THE OPTIMAL THEMATIC MAP READING PROCEDURE: SOME CLUES PROVIDED BY EYE MOVEMENT RECORDINGS

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INTRODUCTION

A thematic map is an assemblage of different kinds of information on a white piece of paper. These bits of information are commonly referred to by cartographers as map elements or map components. Some of these elements include the title, body, legend and source statement. Each of these elements, as well as others, provides the map reader with information that can help him understand or evaluate the message the map author is trying to communicate. Hopefully, as the cartographer proceeds with the creative process of map construction, he structures each of the elements, and then the entire collection of elements, in a way that enhances the flow of information from map to map reader. Most map elements can be placed in an information hierarchy. This hierarchy is commonly reflected in the design of the map where more important pieces of information are visually emphasized by large or bold type or by prominent location near the top-center of the map frame. The features are made large, bold, or prominent to not only order their importance for the reader but also to attract his attention. Thus, the process of map design provides the cartographer with the means to orchestrate the map reading process -- first directing the reader to the most important information and then leading him to other less important map elements in some systematic fashion that he hopes will aid communication. This leads to the question of whether there is an optimal way to read a thematic map of given design. Most cartographers would admit that there are a large number of possible ways to read a map and it would seem likely that some map reading strategies are more productive than others from a communication point of view.

This study has attempted to answer the question of whether there is an optimal map reading process. To do this a typical thematic map was constructed and is shown in Figure 1. This map was prepared as a monochrome and contains a title, body, legend, source, scale, north arrow, author, and neatline. An attempt was made to make this map typical in all respects of the maps that commonly appear in professional geographic publications. The map was shown to twenty college students enrolled in introductory geography courses. While each subject looked at the map his eye movements were recorded on 8mm movie film by means of the corneal reflection technique. In this technique a light is directed at a person's eye. As the person shifts his gaze to look at different parts of the map the reflection of the light off the front surface of the eye also moves. The systematic movement of this reflection can be used to determine the map reading process used by a map reader. The test set-up used to make the eye movement recordings is shown in Figure 2. The subject was seated in front of the back-projected map. His head was held firmly in a head and chin rest to minimize the unwanted movements of the light reflection caused by shifts of the head. The recording camera was located below the screen on which the map was shown and was aimed at the subject's right eye. Through the use of the eye movement recordings made in this way the map reading process can be defined in terms of where on the map the subject looked, how much time he spent looking at the whole map and its elements, and what sequence he followed in reading the map.

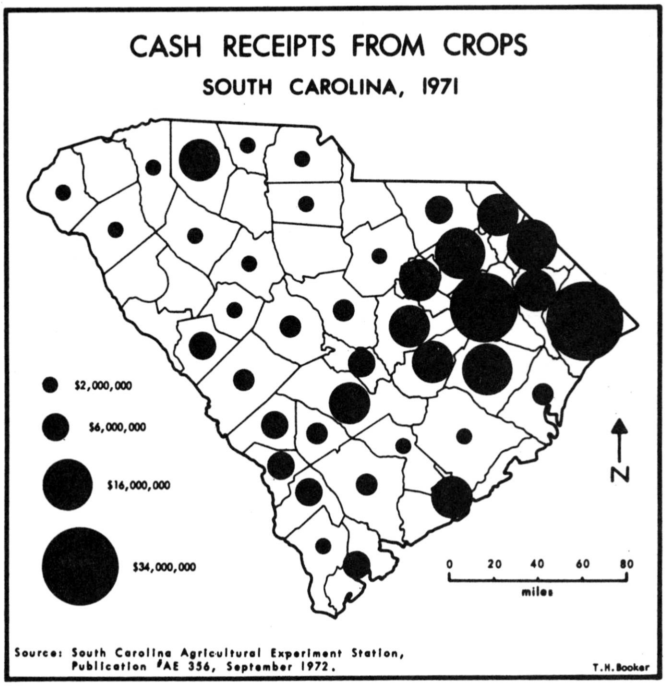

Figure 1. This thematic map is typical of many maps which commonly appear in geographical publications. While 20 subjects looked at this map their eye movements were recorded on film and later analyzed in an attempt to define the map reading process.

