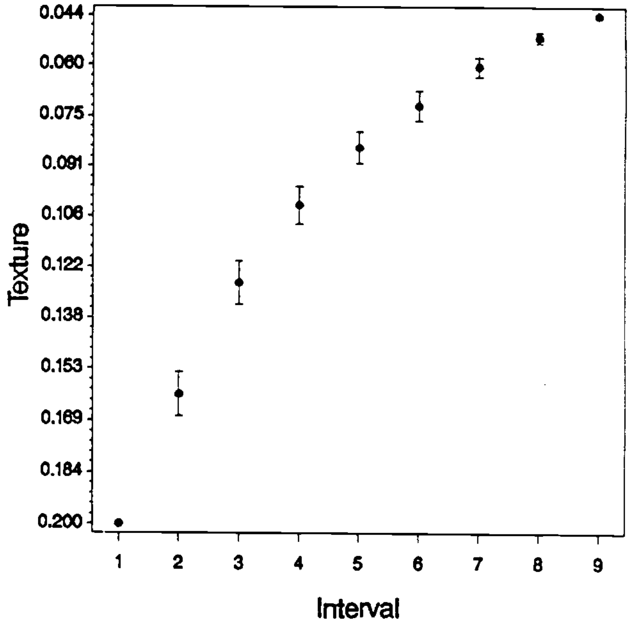
Test packet two was administered to 45 students who were given patterns of 0.4 mm diameter dots ranging from 3.6% area inked to 74.9% area inked. Figure 3A shows the distribution of the means with 95% confidence at each interval. Figure 3B shows calculated log and power curves with mean values overlayed. Table 2 gives a statistical summary by interval. The power and log functions generated from this mean data set are:

Log function: $y = -2.8509 + 5.948 * \log(x)$
(0.4779) (0.3444)

RMSE = 0.4433
R^2 = 0.9771
n = 9

Power function: $\log(y) = -0.2749 + 0.6763 * \log(x)$
(0.0614) (0.0443)

RMSE = 0.0569
R^2 = 0.9709
n = 9



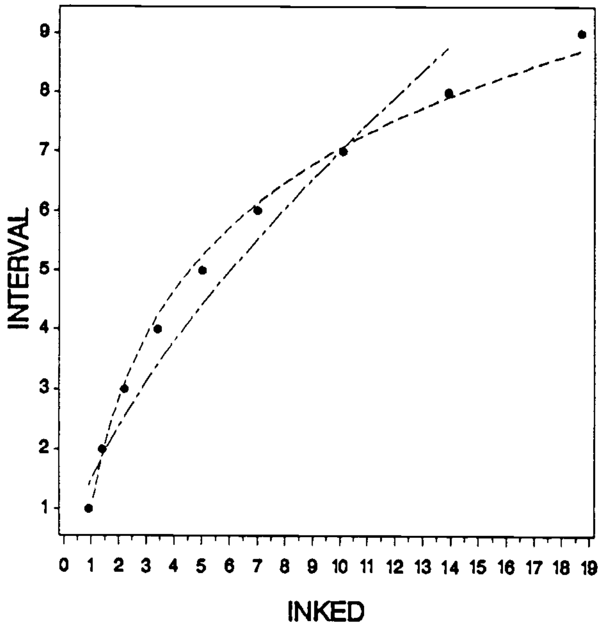
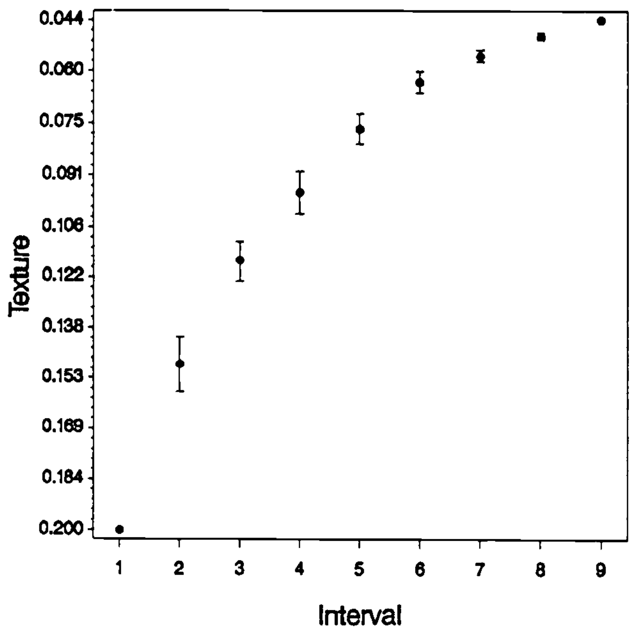


Figure 2A. (left) - Means (black dots) and 95% confidence intervals at each testing interval for test packet one (0.2 mm diameter dot pattern).

