CHOROPLETH MAPS ON HIGH RESOLUTION CRTs : THE EFFECTS OF NUMBER OF CLASSES AND HUE ON COMMUNICATION

By: Patricia Gilmartin and Elisabeth Shelton

Gilmartin, P. and E. Shelton (1990) *Choropleth Maps on High Resolution CRTs: The Effects of Number of Classes and Hue on Communication.* Cartographica, v. 26(2): 40-52.

Abstract:
The research reported here was designed to determine how quickly and accurately map readers viewing choropleth maps on a high-resolution computer monitor are able to identify to which class an areal unit on the map belongs, when the map has between four and eight classes and is produced in shades of either gray, green or magenta. As expected, accuracy rates decreased and reaction times increased as the number of classes on the map increased, Accuracy rates ranged from 91.9% for four-class maps to 68.2% for eight-class maps (averaged for all three colors used in the study). Hue also affected accuracy rates and reaction times, the best results being obtained with achromatic (gray-shaded) maps: 84.5% correct, averaged over all numbers of classes. Maps shaded with magenta proved to be the least satisfactory with an accuracy rate of 72.8%. The study provides cartographers with empirical guidelines regarding what level of map-reading accuracy might be expected for choropleth maps designed with a given number of map classes, in a specific hue, and displayed on a high-resolution graphics monitor.

Article:
Q. *What is the maximum number of shades of gray that people can distinguished reliably on choropleth maps?*

A. *Seven, plus or minus two.*

This maxim has served as a general rule of thumb for cartographers for many years, although the specific number of gray-tones recommended by various authors ranges from five to ten. What is the basis for these recommendations? It appears to be primarily professional judgment because until recently there was no empirical evidence as to how many shades of a color map readers could distinguish from each other in a map context. Furthermore, the recommendation above applies to maps printed on paper. No one, to our knowledge, has approached the same question for maps displayed on CRT monitors, It was the purpose of the experiment reported in this paper to determine how quickly and accurately people could identify to which class an areal unit on a choropleth map belonged when the map had from four to eight classes. The maps were produced on a high-resolution color monitor in either an achromatic (black and white) shading series or one of two monochromatic designs.

Over the years cartographers have conducted a great many studies on various aspects of choropleth maps. This body of research includes studies of data classification techniques, map complexity measures, systems of value and/or color assignments for classes, and the search for perceptually-equal steps in the gray scale. The important question of how many classes can be perceived accurately by the map reader has been all but overlooked by cartographic researchers, although several authors have stated their opinion as to what that maximum number might be. Their estimates fall generally within the range of 'seven, plus or minus two.'

This general guideline 'seven, plus or minus two,' can be traced to an article by psychologist George Miller (1956) in which he reviewed a number of studies designed to measure how many levels of various sensory stimuli people could distinguish from each other. He called this the 'channel capacity' of human observers for unidimensional perceptual variables. Over a wide range of stimuli, Miller found that people's channel capacities did not vary much; they clustered around the 'magical number' seven, plus or minus two. Miller concluded, "There seems to be some limitation built into us either by learning or by the design of our nervous systems, a limit that keeps our channel capacities in this general range. On the basis of the present evidence it seems safe to say that we possess a finite and rather small capacity for making such unidimensional judgments and that this capacity does not vary a great deal from one simple sensory attribute to another" (p. 86).

Miller's findings may be of theoretical interest to cartographers, but he, of course, was not concerned at all with map design in his research. In fact, the studies on which he based his conclusions did not even include any which measured the channel capacity for gray-tones or shading patterns.

Apparently, the two earliest papers by cartographers which dealt with the use of graded shading patterns on choropleth maps both appeared in 1961. Schultz outlined a hypothetical mapping problem and discussed the decisions a cartographer faces in developing a set of shading values. The author stated that, after taking into account the readability and purpose of choropleth maps, the optimum number of classes would fall between three and six (Schultz 1961:224 No references or empirical justification for this conclusion were given, however.

In another 1961 article, Jenks and Knos reported an extensive study of the use of self-adhesive shadings in one-color maps. The authors tested map-user preferences for pattern styles and textures, compared various psychophysical functions of the gray spectrum, and attempted to determine the most practical gray scale for map use. In one test, Jenks and Knos asked subjects to look at some seven-class isarithmic maps based on five different gray-scale functions and to tell *either* which function resulted in the most even gradation from black to white *or* which set of shadings were most easily distinguishable from each other. These results were used to select the gray-scale curves to be used in the final test.

