Map readers are generally faster and more accurate in interpreting relief from layer tint maps than from contour maps. This paper discusses methods of improving contour maps and reports an experiment where conventional contours were compared with contour lines elaborated to produce a 'wedding cake' effect, but this elaboration did not improve performance. The main problem for adults when reading contour maps may be a difficulty in integrating small areas of relief in order to visualise a larger area. If this is correct, no simple elaboration of contour lines will help the map reader unless it gives contours the conspicuity which layer tint colours have in peripheral vision.

An Experiment with Contour Lines

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INTRODUCTION

Today contour lines are one of the most common methods of depicting relief on a map. The difficulty they cause map readers is reflected in the large number of manuals intended to help interpret them (*e.g.* Strahler, 1953; Boxhall and Devereux, 1972). Phillips, De Lucia and Skelton (1975) compared map reading performance on a contour line map with other methods of depicting relief. The contour line map was slower to use and led to more mistakes than a comparable layer tint map on a number of tasks involving visualisation of the landform and the judgment of relative height. However, contour lines were superior to layer tints on a height estimation task. These results, from a group of police cadets, were replicated testing geography undergraduates (Audley, Bickmore and Phillips, 1974). Using a rather different testing procedure, Potash, Farrell and Jeffrey (1978) found very few statistically significant differences between contour and layer maps, but this is probably due to the small number of subjects they tested. (See the Appendix for a discussion of the statistical problem raised here.) Although nonsignificant their means are in quite good agreement with those of Phillips *et al.* (see *Figure 1*).

Although layer tints appear to be a better method of depicting relief than contour lines, there are a number of reasons why contours are so frequently used. Contour lines are printed in one colour whereas layer tints usually require several printing colours, and so are more expensive. Layer tints are necessarily a prominent feature on the map and they may reduce the legibility of other information. Therefore contour lines may be preferable when relief is a relatively unimportant feature of a map. A third reason for using contour lines, which is seldom explicitly stated, is their difficulty. This is almost certainly the motive for using contour lines in orienteering maps, where an artificial difficulty improves a competitive sport.

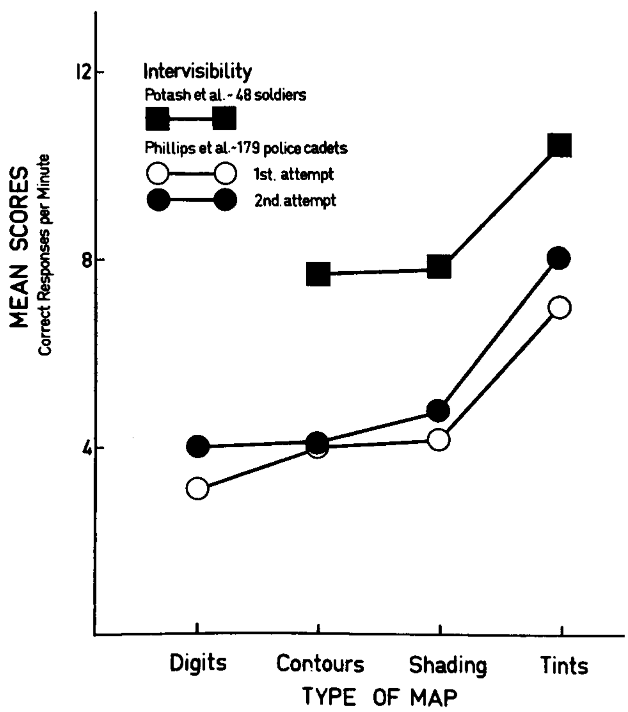

Figure 1. Potash *et al.* (1978) *Defilade* question and Phillips *et al.* (1975) *Can you see someone at A*? question both tested judgments of intervisibility. Although the maps and the testing procedures were different, the means from the two studies are in good agreement. This is also true for a number of other questions, but not for questions requiring absolute height judgments.