Human vision is a complicated process. As the human eye scans a map, or any other visual scene for that matter, it does so by shifting from one location to the next. However, little information is taken in during these rapid shifts known as saccades. Only when the

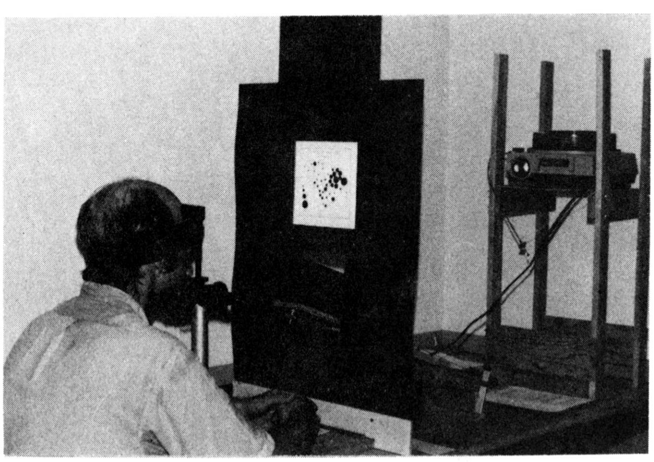

Figure 2. This subject is in position ready to look at the map projected on the screen before him. The eye movement recording camera, located below the screen, is aimed at the subject's right eye.

eye comes to rest for at least 2/10 of a second can visual information be processed. These periods of rest known as fixations average 1/3 of a second in duration but may last two seconds or more. The photographic records of the eye used in this experiment were made at the rate of nine frames per second and therefore, if two successive frames showed the eye to be looking at the same place a fixation was identified. Figure 3 shows the location of the fixations for a single subject. Just what a person sees during one of these fixations is difficult to say. It is known that the sharpness of vision drops off rapidly away from the point of fixation so that it is likely that little detailed information is taken in beyond 1/2 inch from the point of fixation at a reading distance of 18 inches. While peripheral vision plays an important role in map reading, helping the reader to direct his gaze from one area to another, little detailed information is received in this way. Figure 4 shows that portion of the map that was most likely seen clearly by the subject whose fixations were shown in Figure 3. Each of these white circles, about the size of a quarter at a reading distance of 18 inches, reveals that part of the map probably seen clearly by the subject.

Since the eye movement recordings were made on film, the duration of each fixation could easily be determined. After the duration of each fixation was known it was possible to determine the amount of time spent

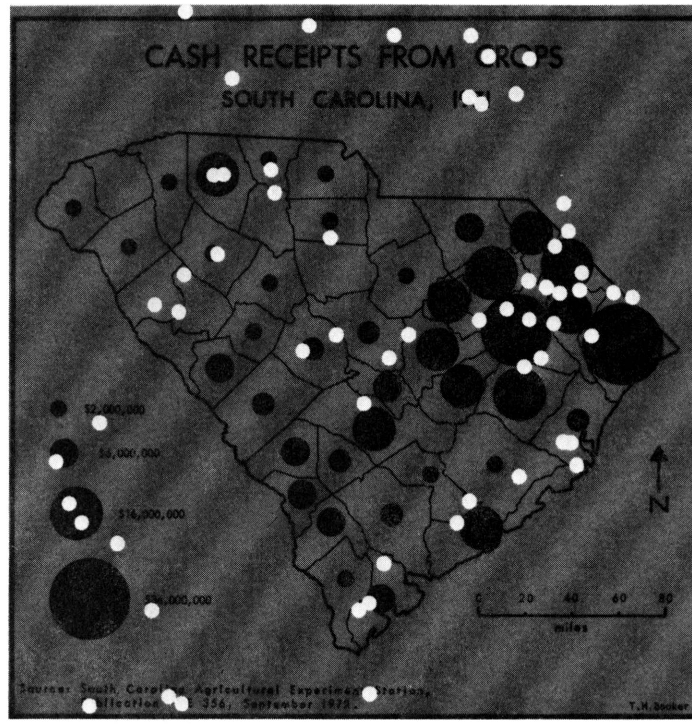

Figure 3. Each white dot represents the location of a fixation of the eye as a subject looked at the map. During these fixations, which average 1/3 of a second, the subject takes in information from the map. Note which parts of the map are and are not looked at.