In the final portion of their research, the authors used as variables four gray-scale functions, from four to eleven classes, and applied the shadings to both isarithmic maps and spectral columns. Subjects in the study were told to judge which illustration (among the ones they were given) appeared to have the most visually-equal steps from black to white. Thus the primary purpose of this experiment was to determine which gray-scale curve produced the most satisfactory equal-step progression between black and white in a more or less map-like context. Discriminability among shadings was not examined in this part of the study.

In the almost-thirty years since these two articles appeared, a number of other cartographers have offered their recommendations on the question of how many values of gray are distinguishable in a complex choropleth map environment. Table I provides a summary of their advice. It is clear from the quotes shown in this table that there is a rather wide range of opinion regarding how many discrete values between black and white can be distinguished reliably from each other on a choropleth map. Some of the authors provided no basis for their recommendations, while others cite the early Schultz, and Jenks and Knos studies. The latter is the only one based on empirical evidence, and it did not directly address the question of how many gray shades can be distinguished in a choropleth map context. Thus, it is not surprising that its results are not particularly applicable to that question, even though it is sometimes cited in that context (see Table t). Jenks and Knos, themselves stated, "Very little can be concluded about the threshold of differentiation from the test ... until further testing can be done it would seem unwise to use more than seven shadings" (1961: 331).

Finally, in 1984, Janet Mersey conducted a study designed to measure the effects of color scheme and number of classes on choropleth map communication. She included ten different map-reading tasks in the research, two of which were related to people's ability to distinguish gray-tones on maps. In one such task, subjects were asked to compare ten pairs of counties on a choropleth snap and tell which of each pair had the higher quantity of the variable represented. The other task required subjects to compare counties on a map to the map legend and indicate to which legend category they belonged (Mersey 1984: 62-63). These tasks were conducted with maps where the data had been divided into three, five, seven, or nine classes, Six color schemes were tested, one of which was an achromatic sequence of values which ranged from black to white. The entire study was conducted using printed maps (reflected light).

TABLE 1. ***SUMMARY OF CARTOGRAPHERS' RECOMMENDATIONS REGARDING THE NUMBER OF CLASSES WHICH CAN BE DISTINGUISHED ON GHOROPLETH MAPS***

The number of brightness steps which people can distinguish is "limited to about ten and often to only six or seven in a complex environment of juxtaposed areas." M. WOOD *1968: 56*

"... each type of shading should he distinctive enough to be recognizable on sight. This places a limit on the number of divisions that can be used, although much will depend on whether colour or black and white only is available. Whichever is the case, a maximum of eight to ten types seems suitable in practice ..."
G.C. DICKINSON *1973: 53*

"... the human eye can confidently identify only a small number of shadings or sizes of symbols. flow small this number is must depend upon the constraints on range of symbols available, upon the spatial context of the symbols and the smoothness of variability portrayed, and upon human factors. Generally, it is taken as seven or eight (Jenks and Knos, 1961); certainly it would rarely exceed ten or fall below four." EVANS *1977*: *98*

"One constraint [on the number of classes that should be used on chloropleth maps] is imposed by some readers' inability to differentiate readily and with consistent results among more than eleven different gray tones (Jenks and Knos, 1961:133). Actually no more than six categories are recommended, even though a specialized audience of planners or researchers might be able to cope with a greater number of classes (Schultz, 1961: 225-216)." M. MONMONIER *1977:* 27

"In the cases where the graphic dimension is variation in the intensity of one hue the question of relative differences becomes extremely critical. As one continues to partition the same domain and create an increasing number of distinctions these differences, of necessity, must become visually less and less distinct. As a consequence, a suitable number of variations within a line probably ranges from four to seven intensity changes." DOBSON AND SIBERT *1982: 32*

"Differences in percentage of black must be great enough to be discernible by the reader. For choropleth maps whose patterns are complex, it is necessary to use a series of screens in increments of so per cent, so the grays will be distinctive even against a complex and variable background." [by implication, a maximum of six classes] GUFF AND MATTSON *1982: 144*

"Perceptually, a reader is limited to relatively few classes on a monochromatic map. Even when both pattern and value are employed, live to eight classes approach the maximum." A. ROBINSON, ET AL. *1984: 348*