Given a need to use contour lines, it is worthwhile to consider how variations in their design affect map reading performance. *Figure 2* illustrates four common ways of labelling contour lines. In (a) and (c), the line is broken for the number, while in (b) and (d) the number sits on the line. This is a trivial difference, but of more interest is the difference between (a) and (b), and (c) and (d). Maps using the convention illustrated by (a) and (b) never rotate contour line labels by more than 90 degrees from their upright position so they are easy to read with the map in the normal orientation. The labels in (c) and (d) are upside down because they show the direction in which the land slopes. On maps of this sort, the label is always placed so that the top of the number is on higher ground. This provides an indication as to which side of the contour line is higher. In layer tint maps the same information is usually provided by a comparison of two bordering tint colours, but on contour maps it is sometimes difficult to decide which side of a line is higher, especially when contour lines are sparse.

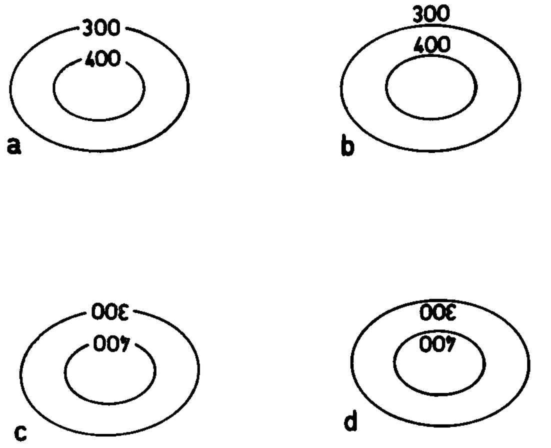

Figure 2. Four different conventions for labelling contour lines.

Since the second world war, Ordnance Survey have labelled their contour lines in the manner illustrated in *Figure 2(c)*, and a number of foreign map establishments also label contours in this way. It is therefore surprising how few experienced users of Ordnance Survey maps make use of this information. Informal questioning of hikers, mountaineers, geography teachers and cartographers suggests that only a small minority are aware that this information is provided. A questionnaire was given to 88 geography undergraduates in two university departments (*Figure 3* shows a typical question) and it was clear that only eight were able to use the information correctly. This ignorance is puzzling: relative height estimation is comparatively difficult on contour line maps and yet map readers ignore a cue which provides information on relative height. This is certainly no mindless ignorance. Our questioning included people who took map reading very seriously, and it seems likely that this orientation cue is not known because in practice it is simply not useful.

One possibility is that people may find it difficult to extract two different types of information from a contour label: the numerical value and the orientation of the number. It is probable that in order to read the numerical

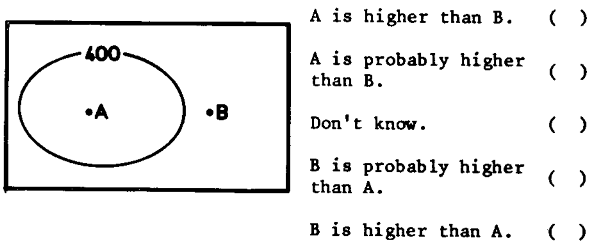

Figure 3. One item from the questionnaire. Students who answered this were told to imagine the areas were from a 1 :50 000 Ordnance Survey map. The correct answer is that B is higher than A.

value of an inverted label the brain must mentally rotate the number before it can be processed further. But this mental rotation could interfere with the perception of the number's orientation. To test this, 103 undergraduates carried out a task analogous to that of interpreting contour line labels. For one group, direction of slope was indicated by the orientation of the label, but for a second group, direction of slope was shown by a separate arrow, thus removing any possible conflict between the label's true orientation and its orientation when mentally rotated. But a statistical analysis of the students' performance showed there was little or no difference between the two groups, and so it was concluded that this explanation was incorrect.

Another experiment attempted to train geography undergraduates to make use of the orientation of the contour label but a subsequent test showed no improvement over a control group who did not have this training. It is difficult to say whether this is because there is no advantage in using the orientation cue, or because, under test conditions, those who were taught the cue reverted to their own well established strategies for interpreting contour lines.