Figure 2B. (right) - Calculated log (constant dash) and power (long/short dash) curves transformed and plotted with interval means for test packet one.



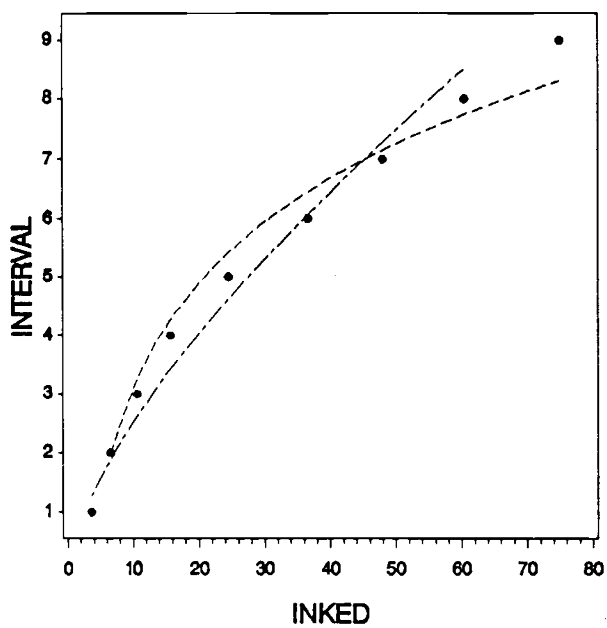


Figure 3A. (left) - Means and 95% confidence intervals at each testing interval for test packet two (0.4 mm diameter dot pattern.

Figure 3B. (right) - Calculated log (constant dash) and power (long/short dash) curves transformed and plotted with interval means for test packet two.

TEST PACKET #1 START PATTERN .2 CM (center to center spacing) END PATTERN .044 CM	RESPONSE INTERVAL						
	1	2	3	4	5	6	7
MEAN	.161	.127	.103	.085	.072	.060	.051
STANDARD DEVIATION	.023	.023	.020	.017	.016	.010	.006
COEFFICIENT OF VARIATION	1.4E-3	1.8E-3	1.9E-3	2.0E-3	2.2E-3	1.6E-3	1.1E-3
STANDARD ERROR	.0033	.0033	.0029	.0025	.0023	.0014	.0008
RANGE	.196- .100	.184- .075	.162- .062	.132- .055	.128- .050	.092- .048	.068- .045

Table 1. - Statistical summary per interval for test packet one (0.2 mm diameter dot pattern).

TEST PACKET # 2 START PATTERN .2 CM (center to center spacing) END PATTERN .044 CM	RESPONSE INTERVAL						
	1	2	3	4	5	6	7
MEAN	.149	.117	.096	.077	.063	.055	.049
STANDARD DEVIATION	.028	.021	.021	.015	.011	.006	.004
COEFFICIENT OF VARIATION	1.8E-3	1.8E-3	2.1E-3	2.3E-3	1.8E-3	1.1E-3	7.7E-5
STANDARD ERROR	.0041	.0031	.0031	.0023	.0017	.0009	.0006
RANGE	.186- .068	.148- .058	.130- .052	.126- .050	.105- .048	.076- .046	.064- .045

Table 2. - Statistical summary per interval for test packet two (0.4 mm diameter dot pattern).

PACKET THREE (0.2 mm line width cross-hatched)

Fifty-four subjects were given test packet four, which consisted of 0.2 mm line width cross-hatched patterns ranging from 19% area inked to 70.2% area inked. Figure 4A shows a plot of the means and 95% confidence intervals at each interval. Figure 4B shows calculated curves plotted with the means at each interval. Table 3 shows the vital statistics per interval for this test packet. The model equations are:

Log function: $y = -17.2256 + 14.2968 * \log(x)$
$\qquad\qquad\qquad(0.4004) \quad (0.2559)$

RMSE = 0.1385
R^2 = 0.9978
n = 9

Power function: $\log(y) = -1.7845 + 1.5453 * \log(x)$
$\qquad\qquad\qquad(0.3115) \quad (0.1990)$

RMSE = 0.1077
R^2 = 0.8959
n = 9

PACKET FOUR (0.4 mm line width cross-hatched)