"The number of classes became somewhat standardized when it was learned that map readers could not easily distinguish between more than eleven areal-symbol graytones [Jenks and Knos, 1961]. In practice, no more than six classes ac recommended [Monmonier, 1977], and a minimum of four is also good practice."
B. DENT *1985: 199-200*

"There is no general best number of classes ... Given that the number of classes must usually be restricted, one may argue for as ninny as are technically/perceptually possible— the common seven or eight."
M. COULSON *1987: 27*

Mersey found that on the first task, comparing the values of two counties to each other, the accuracy rates for the three-, five-, seven-, and nine-class maps were, respectively, 89%, 75%, 68%, and 58% (p. 93). On the second task where subjects were asked to compare the shading of counties to the legend, the accuracy rates (after a downward adjustment for the possibility of guessing) were 96%, 70%, 66%, and 26% (p. 102). Thus, Mersey's study shows that even on a five-class map — a classification level well within the range recommended by most cartographers — people could correctly identify specific gray-tones only about three-quarters of the time, on average.

In addition to the question of how many shading values can be distinguished, there is also a theoretical issue regarding how to design areal shadings for choropleth maps in order to facilitate certain map-reading objectives. One point of view argues that the shadings should be similar to each other to enhance the perception of overall spatial patterns. The other maintains that shadings should be as dissimilar as possible so that people can compare specific areal units to other areal units or to the map legend (Jenks and Knos 1961: 325-326; Mersey 1984: 10--13; Monmonier 1974; Olson 1976; Robinson, *et al.* 1984: 342). Based on the former point of view, it is not so critical that map readers be able to distinguish each grey-tone from all others, while in the latter it is. Since it is not possible to predict or control whether map readers will use a choropleth map to look for regional trends and patterns or to obtain tabular data for specific units on the map (or both), the cartographer must, ideally, try to design the map so that it will fulfill both potential applications.

In practice, most cartographers probably take the maximum range of brightness available (white to black for an achromatic map, or white to 00% of a hue for a monochromatic map) and divide it into as many equally-spaced steps (however that is defined) as they have classes to represent. And in most cases, they would prefer to use as many classes as can be distinguished perceptually, since the greater the number of classes, the smaller the error due to classification. Thus the question of how many values can be perceptually distinguished is an important one.

The purpose of the study described below was to answer that question for choropleth maps on CRT screens. Map shadings in three different hues were examined, since maps on computer monitors are probably produced more often in color than in black and white, as printed maps are. The effects of hue and the number of levels of shading were evaluated by how long it took map readers to match shadings on the map to shadings in the legend (reaction time) and how accurately they were able to do so. Reaction time has been shown to be directly related to how similar two things are along a judged dimension: the more similar they are, the longer it takes to discriminate between them. Thus, differences in reaction time can be used to derive an interval level scale of subjective magnitude differences (Moyer and Bayer 1976; Moyer and Dumas 1978).

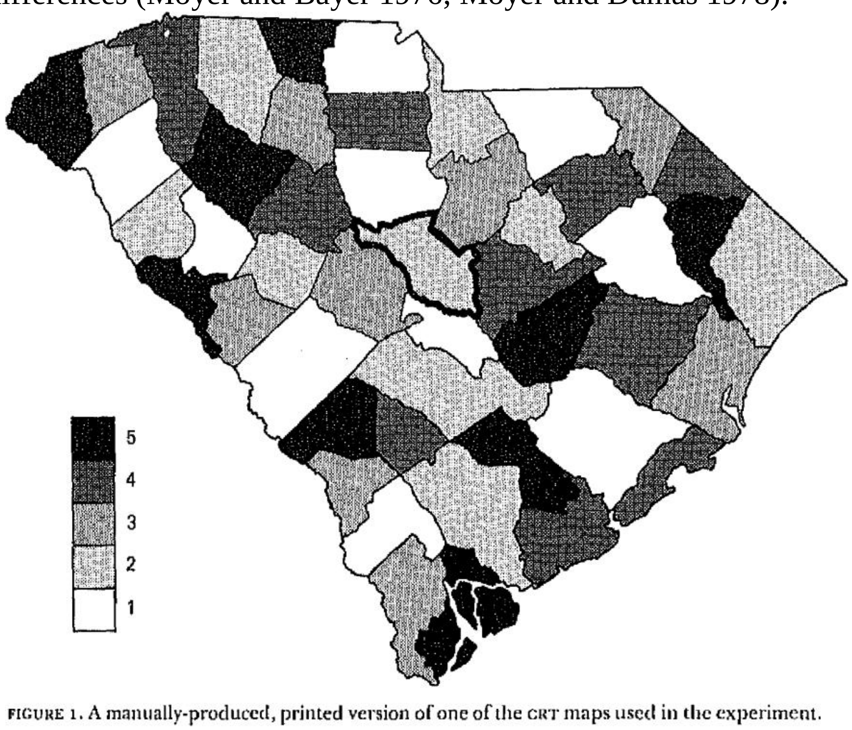

FIGURE 1. A manually-produced, printed version of one of the CRT maps used in the experiment.