Whatever the reason, it is clear that the orientation of the contour line label is not helpful to experienced map readers. Would a relative height cue coded in some other way be more effective? An effective cue would raise map reading performance on contour line maps to a level comparable with that on layer maps, at least where judgments of relative height are involved.

A contour line label can tell the map reader which is the higher side of an isolated section of contour line. Another way of achieving this is Tanaka's (1950) relief contour method but with this it is not necessary for the map reader to search for a label as it is the line itself which codes the direction of slope by means of highlight and shadow. *Figure 4* shows another method of coding the contour line to convey the direction of slope. This 'wedding cake' effect is much easier to produce than Tanaka's method and is likely to interfere less with other map symbols. But does it work? To find out, an experiment was conducted to compare undergraduates' performance using 'wedding cake' and conventional contour maps. Two types of question, both involving judgments of relative height, were used to measure performance.

METHOD

Subjects

The subjects were university undergraduates studying a wide range of courses including geography. There were 59 men and 28 women aged between 18 and 46 (median 20).

Material

The maps used in the experiment were adapted from the two contour line maps used in the experiment by Phillips *et al.* (1975). These were two areas from an oceanographic map presented as though they were topographic maps. There are two versions of each area: *contour* and *wedding cake*, as illustrated in *Figure 4*. The double lines in the wedding cake version were produced by displacing the original contour lines by a vertical distance of about 1.5 mm and drawing them a second time on all south-facing slopes. Each map occupied an area of 262 by 193 mm and was printed in black only on an A4 size page. Besides relief features, each map included a number of place names and was printed with ten 13 mm straight lines labelled A to J for testing purposes.

Each subject received a booklet containing four maps interleaved with blank pages. All maps in a booklet were of the same type (contour or wedding cake) but the first two depicted one area and the second two depicted the other area.

Experimental Design

Subjects were randomly assigned to one of the four conditions: contours A, contours B, wedding cake A or wedding cake B. Subjects in the A conditions were tested on area A followed by area B; those in the B conditions had the areas in the reverse order.

Procedure

Subjects were instructed to open their booklets and to look carefully at the map on the first page. They had one minute to try to visualise the depicted landscape after which they were asked to draw two crosses on the map at its highest and lowest points. They had a further minute to complete this task and then were asked to turn over so that they were looking at a blank page. It was emphasised that for the second question they should work as quickly as possible without making mistakes. For this they were asked to find the short line on the map labelled A and circle its higher end. They were told to treat the other nine lines on the map in the same way, working through in alphabetical order as quickly as possible. They turned the page to start this question and turned again at the end of the half minute time limit. The whole procedure was then repeated with the maps depicting the other area. The questions are similar to questions 1 and 2 used by Phillips *et al.* (1975).

RESULTS

The two questions were scored by counting the number of correct responses. On the first question any cross within the correct contour interval was counted as correct. Four analyses of variance were carried out on the scores for the two questions on the first and second attempts. In all of these, differences between the contour and wedding cake maps failed to reach statistical significance (adopting the $P < 0.05$ level), nor did the interaction of map type with map area. Chi squared tests on the first question also failed to reach significance.

Although this might suggest that there is little difference in performance between the two types of map, it is possible that the failure to reach statistical significance could be due to testing insufficient subjects. In order to assess this possibility, 95 *per cent* confidence limits on the difference between the means have been calculated. (See the Appendix for a discussion of confidence limits.)

Figure 4. These small areas illustrate conventional contour lines (above) and 'wedding cake' maps (below).

For the first attempt at the first question the mean for contour maps was 1.70 and for wedding cake maps it was 1.52. The 95 *per cent* confidence limits on the difference are 0.40 to −0.04 (throughout, a positive difference indicates better performance on the contour maps). For the second attempt at this question the means are 1.65 for contours and 1.49 for wedding cake, and the confidence limits are 0.38 to −0.06. This indicates that *at very best* performance on wedding cake maps could be about 3 *per cent* better than that on contour maps. When Phillips *et al.* (1975) used the same question to compare contour maps with layer maps, the layer maps were about 30 *per cent* better. Clearly, even if a difference of 3 *per cent* were to exist it would be a trivial one compared with the difference between contour and layer maps. Therefore, it is concluded that on this question there is no practical advantage in using wedding cake maps.