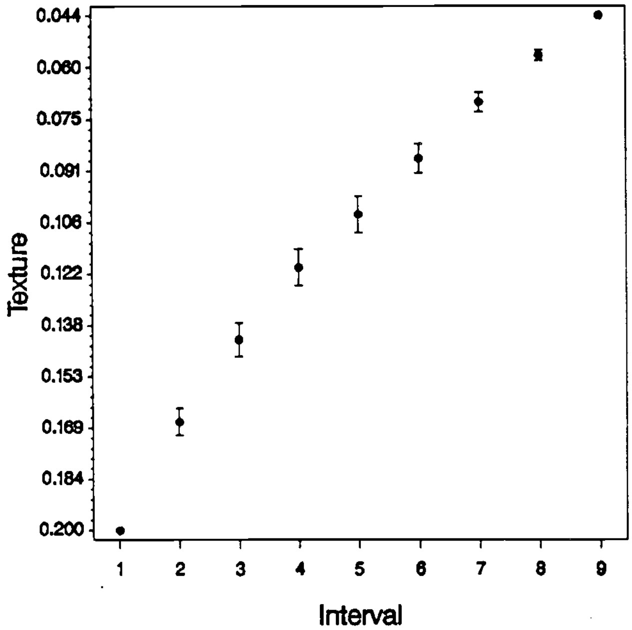
Fifty-three subjects completed test packet four, which consisted of 0.4 mm line width cross-hatch patterns ranging from 36% area inked to 99.2% area inked. Figure 5A shows the means bracketed by 95% confidence at each interval. Figure 5B depicts curves calculated and the means at each interval, with percent area inked on the X axis. Table 4 gives the statistical summary per interval. The logarithmic and power function models fit to the means are:

Log function: $y = -27.3824 + 18.0985 * \log(x)$
$\qquad\qquad\qquad(0.7564) \quad (0.4214)$

RMSE = 0.1800
R^2 = 0.9962
n = 9

Power function: $\log(y) = -2.9669 + 2.0035 * \log(x)$
$\qquad\qquad\qquad(0.3484) \quad (0.1941)$

RMSE = 0.0829
R^2 = 0.9383
n = 9



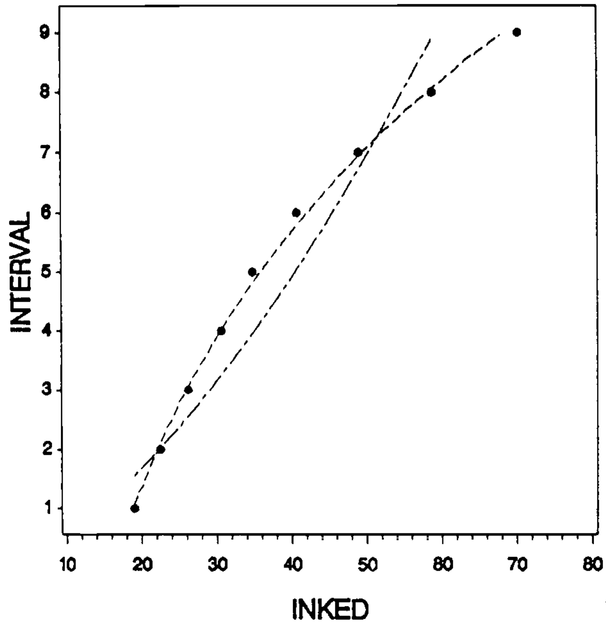
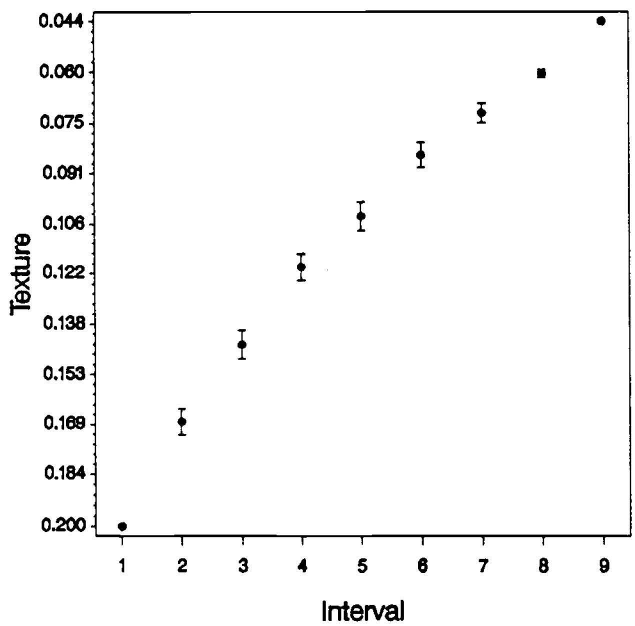


Figure 4A. (left) - Means and 95% confidence intervals at each testing interval for test packet three (0.2 mm line width cross-hatched pattern).
Figure 4B. (right) - Calculated log (constant dash) and power (long/short dash) curves transformed and plotted with interval means for test packet three.