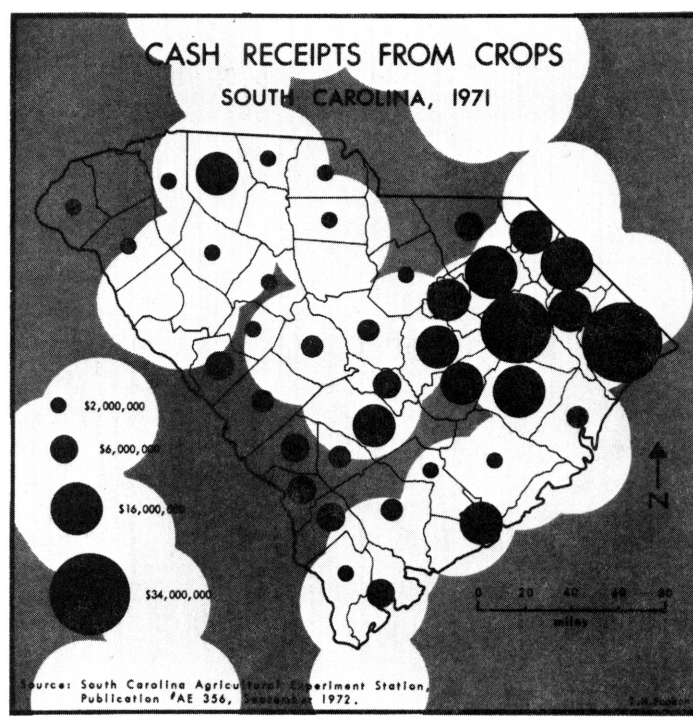

Figure 4. These open circles show that portion of the map that was most likely seen clearly by the subject. Observe that most of the informative parts of the map were covered by his map reading activity.

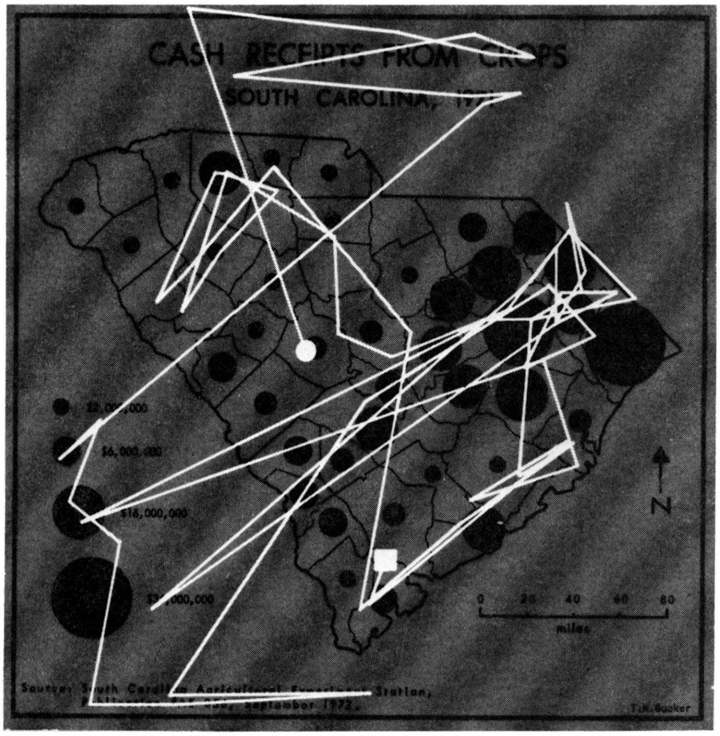

Figure 5. The eye movement film allowed each of the fixations to be linked along the map reading time-line to produce this record of the subject's scan path as he looked at the map. The scan begins at the circle and concludes at the square.

