EXPERIMENTAL METHOD IN CARTOGRAPHIC COMMUNICATION: RESEARCH ON RELIEF MAPS

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Abstract

This paper considers the use of tests of performance based upon map readers' speed and accuracy to evaluate relief maps. It briefly discusses some results which have been obtained from this approach. The process of creating a mental image from a relief map is seen as a data reduction task with the greatest information load occurring in the early stages of visual processing. It is argued that changes in map design will have their greatest effect in these early stages. The advantages and difficulties of testing are discussed and some recommendations are made for designing experiments which test relief maps.

Introduction

The application of performance testing will never be a routine part of designing a map. But nevertheless it must be an essential part of any attempt to understand how maps work as communication systems. Theories of cartographic communication need to be supported by evidence; without data, this year's cartographic theory will soon be dismissed as last year's cartographic fashion.

There is no doubt that the effort and expense of properly conducted tests is considerable. Those who doubt their value will most often point to problems of generality. Tests must be conducted with particular maps, with a particular group of map readers, using particular questions, and so how can one possibly say anything about maps in general? But this is not as serious a problem as many people suppose. Table 1 summarises some of the main findings about performance on three types of map reading question. Many of these results have been replicated using different maps and different groups of map readers. For example, there are at least six studies which have compared contour lines with layer tints. By analysing these it is possible to gain a fairly clear picture of their relative merits.

Although there is a need for much more research, data of the kind presented in Table 1 provide useful information for map designers. It is sometimes said that the type of information presented in Table 1 is self-evident, but this is simply not true. If you ask cartographers to rank maps in this way they will come up with a number of quite different answers. Without objective test data there can be no consensus on design questions of this kind.

Table 1 is, of course, a simplification but it is not so very far from the truth. For a fuller picture see the original papers and the review by Hopkin and Taylor (1979).
TABLE 1
Different types of relief map are tentatively categorised from 1 (=best) to 4 (=worst) for three kinds of map reading task. The table was constructed from test results from a number of sources\textsuperscript{a}.

<table>
<thead>
<tr>
<th>Type of Map</th>
<th>Type of Question</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Visualisation\textsuperscript{b}</td>
</tr>
<tr>
<td></td>
<td>Height</td>
</tr>
<tr>
<td>Tonal Layer Tints</td>
<td>1</td>
</tr>
<tr>
<td>Spectral Layer Tints</td>
<td>1</td>
</tr>
<tr>
<td>Shading &amp; Contours\textsuperscript{e}</td>
<td>2</td>
</tr>
<tr>
<td>Contours\textsuperscript{f}</td>
<td>3</td>
</tr>
<tr>
<td>Digits (e.g. Charts)</td>
<td>4</td>
</tr>
</tbody>
</table>


\textsuperscript{b} Examples of visualisation questions include judgments of intervisibility and matching the map to a relief model.

\textsuperscript{c} A simple relative height question requires subjects to circle the higher ends of straight lines printed on the map. Visualisation is not necessarily involved in this task.

\textsuperscript{d} Subjects must give the numerical value of heights at different points on the map. Visualisation is not necessarily involved in this task.

\textsuperscript{e} For shading without contours see Castner and Wheate (1979).

\textsuperscript{f} It is likely that Tanaka's method and similar elaborations of contour lines produce levels of performance close to those with contour lines alone (see Wheate, 1978; Phillips, 1979).
The Psychology of Relief Maps

Possibly the most important aspect of reading a relief map is the creation of a mental image of the three dimensional surface depicted on the map. Without some form of mental image it would be very difficult to either use the map for navigation, or to give a verbal description of the landform. It would also be difficult to match the map to a picture or a relief model, or to make judgments about intervisibility, or to do many other map reading tasks. However there are a few tasks which do not necessarily depend on the ability to visualise, for example, the estimation of height at a point.