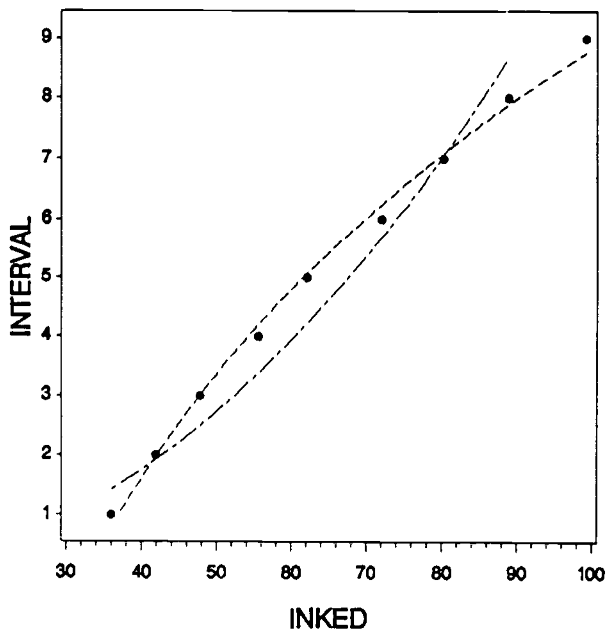


Figure 5A. (left) - Means and 95% confidence intervals at each testing interval for test packet four (0.4 mm line width cross-hatched pattern).
Figure 5B. (right) - Calculated log (constant dash) and power (long/short dash) curves transformed and plotted with interval means for test packet four.

RESPONSE INTERVAL TEST PACKET # 3 START PATTERN .2 CM (center to center spacing) END PATTERN .044 CM	1	2	3	4	5	6	7
MEAN	.167	.142	.120	.104	.087	.070	.056
STANDARD DEVIATION	.015	.019	.020	.020	.016	.011	.006
COEFFICIENT OF VARIATION	9.3E-2	1.3E-3	1.7E-3	2.0E-3	1.8E-3	1.5E-3	1.0E-3
STANDARD ERROR	.0021	.0026	.0028	.0028	.0022	.0015	.0008
RANGE	.195-.128	.192-.095	.156-.065	.160-.045	.122-.050	.095-.046	.070-.045

Table 3. - Statistical summary per interval for test packet three (0.2 mm line width cross-hatched pattern).

RESPONSE INTERVAL TEST PACKET # 4 START PATTERN .2 CM (center to center spacing) END PATTERN .044 CM	1	2	3	4	5	6	7
MEAN	.168	.144	.120	.104	.085	.072	.060
STANDARD DEVIATION	.015	.016	.015	.016	.014	.010	.005
COEFFICIENT OF VARIATION	9.2E-2	1.1E-3	1.2E-3	1.5E-3	1.6E-3	1.4E-3	8.6E-2
STANDARD ERROR	.0021	.0022	.0020	.0022	.0019	.0014	.0007
RANGE	.198-.130	.176-.106	.152-.082	.140-.066	.128-.060	.104-.054	.074-.048

Table 4. - Statistical summary per interval for test packet four (0.4 mm line width cross-hatched pattern).

PACKET FIVE (0.2 mm dot diameter and line width mixed patterns)

Twenty-four subjects completed test packet five, a mixed pattern test consisting of 0.2 mm diameter dots and 0.2 mm line width cross-hatch patterns. The percent area inked for this test ranged from 0.9 % for the most sparsely textured dot pattern to 70.2% for the most densely textured cross-hatched pattern. The resulting bimodal curve is indicated in Figure 6, a plot of the means per interval. The curve is obviously neither a power or log function, but rather appears to be a higher order polynomial. Therefore, each pattern within the test was also modeled separately (see Figures 7 and 8). Results are as follows:

Log function for both patterns:

$$y = \underset{(0.5108)}{0.7129} + \underset{(0.3922)}{3.8071} * \log(x)$$

RMSE = 0.7699
R^2 = 0.9308
n = 9

Power function for both patterns:

$$\log(y) = \underset{(0.0416)}{0.1199} + \underset{(0.0319)}{0.4421} * \log(x)$$

RMSE = 0.0627
R^2 = 0.9647
n = 9

Log function for dot pattern only:

$$y = \underset{(0.8719)}{0.5058} + \underset{(0.9147)}{4.9361} * \log(x)$$

RMSE = 1.1917
R^2 = 0.8292
n = 8

Power function for dot pattern only:

$$\log(y) = \underset{(0.0443)}{0.0589} + \underset{(0.0465)}{0.0443} * \log(x)$$

RMSE = 0.0605
R^2 = 0.9681
n = 8

Log function for cross-hatched pattern only:

$$y = -14.0698 + 12.6183 * \log(x)$$
$$\quad\;\; (1.7018) \quad (1.1164)$$

RMSE = 0.6673
R^2 = 0.9481
n = 9

Power function for cross-hatched pattern only:

$$\log(y) = -1.3288 + 1.2880 * \log(x)$$
$$\quad\;\; (0.4179) \quad (0.2741)$$

RMSE = 0.1639
R^2 = 0.7592
n = 9

PACKET SIX (0.4 mm diameter dots and line width cross-hatched pattern)