METHOD

Subjects in the study were 23 females and 17 males drawn from geography classes at the University of South Carolina. Their participation was voluntary, and they were paid $5.00 for their assistance.

The maps for the experiment were produced on a dedicated computer system consisting of a 19-inch Aydin color monitor with a resolution of 670 × 480 pixels and capable of displaying 16.8 million colors. The host computer was an IBM-XT equipped with a millisecond clock and an Artist it color graphics board. The study was conducted in a research lab within the Department of Geography where room lighting and computer settings could be controlled.

The maps used as stimuli were choropleth maps of South Carolina on which the forty-six counties of the state had been divided into either four, five, six, seven, or eight classes, with approximately equal numbers of counties assigned to each class. (A sample map is shown in Figure). The counties were shaded using one of three color systems: an achromatic scheme (gray-tones) or a monochromatic series using either green, (a primary color) or magenta (a secondary color comprised of blue and red wavelengths). In all cases, the maps were displayed on a black background. The brightness levels assigned to the various classes on the maps were calculated by taking the entire range of brightness available and dividing it into equal intervals. In objective terms, the gray scale ranged from zero foodainhefts (fi) for black to 34.70 fl for white; the magenta brightness ranged from 14.15 fl to 34.70 fl; and the green varied from 20.6 fl to 34.70 It Thus the gray scale provided the greatest range of objective brightness values, and the green scale had the smallest range.

Each map had a legend located in the lower left corner. The legend boxes were numbered one to 'n' depending on how many classes appeared on the map (see Figure 1). No titles were given to the maps.

Participants were tested individually. The experimenter read the instructions to the subjects (the instructions are reproduced here in Appendix A) and started them on some practice trials to familarize them with the procedures and equipment being used. They were given 20 practice rounds in using the numeric pad for their responses and five trials with the maps themselves. Subjects could repeat the practice trials until they felt comfortable and ready to proceed with the actual experiment.

In the experiment, the maps were presented to the subjects one at a time, in random order, on the computer monitor. Participants were to compare the brightness of the shading for Richland County to the shadings shown in the legend and tell which class Richland County belonged to. (Richland County was chosen as the target because it is located at the approximate geographic center of the state and is where the University is located, making it familiar to the students. See Figure 1.) The subjects sat with their preferred hand positioned over the number-pad of the computer keyboard and gave their response by pressing a number (one through eight). After they gave their answer, the screen cleared and another map appeared in a few seconds. Response times were recorded as the time elapsed between the presentation of the map on the screen and the subject pressing a number-key to answer.

Each subject saw every possible combination of hue and number of classes for a total of go maps (three hues times so maps per hue (4 + 5 + 6 + 7 + 8 classes =, 30)). Subjects took about twenty minutes to complete the set of go maps.

ANALYSES AND RESULTS

The independent variables in the study were the number of classes in the maps (five levels) and the hue used to shade the map (three levels). The dependent variables were the percent correct answers and the time required to respond. The means of the dependent variables were compared using the General Linear Model analysis of variance of SAS (Statistical Analysis System). Figures 2 through 5 and Tables 2 and 3 summarize the results of the study.

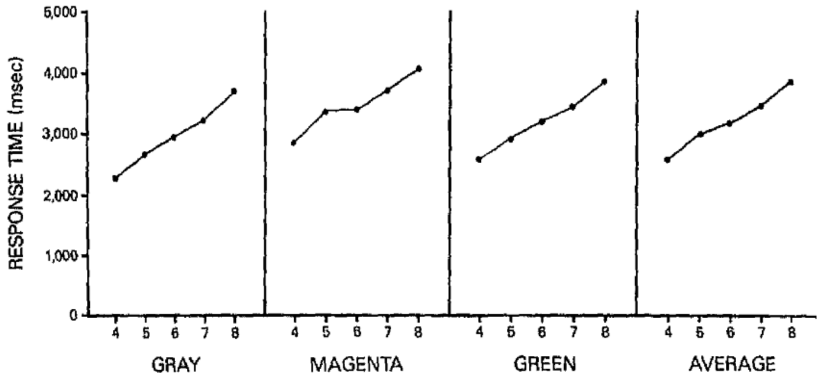

FIGURE 2. Mean percent correct responses for each level of classification, hue, and combined for all hues.