It is likely that a map reader’s efficiency in reading a relief map depends largely on this process of creating a mental image. The process can be viewed as a data reduction task where the very large amount of raw information from retinal images is progressively reduced and structured by the brain. Despite its sophistication the visual system (the eye and the brain) has definite limitations in the early stages of processing when the information load is greatest. These shortcomings have direct implications for depicting relief and they appear to be universal that is to say they are only minimally affected by factors such as age, education and culture.

One obvious limitation of the visual system is that the eye’s retina is not uniformly sensitive across its surface. It one stares at a single point on a contour map, only a small area of the map can be read, it is necessary to move the eyes to see more. It follows that in order to visualise an area of relief the eyes must take a series of “snap shots” of different parts of the map which the brain must put together. To do this, it would seem that the brain must be able to store relevant information about each part of the map as it is examined by the eyes.

This memory or storage task is affected by another serious limitation in the visual system. There is quite a low limit to the amount of unprocessed visual information we can hold in our heads. To illustrate this take a 1,50,000 map with contours and choose a hilly area. Ask some inexperienced map readers to remember the pattern of contour lines within a single kilometer square. Remove the map after fifteen seconds and ask them at once to sketch the contour lines. The sketches produced are a crude representation of the original and often have important features omitted or grossly misplaced. It seems that the ability to recall even quite small amounts of visual detail over short periods of time is very limited. It is important to emphasise that once we have organised the information in our heads the problem is greatly reduced; the difficulty is with raw, undigested visual information.

We appear to have a problem. On the one hand a map reader is unable to see the whole map in one instant because of limitations in the resolution of the eyes, but on the other hand the map reader cannot adequately store in memory “snap shots” of different parts of the map to piece together.

The solution to this problem seems to be in the role of peripheral vision, that is, vision from areas of the retina which
do not provide fine detail but do cover a large area of the visual field. The importance of peripheral vision in map reading can be appreciated by trying to work without it. No surgery is needed! Simply obtain a tube about 20cm long and 1cm in diameter. Close one eye and look down the tube with your other eye. If you now try to read an unfamiliar map you will find the task difficult or even impossible. But if you attempt to read this article in the same way you should have very little difficulty.

A tube of this size limits your vision to a diameter of about three degrees. As you carry out these tasks you will naturally move the tube so that your central vision is unimpaired but most of your peripheral vision is blocked. Unlike reading text, map reading depends heavily on peripheral vision.

There are several reasons why peripheral vision is important in map reading but one is certainly because it provides a reminder of the detail on the map which we have previously interrogated with central vision. In order to piece together the "snap shots" we need both peripheral vision and memory. Peripheral vision is not adequate on its own because it is poor in detail, memory does not have the capacity, but together they give us access to enough information to build up a mental image of a landform.

The limitations of visual memory and peripheral vision in the very early stages of visual processing set limits to the amount of information which can be passed on up through the visual system in order to create a mental image. It is highly probable that there are other important limitations in these early stages because it is here that the amount of information being handled is greatest. Although it is likely that these limitations are only minimally affected by factors such as age and experience, changes in map design can substantially affect the processing of information in these early stages. For example, appropriate colour coding can both increase the amount of information from peripheral vision and allow the rapid extraction of features in a particular colour.

No one knows, of course, how the brain takes raw visual information and turns it into a mental image. Nor do we know what a mental image is. Those psychologists who are willing to discuss mental images (and not all do) would agree that they are not just internal pictures. A mental image must be an assembly of information which retains some of the structure of the original but is distinctly different from it. Leeuwenberg (1971) is one of several authors who has speculated about the kind of mental code which might be used to construct images.

In creating a mental image the brain is carrying out a data reduction task. It takes large amounts of raw visual information and turns it into information which is useful. It imposes structure on chaos. If we have a mental image of a landform we can answer questions about it. It is also much easier to remember a structured mental image than raw visual information, such as a web of contour lines.