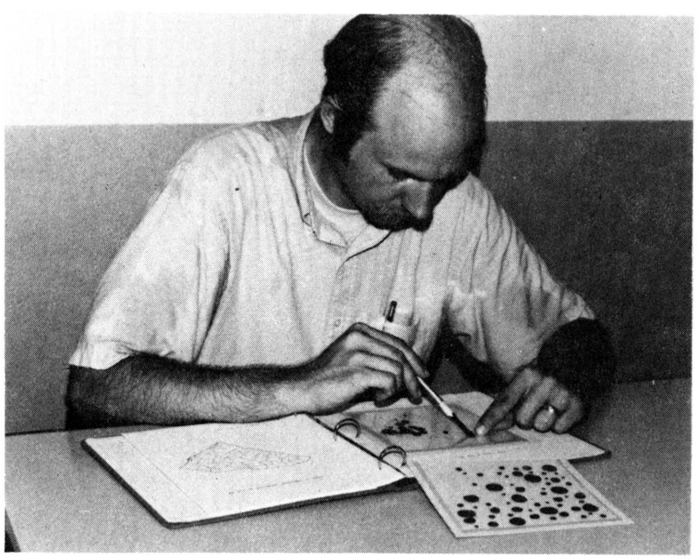

Figure 6. This subject is reconstructing his memory of the pattern of circles on the original map by transferring adhesive backed circles to a blank outline map.

looking at the entire map as well as the time devoted to each of the map elements.

The recording of the fixations on film also made it possible to link the fixations along a map reading time-line. Figure 5 shows the path connecting the fixations that was followed by a subject as he read the map. The circle indicates where he began reading and the square where he stopped reading.

These three characteristics, the location of the fixations, the duration of the fixations, and the sequence of the fixations, were used in this study to define the map reading process. Through the use of the eye movement recordings the map reading process used by each subject was determined.

In order to say which subject did the best job of reading the map, or in other words which map reading process resulted in the best transfer of information, it was necessary to obtain a measure of information flow from map to reader. This was done by means of a map reconstruction test. After each subject finished looking at the map and having his eye movements recorded, he was asked to prepare, to the best of his abilities, a replication of the pattern of circles making up the body of the map. In order to reconstruct the map body each subject was given a black outline map of the State of South Carolina and a supply of adhesive back circles of the same sizes as those used on the original map. In Figure 6 a subject is seen transferring one of the circles to the base map as he "builds" his reconstruction. Subjects were free to use as many circles as they desired and they could adjust location and add or delete circles as they proceeded with reconstruction.

The 20 reconstructed maps were then shown to another group of 70 students who looked at each of the reconstructions paired with the original map body and evaluated the similarity of the two. They were asked to score each pair between 1, meaning very different, and 7, meaning very similar. Figure 7 shows the original map body on the right and a reconstruction on the left. The average similarity score for the lefthand map was 3.51. Scores ranged from 2.01 to 3.95.

The information contained in the original pattern of circles shown on the righthand side of Figure 7 was considered the primary message the map author was trying to communicate with this map and thus the degree to which a subject replicated this pattern of circles was the degree to which it was assumed he understood the map message. It was also assumed that those subjects who did the best job of reconstructing this map body did so because they used the most efficient map reading process. An optimal map reading procedure therefore, could be defined in terms of the map reading procedures used by the subjects whose map reconstructions were most similar to the original map body.

THE MAP READING PROCEDURE

Where did subjects look on the map? Figure 8 shows where all 20 subjects looked on the map. Three, not very obvious, clusterings of fixations exist -- one on the title, one on that part of the body where largest circles are located, and one on the legend. Only two large areas were totally ignored -- one to the left and the other to the right of the title where no information was present.

Considerable variation between subjects was found in the number of fixations that occurred on each of the map elements. This paper considers the differences in

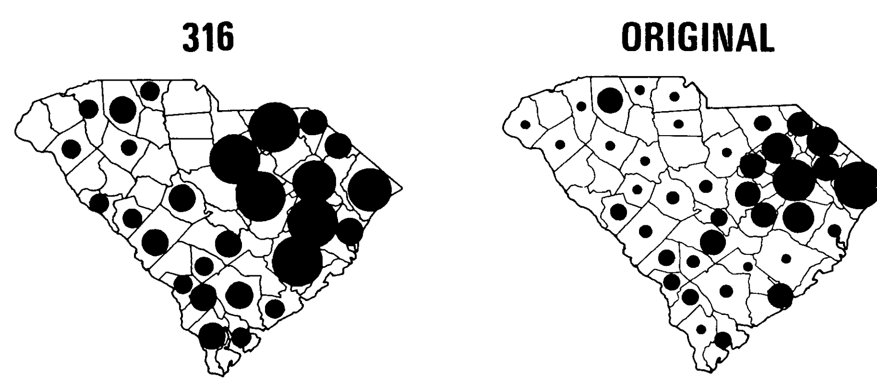

Figure 7. On the right is the original map viewed by all 20 subjects in this experiment. On the left is a sample map reconstruction. In order to evaluate how good this reconstruction was the above pair of maps was shown to 70 other people who were asked to rate the similarity of the two maps from 1 (very different) to 7 (very similar). The average score for the map on the left was 3.51.