As can be seen from Figure 2 and Table 2, the accuracy with which subjects were able to match a value on the map with the corresponding value in the legend decreased as a function of the number of classes on the map, from a high of g I .g correct for four classes (averaged for all three hues) to a minimum of 68.2% correct with eight classes. This difference is highly significant statistically ($F(4,3595) = 27.09$, $> F = .0001$). Multiple comparisons of the means using the Student-Newman-Keuls (sNa) method indicated that there was no significant difference between the mean percent correct answers for maps with six and seven classes, but all others were significantly different from each other at the .05 level (see Table 2).

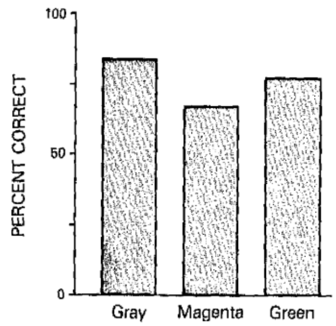

FIGURE 3. Mean percent correct responses by hue.

There was also a significant difference in accuracy based on hue ($F(2,3597) = 43.24$, $P > F = 0.0001$). Subjects performed best with the map shaded with gray-tones, while the worst performance was on the magenta map (Figures 2 and 3 and Table 2), Post hoc comparisons showed that the means for all three hues were significantly different from each other ($p > .05$) (Table 2), but the interaction between hue and the number of lasses was not significant ($F(8,3591) = 1.62$, $P > F = .1142$).

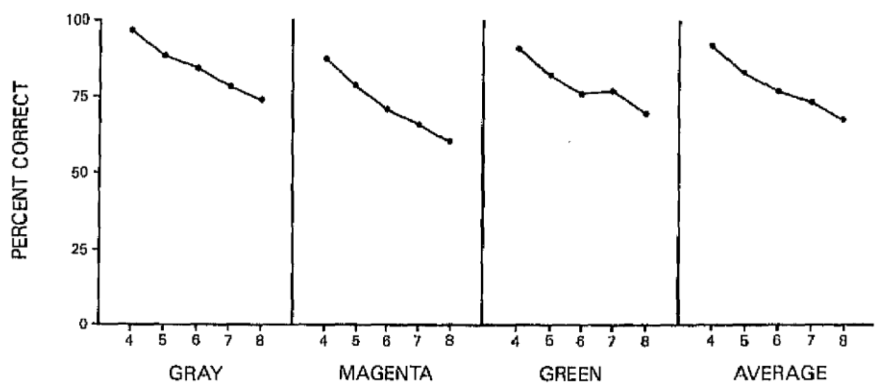

FIGURE 4. Mean reaction times for each level of classification, hue, and combined for all hues.

The main effect of reaction time was also affected by hue and the number of classes on the map. The greater the number of classes, the longer it took for the subjects to identify the class to which Richland County belonged (Figure 4 and Table 3). These differences were significant at the .0001 level ($F(4,3595) = 25.45$). According to the SNK multiple means comparison, the reaction times for the five-and six-class maps are not significantly different from each other, but all others are (Table 3).

Hue also had a significant effect on reaction times (F(2,3597) = 11.75, P > F = .000). Gray again proved to be superior overall (fastest response times), and magenta produced slowest response times. (See Table 3 and Figures 4 and 5). There was no significant interaction for the reaction times between hue and number of classes (F(8,3591) = 0.21, P > F = .99).

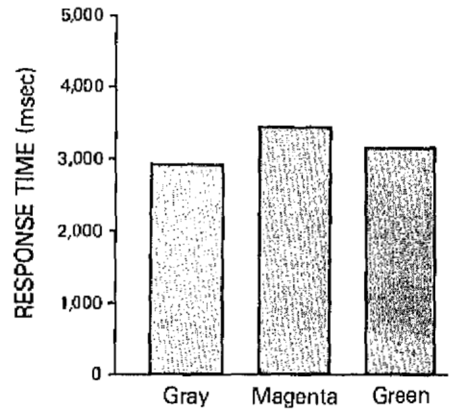

FIGURE 5. Mean reaction times by hue.