Test packet six was administered to 25 students. The packet consisted of 0.4 mm dot diameter and 0.4 mm line width cross-hatch patterns. The percent area inked range was 3.6% (most sparsely textured dot pattern) to 99.2% (most densely textured cross-hatched pattern). Figure 9 shows the bimodal curve defined by the means of the intervals. The curve again appears to be a higher order polynomial. Logarithmic and power function models for the entire curve and for each pattern (see Figures 10 and 11) within the test are as follows.

Log function for both patterns:

$$y = -2.7687 + 5.1762 * \log(x)$$
$$\quad\;\; (1.0076) \quad (0.6402)$$

RMSE = 0.9105
R^2 = 0.9033
n = 9

Power function for both patterns:

$$\log(y) = -0.3103 + 0.0355 * \log(x)$$
$$\quad\;\; (0.0355) \quad (0.0226)$$

RMSE = 0.0321
R^2 = 0.9908
n = 9

Log function for dot patterns only:

$$y = -3.0459 + 5.5258 * \log(x)$$
$$\quad\;\; (1.2194) \quad (0.8023)$$

RMSE = 1.0498
R^2 = 0.8714
n = 9

Power function for dot patterns only:

$$\log(y) = -0.3595 + 0.6712 * \log(x)$$
$$\quad\;\; (0.0421) \quad (0.0277)$$

RMSE = 0.0362
R^2 = 0.9882
n = 9

Log function for cross-hatched patterns only:

$$y = -20.7683 + 14.7992 * \log(x)$$
$$\quad\;\; (2.7714) \quad (1.5622)$$

RMSE = 0.7217
R^2 = 0.9373
n = 8

Power function for cross-hatched patterns only:

$$\log(y) = -2.0318 + 1.522 * \log(x)$$
$$\quad\;\; (0.6523) \quad (0.3677)$$

RMSE = 0.1699
R^2 = 0.7407
n = 8

RESULTS OF NON-PARAMETRIC STATISTICS

Non-parametric statistical analysis was performed using the NCSS package. The correlation being tested is whether a selected non-random subset of the population would chose intervals that were significantly different than the means derived from the entire population. Personal characteristic information was compiled from responses on the post-test questionnaire (See Appendix B). Characteristics tested were: (1) Age, (2) Gender, (3) Time spent on test, and (4) Experience (Relative scale). Spearman's, Pearson's and Kendall's Coefficients were calculated. None of the population subsets showed a significant correlation with test results.

Therefore, a logical conclusion is that perception is not influenced by any single personal characteristic measured in this study. Tests were not performed to rule out the possibility that several of the measured variables, or others not measured here, in combination may correlate with perception. Additionally, it must be recognized that the range in respondents age was relatively small and heavily weighted to the 18 to 20 year old grouping, a potential source of bias.

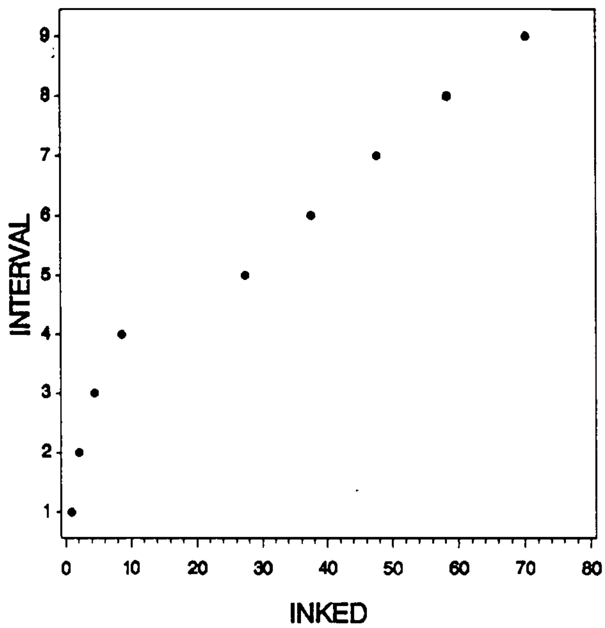


Figure 6. -Distribution of means from test five, with both 0.2 mm dot and cross-hatched patterns included.