Turning to the second question, at the first attempt the mean for contours was 6.35 and for wedding cake, 6.31. The 95 *per cent* confidence limits on the difference are 0.95 to −0.87. On the second attempt the means are 7.46 for contours and 7.41 for wedding cake, and the confidence limits are 0.92 to −0.87. Arguing as before, *at best* the wedding cake maps could be about 12 *per cent* better than the contour maps. Using the same question, Phillips *et al.* (1975) found that the layer tint maps were about 40 *per cent* better than contour maps. Against this a possible difference of 12 *per cent* is small and again it is concluded there is no advantage in using wedding cake maps.

DISCUSSION

The fact that there were no statistically significant differences between contour maps and wedding cake maps means only that no differences are proved. But an examination of confidence limits tells us that if there is any advantage in the 'wedding cake' technique it is very small compared with the difference between layer maps and contour maps. Although this argument may seem cumbersome it is suggested in the Appendix that a number of papers published in cartographic journals which report nonsignificant results have failed to prove a difference rather than demonstrated that no difference exists.

Although map readers making relative height judgments are worse when working with contour maps than with layer maps, it does not help them to add information to the contour lines to show which side of the line is the higher. At least, this is true for the 'wedding cake' technique and for contour label cues, and so it would appear that this approach to improving contour maps is wrong.

It is useful to ask what strategies people use in interpreting contour lines. When experienced map readers are questioned about this, they often refer to two processes: a process of deduction starting from contour line labels, spot heights and other map symbols, and a process of visualisation in which they attempt to 'see' the landform. The way these interact is not clear—are they different ways of solving the same problem, or is one dependent on the other?

Visualisation itself is a puzzle. A factor analytic study by Richardson (1977) has shown that visual imagery is not one process but a number of quite independent abilities. What form of visualisation is involved in contour interpretation? If someone is asked to study a small area of contour map which is then removed and they are asked to sketch the contours, the result is a very crude reproduction of the original, often including gross inaccuracies. Clearly, visualisation does not imply detailed memory of the relief. Visualisation only works well with the map present; relief contains too much information for people to hold much detail in memory.

Perhaps when we speak of visualising relief we mean we are structuring our perception of the map in accordance with our understanding of the relief. As an example of how this might happen consider the pairs of concentric ellipses in *Figure 2*. Ignoring the labels, it is easy to see these in two different ways: either as a doughnut shape or as a small object on top of a larger one. Having chosen to see the figure one way or the other, look away for a few moments and then return your gaze to it: the chances are it will retain the structure which you originally imposed on it.

Interpreting contour maps may involve a series of operations of this kind. The map reader inspects a small area of the map and, using cues such as spot heights and rivers, decides which areas are higher or lower. He then structures his perception so that he sees the contour lines in this way. If he turns his attention to a different area of the map, he may still be able to look back and see the same arrangement without needing to refer again to cues such as spot heights.

If this speculation is correct, the efficiency of this process should depend on two things: firstly, the ease with which the map reader can interpret the map and correctly structure his perception of the contour lines, and secondly, his ability to retain this structure while looking at other areas of the map.

The methods for improving contour lines discussed in this paper have been directed at the first of these stages, that is, the interpretation of the contour lines, but it is possible that it is the second stage which poses more serious problems for the adult map reader and which is responsible for the important differences between types of map. Some experienced map readers claim they can interpret contour lines without any need to refer to spot heights and similar cues. This can only be possible when the landform contains familiar features, as is often the case on small scale topographic maps, and even with these it is probably unusual for relief interpretation to depend solely on contours. However, the act of contour interpretation need not be an especially difficult one and it may be the integration of relief across a large area of the map which is the real problem.