TABLE 2. PERCENT CORRECT BY NUMBER OF CLASSES AND HUE

Number of classes	Hue			Overall mean*
	Gray	Magenta	Green	
4	96.9	87.6	91.1	91.9 A
5	88.5	78.0	82.2	82.8 B
6	84.6	70.7	76.3	77.2 C
7	78.1	67.1	78.6	74.6 C
8	74.3	60.4	69.8	68.2 D
Overall mean*	84.5 A	72.8 B	79.6 C	

*Means with different letters are significantly different from each other at the .05 level, according to the SNK multiple means comparison.

TABLE 3. RESPONSE TIMES (MSECS) BY NUMBER OF CLASSES AND HUE

Number of classes	Hue			Overall mean*
	Gray	Magenta	Green	
4	2280	2854	2578	2578 A
5	2647	3372	2922	2980 B
6	2957	3379	3202	3179 B
7	3221	3704	3420	3448 C
8	3679	4047	3842	3856 D
Overall mean*	2957 A	3471 B	3193 C	

*Means with different letters are significantly different from each other at the .05 level, according to the SNK multiple means comparison.

In sum, in spite of the fact that the subjects took longer to answer the more difficult questions (i.e., when discriminations were finer due to a higher number of classes and when the map was colored in magenta), there was still a loss of accuracy in their answers. Thus, there was no successful trade-off of time for accuracy. Subjects did not take longer and produce more accurate answers; on the contrary, they took longer to answer but their answers were more inaccurate.

The data were also analyzed for differences in performances based on gender. The differences in accuracy rates for men and women did not quite reach commonly accepted levels of statistical significance (males = 80.2%, females = 78.1%; (F(1,3598) = 3.19, P > F = .0741)). In response times, however, the females were significantly faster than the males (males = 3469.2 msec, females = 3041.7 msec; (F(1,3598) = 24,40, P > F = .0001)). there was no significant interaction between gender and any of the other independent variables.

DISCUSSION

The general findings of this study were predictable; i.e., if you take a finite range of a physical stimulus, such as brightness, and divide it into finer and finer increments, it will become more difficult for observers to discriminate among the increments. Stated in cartographic terms, the greater the number of classes on a monochrome choropleth map, the less the accuracy with which people can match a particular areal shading on the map to the same shading in the legend. The specific contribution of this research, then, is in providing absolute levels of accuracy and reaction times which might be expected for maps with a given number of classes on a high resolution ma monitor.

TABLE 4. COMPARISON OF PERCENT CORRECT, MERSEY (1984) AND THIS STUDY

Number of classes	Mersey (1984)	This study
5	69.9	85.6*
7	66.4	74.5*

*Means on black and white maps, adjusted to compensate for guessing, as in Mersey, 1984,p. 104. See accompanying text.

In addition, the research shows that there are significant differences in how well people can distinguish between brightnesses levels of different hues. Again, common sense would suggest that the brightness continuum between black and white would provide the greatest number of discriminable brightness levels, since the range of brightness between black and white is the maximum possible. However, the fact that scores for the green map were significantly better than scores for the magenta map — even though magenta had a greater range of objectively-measured brightness should be of interest to cartographers.

There is little prior research with which to compare these results. The study by Mersey (1984) was similar in its objectives, but its methodology was somewhat different, and it was conducted with printed maps rather than maps on a computer monitor, Nevertheless, it might be of interest to compare the findings of the two studies as much as possible. The only portion of her research which is comparable to the experiment reported here was one described earlier in this paper. Using choropleth maps with three, five, seven, and nine classes printed in black ink on white paper, subjects were asked to identify to which class in the legend a particular county on the map belonged. Mersey then applied an adjustment factor to the percent correct answers to account for the possibility that subjects may have guessed at some answers. The scores from this study were similarly adjusted using the equation from Mersey,

$$\text{Adjusted score} = \text{number correct} * \left[\frac{1}{(\text{no. of classes} - 1)} * \text{number incorrect}\right]$$

and the resulting scores are summarized in Table 4. (Comparisons between the two studies are possible only for the black and white maps having five and seven classes).