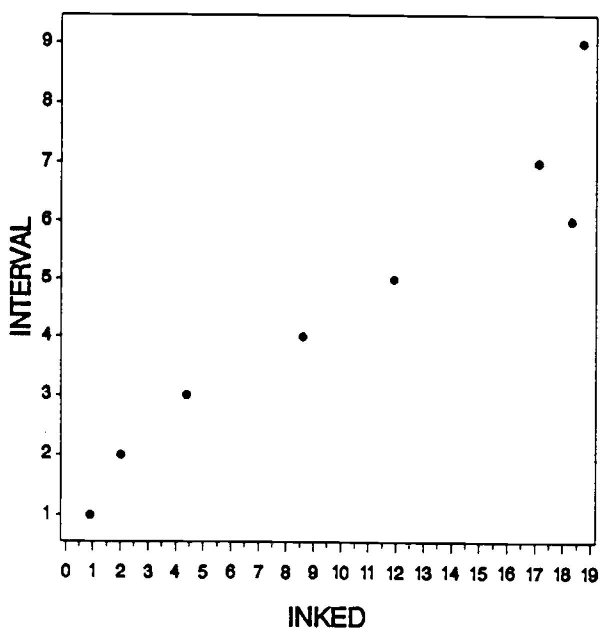


Figure 7. -Distribution of means from test five, 0.2 mm dot pattern only.

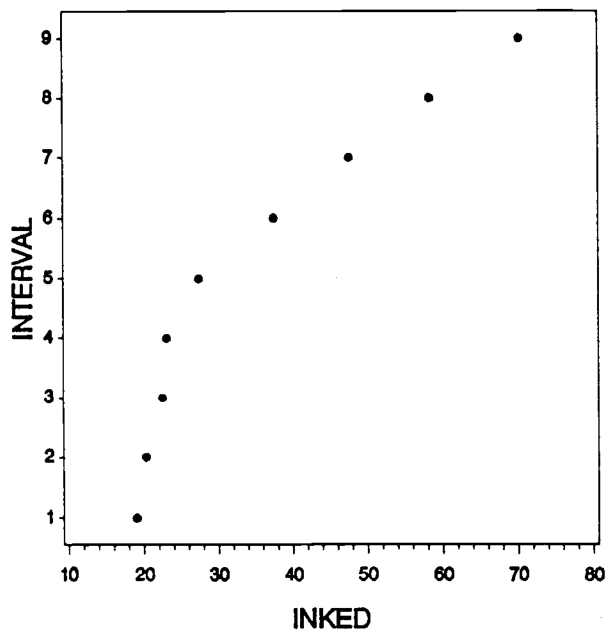


Figure 8. -Distribution of means from test five, 0.2 mm line width cross-hatched pattern only.

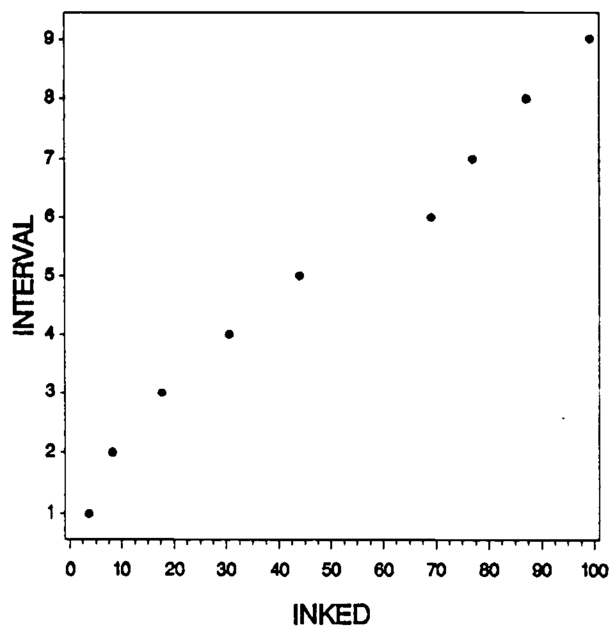
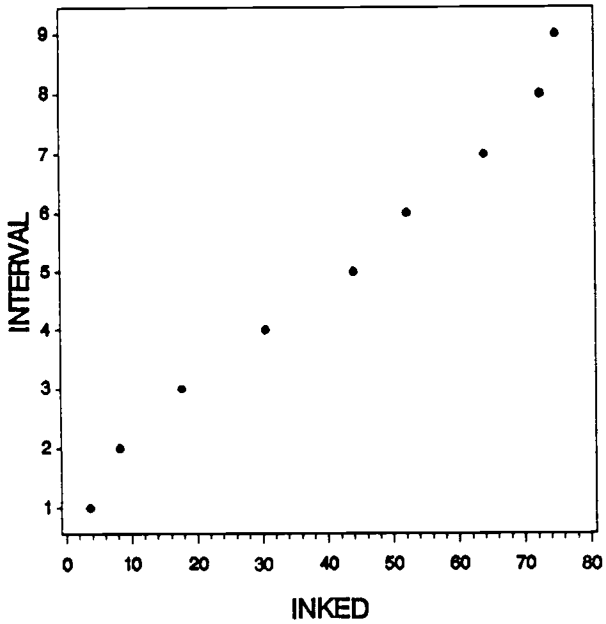


Figure 9. -Distribution of means from test six, 0.4 mm dot and cross-hatched patterns included.