number of fixations that occurred on the map body because attention to that part of the map seems most closely related to the reconstruction task. Figure 9 shows the variation between subject in the number of fixations that occurred on the body -- 10 on #306 and 84 on #305. One might expect that a larger number of fixations would allow for more complete visual coverage of the entire body and might , therefore , correlate strongly with reconstruction scores. This is not confirmed by the results of the study. While the reconstruction score for #306 was the poorest, that for #305 was only 10th best out of the group of 20. In fact when the numbers of fixations on the body were correlated with reconstruction scores for the whole group, the correlation coefficient was only .19. Evidently these subjects' understanding of the map message had little to do with the number of times they fixated on the map body. However, when the fixations

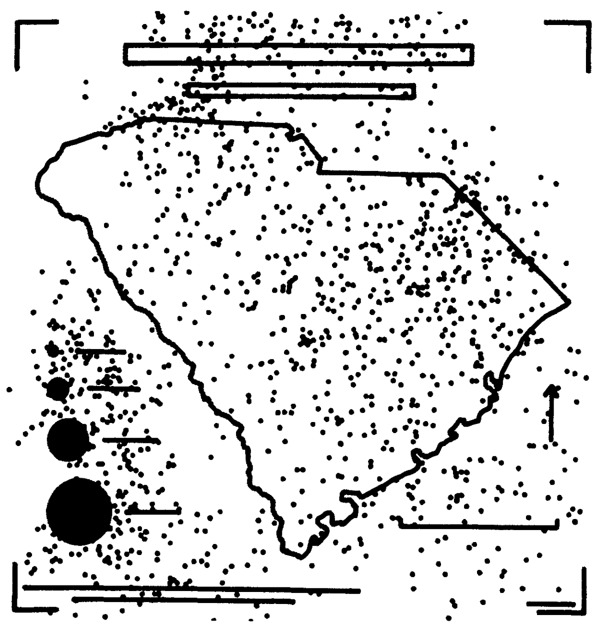

Figure 8. All of the fixations for the 20 subjects are shown above. Note the clusterings of fixations on the title, legend, and that part of the map body containing the largest circles.