Clearly, mental images can vary in sophistication. A geomorphologist will see far more in a landform than a child.
because the geomorphologist’s mental image has abstracted more useful detail. Unlike the limitations of visual memory and peripheral vision, the limitations in the later stages of forming mental images are not universal. Age, education, experience (and possibly some innate factors) determine the ease with which we can build up and manipulate useful mental images of landforms.

It seems useful to distinguish two stages in the creation of a mental image from a relief map (see Figure 1). There is an initial low level processing stage where the visual system must handle large amounts of unprocessed information and where the limitations in short term visual memory and peripheral vision are important. And there is a higher level of processing where there is far less information to handle and where the limitations are in the cognitive strategies available which are largely determined by experience. Table 2 summarises this distinction. The dividing line between these stages need not be drawn precisely. Olson’s (1976) “level one” tasks are probably all processed at the lower level. Psychological ideas such as the icon, preperceptual processing and substantial parallel processing could also be tentatively placed at this level.

Visualising from Contours and Layers

In general it is easier to carry out visualisation tasks on a layer tint map than on a contour map. The effects are often quite large; on five out of 13 questions used by Phillips, DeLucia & Skelton (1975) the mean performance scores for layer tints were more than 50 per cent greater than those for contours. The difference is not greatly affected either by the experience of the groups tested or by the type of contour and layer maps used.

There seem to be two possible explanations for this difference between contour and layer maps. The first is that with certain types of terrain, for example, chalk downs, it is not immediately obvious which side of a contour line represents the higher ground, but on a layer tint map the direction can be seen more easily. The second reason relates to the demands made on peripheral vision and visual memory which have already been discussed. If we are looking at a particular location on a contour map, it is only in the immediately surrounding area that contour lines can be seen distinctly: other information must be held in memory. But on a layer tint map it is possible to see a much larger area without moving one’s eyes. In peripheral vision, areas of colour are much easier to discriminate than thin lines. It seems likely that this makes the integration of the shape of the landform much easier on a layer tint map than on a contour map.

The first of these factors (direction of slope) is almost certainly tackled by the brain at the higher level of processing. Map reading experience is important here and a number of cognitive strategies are available such as the use of other map features to determine the direction of slope. The second factor (the load on memory and peripheral vision) must be located at the lower level of visual processing.

Which of these is more important in practice? Let us suppose it is the first factor (direction of slope). If we take a contour
FIGURE 1
It is helpful to distinguish two levels of visual processing in the formation of a mental image from a map.
### TABLE 2

Some differences between low and high level visual processing as they affect the design of relief maps.

<table>
<thead>
<tr>
<th>Limitations of the Visual System</th>
<th>Low Level Processing</th>
<th>High Level Processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity limitations of short term visual memory, the poor resolution of peripheral vision.</td>
<td>The available cognitive strategies determined by experience, age, culture etc.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Effects of Map Design</th>
<th>Low Level Processing</th>
<th>High Level Processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good design can help considerably at this level, e.g. by structuring information to help data reduction. Changes help experts and novices alike.</td>
<td>Design changes have less effect at this level and will depend on experience, culture, age etc. Inexperienced map readers will probably benefit most from good design here.</td>
<td></td>
</tr>
</tbody>
</table>
map and make it easier to determine the direction of slope then performance on visualisation tasks should rise. Phillips (1979) tried two variations on contour lines which made it easier to discover the direction of slope but found no improvement in performance. This result suggests that the first factor (direction of slope) does not account for the large differences found in performance between layer and contour maps. Therefore the second factor (limitations in memory and peripheral vision) seems more likely to be responsible.

Further evidence comes from the similarity of this relief map research with research on colour coding on maps (e.g. Christner & Ray, 1961, Phillips & Hoyes, 1980). Experiments which have compared colour codes with other types of symbol have also found large differences in performance and in this case, there can be little doubt that the advantage of colour occurs in the early stages of visual processing.