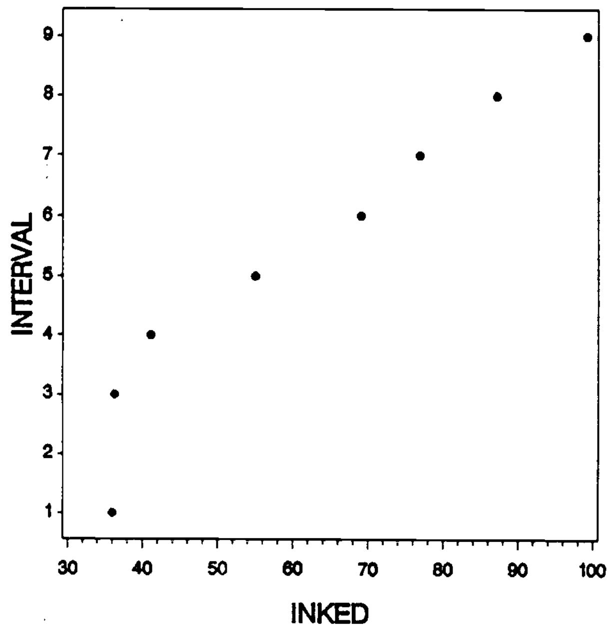


Figure 10. (left). - Distribution of means from test six, 0.4 mm diameter dot pattern only.
Figure 11. (right). - Distribution of means from test six, 0.4 mm line widht cross-hatched pattern only.

DISCUSSION

Although both models reported for tests one through four show a reasonable fit based solely on the correlation (R^2) values, it is clear that logarithmic functions provide the best fit. In addition to having consistantly higher R^2 values than the power functions, the logarithmic functions are more linear in appearance (Figures 2B - 5B). It should not be surprising that both models fit the data as well as they do considering only nine points define the curve and the fact that power and logarithmic functions are not dissimilar.

Several previous studies dealing with gray tone perception have used similar testing methods (Plateau, 1873; Munsell, 1915; Kimerling, 1975) yet all their results indicated perception of gray tone conforms to power function laws. Stevens (1975) contends that indeed most sensory-stimulus continua adhere to the psychophysical power law. Several other studies, however, have also utilized similar methods to deduce logarithmic or other types of functions (Fechner, 1858; Williams, 1958; Jenks and Knos, 1961).

Why the difference in calculated model functions? One possible explaination is that the continuous tone gray scales, devoid of obvious pattern (such as those examined by Kimerling and Munsell) represent a prothetic continuum as defined by Stevens (1975). The introduction of pattern into the gray scale, as was done by Williams, Jenks and Knos, and this study, may be representative of a continua that is metathetic. The studies of Castner and Robinson (1969) seem to confirm this hypothesis. They noted that patterns below 40 lines per inch are perceived only as pattern with no associated gray value. Further, dot patterns below 75 lines per inch have obvious pattern affects. Although a gray value may be associated with the pattern, it seems to be a poor definition of the pattern by itself.

The influence of pattern is illustrated in Figures 2B - 5B and Tables 1 - 4. The width or range in confidence intervals and error measures at interval two are far smaller then the same measures at interval eight. For all but test four, the starting patterns of the partitioning tests are less than 20% area inked, which is in the area of perceived pattern only according to Castner and Robinson. In each testing case the percent of area inked range falls totally or partially under the 75 lines per inch upper threshold specified by Castner and Robinson.

While it is clear that patterns used for test one through four are best defined by a logarithmic function, very observable perceptual differences exist for dot patterns and cross-hatched patterns. Statistics per interval for the dot patterns, reported on Tables 1 and 2, show a distinct similarity. The standard deviations (and associated SE's) decrease systematically from interval one to interval seven (end points excluded). This indicates test subjects had greater relative difficulty partitioning at lower values than at higher values, increasing variability. This phenomina is consistant with observations and conclusions of previous studies, particularly the work of Castner and Robinson. It is also corroborated by comments gleaned from the post-test questionaire, where several subjects reported they could "see only dots" and no gray when evaluating the more sparsely textured low value options for their continuum.

In contrast to the dot patterns, the standard deviations and associated standard errors at each mean interval for the cross-hatched patterns (Tables 3 and 4) do not systematically decrease. Rather, they increase slightly or remain constant up to interval four (end points excluded), then decrease. This seems to indicate test subjects had more difficulty choosing the first interval or center point of the continuum, producing greater variability in the middle range of the curve. This appears especially true for test packet three, which contained 0.2 mm cross-hatched patterns with a range of value lower than the 0.4 mm cross-hatched pattern.