Subjects obviously performed much better in the study reported here than in Mersey's study (see Table 4). It would be fruitless to speculate on the reasons for such divergent scores because the experiments differed from each other on several critical parameters, including stimuli (printed versus CRT maps), method of administering the test (group versus individual testing), instructions, and the like. It is quite discouraging to think that map readers can distinguish gray-shades on a five-class printed map at only a 70% accuracy rate. These two studies suggest that people can discriminate brightness better on a CRT monitor, but additional research would be needed to substantiate such a conclusion and to account for it.

This study provides cartographers with some guidelines regarding the level of map-reading accuracy they can expect on CRT choropleth maps with between four and eight classes in one of three colors. Ultimately, of course, the individual cartographer still faces the problem of how best to balance the loss of map-reading accuracy which results from increasing the number of classes on a map against the concommitant gain in data-handling accuracy. In addition, there is still the consideration of whether the perception of overall spatial patterns (in contrast to the identification of a specific areal unit) is affected by the numbers of classes and, therefore, the size of the increments in shading values. The research reported here did not deal with that question, but it is an important one.

Most of the design guidelines that cartographers currently depend upon were formulated for traditional maps printed on white paper backgrounds, There is still a great deal of research that needs to be done on the subject of how to design maps that will be presented to the viewer on CRT monitors. The 198os saw the introduction of electronic atlases, and that trend appears certain to continue and grow. It is hoped that people involved in the production of such atlases, as well as others who design maps for electronic display, will benefit from the research reported here.

REFERENCES

COULSON, MICHAEL R.C. 1982. In the matter of class intervals for choropleth maps, *Cartographica, 42/2,* Monograph 37: 16-39.
CUFF, DAVID J. and MARK MATPSON 1982. *Thematic maps: their design and production,* New York: Methuen.
DENT, BORDEN D. 1985. *Principles of thematic map design,* Reading, Mass: Addison-Wesley Publishing Co.
DICKINSON, G.C. 1973. *Statistical mapping and the presentation of statistics*, 2nd edition, London: Edward Arnold,
DOBSON, MICHAEL W. and JOHN SIBERT 1982. The design of thematic maps for computer display, NST Report 82-17, School of Engineering and Applied Science, George Washington University, Washington, ne.
EVANS, I.S. 1977.111e selection of class intervals. *Transactions, Institute of British Geographers,* (New Series) 2: 98-124.
JENKS, GEORGE F, and DUANE KNOS, 1961. The use of shading patterns in a graded series, *Annals, Association of American Geographers,* 51/3: 316-334.
MERSEY, JANET E. 1984. The effects or color scheme and number of classes on choropleth map communication. Unpublished Ph.D. dissertation, Department of Geography, University of Wisconsin-Madison.
MILLER, GEORGE A. 1956. The magical number Seven, plus or minus two: some limits in our capacity for processing information, *The Psychological Review,* 63/2: 79-97.
MONMONIER, MARK S. 1974. Measures of pattern complexity for choroplethic maps, *The American Cartographer,* 1/2: 159-169.
t 977. *Maps, distortion, and meaning,* Resource paper no. 75-4. Washington, DC.: Association of American Geographers.
MOYER, R.S. and R.H. BAYER 1976. Mental comparison and the symbolic distance effect, *Cognitive Psychology,* 8: 228-246.
MOYER, R.S. and S.T. DUMAS 1978, Mental comparisons, in *The psychology of learning and motivation, vol.* 12, G. Brawn, ed. New York Academic Press.
OLSON, JUDY M. 1976. A coordinated approach to map communication improvement, *The American Cartographer,* 3/2: 151-159.
RCM INSON, ARTHUR H., RANDALL SALE, JOEL MORMON, PHILLIP MUEHRCKE 1984. *Elements of Cartography,* 5th edition, New York: John Wiley & Sons.
SCHULTZ, GWEN M. 1961. An experiment in selecting value scales for statistical distribution maps, *Surveying and Mapping,* 21: 224-230.
WOOD, nt. 1968. Visual perception of map design, *The Cartographic Journal,* 5/1: 54-64.

APPENDIX A. INSTRUCTIONS TO SUBJECTS

Instructions to Participants

I am going to show you a series of maps called "choropleth" maps. Here's an example of what a choropleth map looks like: all of the counties are shaded, and the shading shows that the county belongs to a certain class. In order to tell which class a county belongs to, you would have to refer to the map legend. On this sample map, you can see that <this> county falls into <this> class, and ≪this≫ county falls into ≪this≫ class. Do you see how choropleth maps work?