If a careful examination is made of those experiments on map design which have shown very large differences in performance, it would seem that all of them can be explained by effects at the lower level of visual processing. These include work on colour coding, typographic coding and relief maps. The map symbols tested in these experiments differed in their use of colour coding or size coding, and it has been shown that coding by colour or by size can be a very efficient way for cueing the selection of information from preperceptual visual memory (Von Wright 1968). In other words, the better map symbols aided the data reduction task in the early stages of visual processing.

When a map reader looks at the water symbols on a map, the decision to attend to the blue parts of the map must be made at the high level of processing but the actual extraction of blue symbols is made at the low level. However, not all separations of "figure and ground" can occur at the low level, it must depend on the type of symbols used.

It is, of course, often difficult to say at what level of processing effects occur. The interesting work on perceptual confusions from contour lines (Griffin & Lock, 1979, Underwood, 1980, 1981) could be operating at several levels. Some experiments on the use of cutting and embankment symbols (Phillips, Coe, Kono, Knapp, Barrett, Wiseman & Eveleigh, 1983) almost certainly operates at the higher level. School children's performance was moderately affected by the symbols used, but expert map readers showed no effects, presumably because they had more cognitive strategies to cope with symbol variations.

It has been argued that a mental image of a landform is an internalised representation which provides us with the experience of being able to visualise it and which is useful in that it allows us to answer question about it. But it must be emphasised that a mental image is not the same thing as a picture. Indeed, the process by which the brain constructs a mental image from a map is not very different from constructing a mental image from a picture or the landscape, or from the landscape itself. All involve the processing of large amounts of visual information from which a workable mental representation must be abstracted.
Computer-generated views (e.g. from SYMVU) are a method of representing relief which comes close to viewing the landscape itself. People will often prefer to look at views than at layer tint maps because they claim to be able to see the landscape more vividly. But this does not mean that their mental image is more detailed. In fact there is some evidence to the contrary: experiments by Phillips and Noyes (1978) and by Mead (1978) found worse performance on views than on more conventional maps.

Tasks for Map Evaluation

It is beyond the scope of this paper to offer detailed advice on the design of experiments but a number of recommendations can be made about the questions on which tests are based. Firstly, it seems desirable that questions should measure map reading performance rather than survey users' opinions. The complexity of map reading suggests that experiments should measure performance on a number of different questions. The papers cited have used many different tasks and an examination of these is useful in devising future experiments.

Although Board (1975, 1983) has rightly argued that questions should be based on real map reading tasks, simple questions seem preferable to extended map interpretation tasks. There are several reasons for suggesting this. The aim of the research is to discover differences between types of map and not between map readers: tasks which are appropriate for testing people are not necessarily appropriate for testing maps. People will vary considerably in how they perform complex map interpretation tasks and these differences are likely to swamp any differences between the maps. To be of any value, a performance difference between two map designs must be shown to be statistically significant. However there are some map reading tasks which may vary considerably in difficulty from one map to another but where it is quite impracticable to demonstrate this difference to a satisfactory level of statistical significance. This is likely with any complex map interpretation task where there is considerable scope for differences in the way people tackle it. Probably the best type of question from this viewpoint is a simple task which is repeated a number of times in different parts of the map (Poulton, 1965).

Furthermore, it has been argued that the larger and more robust differences between map designs probably operate at a low level of visual processing as it is here that information overloads are most likely to occur. These differences should be readily detectable with a range of simple questions and it seems unlikely that there are any major differences between map designs which only complex tasks can detect.

Conclusions

This paper has argued that performance tests have contributed to our understanding of cartographic communication both at a theoretical and a practical level but there is still a great need for further research of this kind. Many studies have demonstrated effects of map design on map reading performance,
but it has been argued that, where large differences in performance have been found, the effects probably operate in the early stages of visual processing. This has implications for the design of future experiments.

Although an understanding of low level visual processing explains many of the effects of map design it is not, of course, sufficient to explain the cognitive strategies used in map interpretation, nor to explain individual differences between map readers. Here higher mental processes are important and different experimental methodologies are demanded.

References


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