Although the standard deviations and standard errors at the means from test packets one through four suggest dots are perceived differently than cross-hatched patterns, it is not possible to make this statement conclusively because each test involved a different range in value.

Results from test packets five and six, the mixed pattern tests, provide additional insight. Were dot and cross-hatched patterns perceived the same, that is simply as a "generic" pattern, the curves generated from the tests should be comparable to those generated for tests one through four. While the range in value was different for dot and cross-hatched patterns within either test, there was considerable overlap. This allowed test subjects to complete the partitioning test with any of a large number of pattern combinations that would created a progression of value (based on percent area inked).

However, results from both test five and six show a bimodal distribution. The shape of the curve indicates test subjects deemed the cross-hatched pattern to be "darker" than the dot pattern when the percent of area inked was in fact equal. Subjects were apparently hesitant to mix the two patterns freely and tended to utilize dot patterns for the first four intervals and cross-hatched patterns for the rest of the partitioning. While this choice may indicate a preference for sparsely textured, low value dot patterns over sparsely textured cross-hatched patterns, it may also be nothing more than an artifact of the testing method. Because it is clear that sparsely textured patterns are difficult to match to a gray value, test subjects may have simply utilized dot patterns through the first intervals to remain consistent with the beginning pattern, which also was a dot pattern. The same may have been done with the ending intervals in efforts to match the ending pattern.

While much has been learned about the effect of pattern on value perception, it is apparent that much work is still left to do. One obvious need is for further studies to test perception of pattern on gray value in a map context. Comparison of patterned gray scales on choropleth maps, for example, may be warranted.

SUMMARY

The effect of pattern on gray tone area symbol perception has been examined in this paper. While several factors have been shown previously to have an affect on gray tone perception, such as lighting and background, the effect of pattern and texture is not as well understood. A partitioning experiment was performed to: (1) assess the nature of the gray scale curve when pattern is obvious, and (2) assess the potential perceptual differences between patterns.

While it is likely that perception of gray scales devoid of pattern adheres to power function laws, as suggested by Stevens (1975) and Kimerling (1975), curves derived from the partitioning experiment suggest that perceived gray scales with obvious pattern conform to logarithmic laws. In essence, obvious pattern makes the use of value as a single measure ineffective, as suggested by Castner and Robinson, and shifts the gray scale from a prothetic continuum to a metathetic continuum.

It is also clear that not all patterns are perceived the same, even simple geometric patterns at the same texture. Results of the partitioning experiment indicate low value dot patterns are more difficult to partition at the lowest values represented, whereas cross-hatched patterns appear to be more difficult in the middle range of values. Further, cross-hatched patterns seem to be perceived "darker" than their dot pattern counterparts at the same percentage area inked. This suggests use of more than one pattern in mapping is suspect when the goal is to show a progression of value for a single variable. It is therefore important that cartographers continue research utilizing psychophysical methods in order to create better, more comprehensable map products.

INSTRUCTIONS

The experiment you are about to participate in is called an equal interval partitioning test. It is not a test in the sense that there are right or wrong responses, but rather an experimental situation where your results will help define an "average" perception of pattern densities. As in any experiment a sincere effort on your part is highly important.

Before you are several squares with a pattern on each (either dots, crosshatch or both). I will provide you with a starting and ending pattern. Your task is to first select the pattern that visually has a density (or visual darkness) halfway between the starting and ending patterns (see diagram below). Then choose a pattern halfway between the starting pattern and the chosen halfway pattern. Repeat this sequence to fill each space by always choosing the pattern you feel is visually halfway between the patterns on each adjacent side. The objective for you is to place seven equally stepped intervals (partitions) of visual density between the given starting and ending patterns.

You are allowed to change any or all of your responses at any point, but you will probably find it helpful to lay out most of the seven responses before you change any of them. There is a lettering code on the back of each pattern square. This code does not indicate a progression, it is a random code. So please do not utilize it to help you decide on your choices.

There is no time limit to this experiment. Simply work at your own pace. If you have any questions please ask them now. If everytning is clear to you, go ahead and begin.

1	2	3	4	5	6	7	8	9
Starting Pattern		2nd or 3rd		First		2nd or 3rd		Ending Pattern

POST-TEST QUESTIONAIRE

1. Age _____ 2. Gender ___M ____F 3. Time ______

4. Any serious vision problems?

5. Experience level (Rate yourself from one to ten on familiarity with perception studies and/or the use of patterns).

6. Briefly describe how you accomplished this test.

7. Briefly describe anything concerning this test you felt was more difficult or less difficult than the rest of the task.

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