The purpose of the study is to see how many classes people can tell apart on maps like these. You will be shown some choropleth maps of South Carolina on the computer monitor. I want you to look at Richland County on each map ... (here is Richland County on this map, and it will always be outlined to identify it on the maps in the experiment).., and simply tell me the number of the class that it belongs to, The legend will always be here in the lower left corner of the screen, and each legend box will have a number with it. Type the number of Richland County's class using these numbered keys on the computer. In this example you would type "___."

On some maps it will be very easy to tell which class Richland County belongs to, and on others it will be more difficult. On the difficult ones, just do the best you can and give an answer even if you are not sure if you are right or not. I will be keeping track of how long it takes you to answer and whether your answer was right or not, so answer as quickly and accurately as you can.

Do you have any questions?

Let's start with some practice trials. These don't count toward the real experiment ... they are just so you can get used to what you are to do.

First I'll give you some practice with using the number keys so you can answer quickly without fumbling around too much. Sit with both of your hands positioned over the keyboard like <this>, with your fingers on numbers 1-8, and watch the screen for a number between 1 and 8 to appear. As soon as you see it, hit that number key. If you make a mistake, a "beep" will sound to let you know that you hit the wrong key. Press the space bar to see the next number. There will be twenty of these practice numbers.

OK, now let's do a few practice rounds with the actual maps. You will see five maps come up one at a time on the screen. Remember ... look at Richland County and tell which class if falls in by pressing one of the number keys.

Now we are ready for the actual experiment. This will probably take you about 15 minutes to complete.

RESUME La recherche decrite ici a etc concue pour determiner la vitcsse et la precision avec lesquelles les usagers d'une carte choroplethe affichee stir un ecran informatique a haute resolution peuvent identifier a quelle dasse tine unite cartographique de surface appartient, alors que le nombre de classes representees stir la carte wale de quatre a huit et que la carte est produite dans des tons de gris, vert no magenta. Tel que prevu, la precision a diminue et le temps de reaction a augments mesu re que le nombre de classes augmentait. Les taux de precision allaient de 91,9%, pour des cartes presentant quatre classes, a 68,s% pour des cartes renfermant huit classes (la moyenne ayant ete fake pour les trois couleurs utilisees lots de retude), Les teintes affectaient aussi la precision et le temps de reaction, les meilleurs resultats ayant *ete* obtenus avec des cartes achromatiques (grises), soil des reponses correctes a 84,5%, en faisant la moyenne de tons les nombres de classes. Les taux de precision les moins satisfaisants ont ete obtenus a partir de cartes utilisant des tons de magenta, avec on resultat de 7a,8%. Cette etude procure done aux cartographes des indices empiriques quant au niveau de precision que l'on peat attendre de in lecture dune carte choroplathe, concue 1 partir d'un nombre de classes donne, clans tine teinte specifique et affichee stir un &ran informatiqtte a haute resolution.

KURZFASSUNG Das Objekt der hies beschriebenen Forschung war, herauszufinden wie schnell und genau Kartenleser, die Choroplethen-karten auf Computermonitoren betrachteten, filing waren, die Hlassenzugehorigkeit einer Gebietseinheit zu bestimmen, wenn die vorgeftlhrte Karte xwischen vier und acht Klassen enthalt und in Grint-, Grau- oder Magentastufen erscheint. Wie erwartet nahmen die Genauigkeitsgrade abund die Reaktionszeit zu, wenn die Zahl der Klassen grti8er wurde, Die Genauigkeitsgrade schwankten zwischen 91,9% fur Vierklassenkarten und 68.2% ftir Achtklassenkarten im Durchschnitt far alle drei Farben. Die Farbtone beeinflunten ebenfalls die Genauigkeitsgrade und Reaktionszeiten. Die beaten Ergebnisse warden mit achromatischen (graugestuften} Karten erzielt: 84.5% ricking im Durchschnitt alley Klassenzahlen, Magentagetonte Karten erwiesen sick als am wenigsten befriedigend mit einem Genattigkeitsgrad von 72.8%.

Die Untersuchung liefert finKartographen empirische Richtlinien, welcher Grad von Lesegenauigkeit ztt erwarten ist fiir Chowplethenkarten mit einer gegebenen Anzahl von Klassen und einem bestimmten Farbton, die auf einem graphischen Monitor dargestellt wet-den,