This could explain some of the differences between contour and layer maps. 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, but on a layer map it is possible to see a much larger area of colour or tone without moving one's eyes. In peripheral vision, colours and tones are much easier to discriminate than thin lines. Clearly, this makes the integration of the shape of the landform much easier on a layer map than on a contour map. On a contour map it is necessary to work on small areas at a time, interpreting them, structuring ones perception accordingly, and holding on to this structure as new areas are looked at. On a layer map, much larger areas can be handled at a time and even when the eyes have moved away from it, the brain is still receiving some information in peripheral vision about a large area. Perhaps the difference between reading contour maps and layer maps is rather like the difference between assembling a jig saw puzzle from a hundred pieces and from only a dozen pieces.

All the important historical developments in map symbols have involved the replacement of a pictorial symbol with a more abstract one. For example, the change from depicting buildings viewed from the side, to symbols showing the view from above. Although there is no firm rule that abstract symbols are better than pictorial ones, it is easy to be misled into assuming that anything which is pictorial works well. For example, the SYMVU method of depicting a surface makes an attractive illustration but when it comes to using it, more conventional cartographic methods work better (see Phillips and Noyes, 1978). The 'wedding cake' technique also has pictorial appeal but the experiment reported here suggests that it is no improvement on conventional contour lines. Would other pictorial elaborations of contour lines work better, for example, Tanaka's method or anaglyph maps? (Adams, 1970). Clearly they should be the subject of further experiments but if the argument developed here is correct, the special advantage of layer maps is the conspicuity of the layer colours in peripheral vision and it would be difficult to incorporate this feature in any other method of depicting relief.

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Appendix

A number of papers published in cartographic journals make a serious error in the interpretation of statistical tests. They assume that if a test fails to show a significant difference between the performance on two maps, then there is no appreciable difference between the maps. This is incorrect. There are several reasons why a statistical test can be nonsignificant even though an appreciable difference exists between the maps and the most common reason is that insufficient subjects were tested. Nonsignificance is equivalent to uncertainty and so in psychological journals editors are reluctant to publish papers where no statistically significant effects are reported.

What should an experimenter do if he suspects that two maps do not differ appreciably on a particular map reading task? Most statistics textbooks completely ignore this problem. In general it is much harder to prove that two things are the same than to prove they are different. But the map designer does not need to show two maps produce *exactly* the same performance, but rather wants to show that the difference is of no practical importance.

One approach to this problem is to report confidence limits for the difference between the mean scores. Suppose two types of bus map are being compared by asking people to name the bus routes which link several pairs of places. Thirty people use map A and 30 use map B. The mean time to complete the questions with map A is 9.3 minutes and with map B it is 9.7 minutes. A t-test on these times is nonsignificant ($P > 0.05$, two tail) but could there still be an appreciable difference between the two maps? The difference between the means is 0.4 minutes. It is an easy matter to calculate 95 *per cent* confidence limits for this difference (see Hays, 1963, section 10.16). These might be 0.4 ± 1.1. This implies that if the same experiment were repeated many times the difference would be in the range 1.5 to -0.7 on 95 *per cent* of occasions.

The hypothesis is that two maps are equally good for all practical purposes, but the confidence limits tell us that map A may be as much as 1.5 minutes faster than map B, or that map B may be as much as 0.7 minutes faster than map A. The crucial question is whether differences this small are of practical importance. Clearly, this is a subjective question and although an experimenter is likely to have an opinion as to whether the differences are of practical importance, he should allow his readers to reach their own conclusions by reporting the confidence limits.

Sometimes it is easier to express differences as percentages by dividing by the grand mean and multiplying by 100. In the above example the 95 *per cent* confidence limits are between A being 15.8 *per cent* faster than B, and B being 7.4 *per cent* faster than A. One may feel that 15.8 *per cent* is too large a difference to be dismissed as negligible. In this case the only course of action is to run more subjects in order to obtain a more accurate estimate of the true difference between the means.