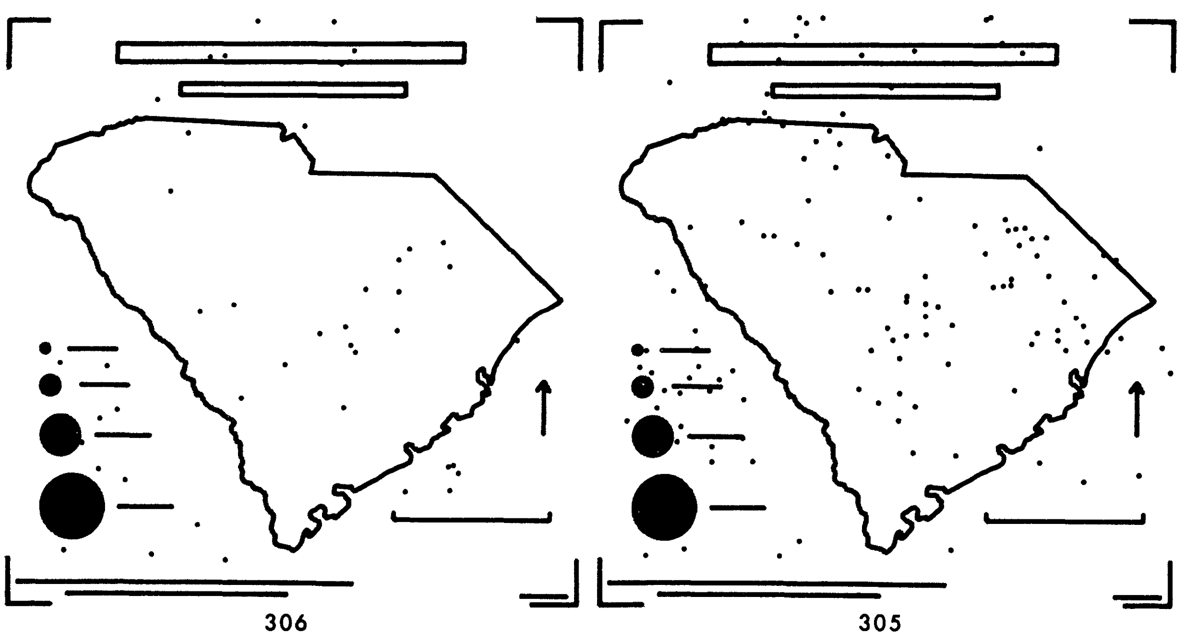

Figure 9. Considerable variation can be seen between these two subjects in the number of times they fixated on the map body. Subject #306 had only 10 body fixations while subject #305 had 84.

Figure 10. These two records show the variation in the percentage of fixations which occurred on the body. Seventy-five percent of the fixations of subject #307 fell on the body while only 28 percent of those of subject #302 fell in the same area. The subjects that had a higher percentage of their fixations on the map body generally did a better job of reproducing the map from memory.

Figure 11. Subject #305 looked at the map longest (40.3 seconds) but did a relatively poor job of reproducing the map while subject #308 looked at the map for the shortest time (12.6 seconds) but did a good job of reconstructing the map from memory. It seems there is little relationship between how much time a person looks at a map and his ability to reproduce it.

on the body were calculated as a percentage of total fixations, the results were different. Figure 10 shows the fixations of two subjects. Subject #307 had 75% of his fixations on the body and the 10th best reconstruction while subject #302 had 28% of his fixations on the body and a reconstruction score that ranked 17th. The correlation coefficient between percent of fixations on the body and reconstruction scores for the whole group was .46.

How much time did the subjects spend looking at the map. The total amount of time spent looking at the map by the 20 subjects was 449 seconds or an average of 22.4 seconds per subject. Time spent looking at the map ranged from 12.6 seconds to 40.3 seconds. One might also think that the longer a person looks at the map the better he would understand the map message. The two maps in Figure 11 indicate that this was not necessarily true. Subject #305 looked at the map longest but his reconstruction ranked 13 out of 20 while Subject #308 looked at the map for the shortest time but had the second best reconstruction. The correlation between total time looking at the map and the reconstruction scores was a poor -.17.

Total time looking at the body also does not do an adequate job of explaining a person's understanding of the map message. When time looking at the body was correlated with reconstruction scores, the correlation coefficient was only .11. But when the time looking at the body was taken as a percentage of the total time looking at the map, it appeared to be more important. This correlated with map reconstruction scores at .43.

In what sequence were the map elements looked at by the subjects? When subjects first looked at the map their attention was directed to the central and upper part of the map body as well as to the title as seen in Figure 12 where the first three fixations of every subject are plotted. From this point on, however, the scan paths become more and more individualized. A plot of the last three fixations of all subjects indicates this diversity (Figure 13), and demonstrates that while most subjects began their look at the map in a restricted area they went their separate ways shortly and concluded their scores in many different places. Despite several different approaches to the problem of analyzing map reading sequence, it has not yet been possible to systematically classify the reading patterns of subjects to see if a correlation exists between reading sequence and reader understanding of the map message. Two things have hindered this effort. First, the highly variable length of time spent looking at the map by the subjects creates problems

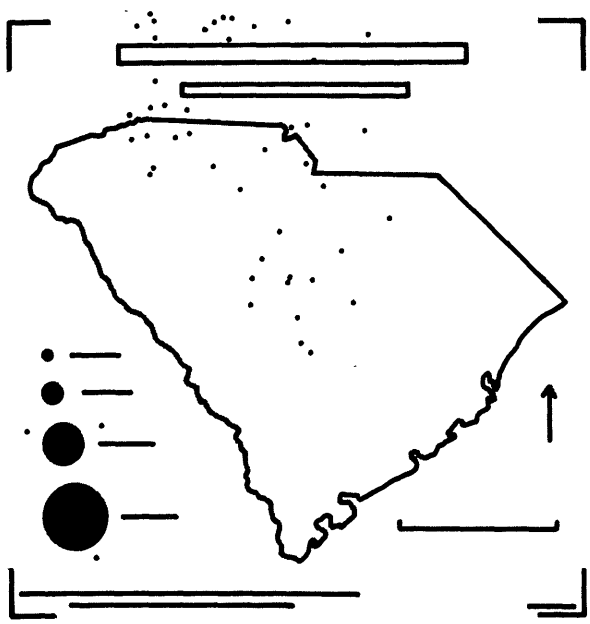

Figure 12. These dots show the location of the first three fixations of all 20 test subjects. Note the concentration of fixations at the beginning of the map scan on the upper part of the map body and on the title.

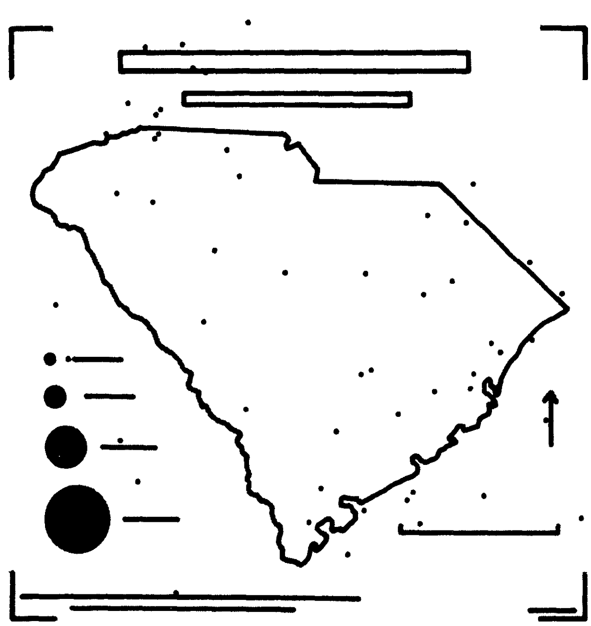

Figure 13. These dots show the location of the last three fixations of all 20 test subjects. Note the dispersion of these fixations indicating that people do not terminate their scans of the map in the same general location.

of compatibility of records, and second, the large percentage of time spent looking at one map element -- the body -- means that there was a significant repetitive factor to take into consideration. Hopefully some technique will be worked out in the future to successfully analyze map reading sequences.

CONCLUSION

In conclusion I would like to restate my original question: Is there an optimal map reading procedure and, if so, what is it? The answer to this is "yes" but it has not been as clearly defined by this study as was originally intended, partly because of the great complexity of the process. There are several aspects of the map reading process that seem to contribute to a better understanding of the map message. A large proportion of both the total number of fixations and the total map reading time devoted to the map body seems to result in better understanding. Apparently this concentration on the body helps to crystalize the map image in the subject's mind. Absolute time, or number of fixations on the body, is not a good indicator because large amounts of time or a large number of fixations may also be devoted to other less informative map elements. The subjects who spent a shorter time looking at the whole map were found to have done a better job of reproducing the map body but it is not clear whether this was due to the fact that a longer look may have clouded their memory of the map or to the existence of some inherent ability of those readers that allows them to process the map information more rapidly. Another finding of this study supports this latter possibility. When a correlation was run between the average duration of both the fixations over the whole map as well as just the fixations on the body and the reconstruction scores, the correlation coefficients were -.53 and -.41 respectively. In other words the best reconstructions were produced by people who had short fixations. It is possible that this relationship may be similar to the inverse relationship existing between fixation duration during reading and reading comprehension, which is in part thought to be a function of reader intelligence. Since nothing is known about the intelligence of the map readers in this experiment, it cannot be determined if there is a cause-effect relationship between fixation duration and reconstruction scores.

This study has determined that the optimal map reading procedure involves a relatively short look at the map, a high percentage of fixations and time concentrated on the map body, and shorter than average fixations. Certainly this study has not provided a definitive description of the optimal map reading procedure but it is the author's hope that it has at least provided the first step in that direction. Cartographers must know more about the map reading process in order to design maps which communicate better. When map design proceeds according to a set of well-tested principles rather than dogmatic conventions, we will all be more confident of our ability to communicate with maps.