The comparative effects of 2D and 3D representations on human wayfinding

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This paper reports on new research comparing the effectiveness of conventional topographic maps and new computer-based visualisation systems as aids to navigation in wilderness mountain areas in Scotland. As the study is considering both the cartographic products and the mental processes involved in their use a brief historical review is offered on the evolution and application of both conventional and digital systems. The research programme is introduced with an outline of the first main experiment which asks subjects to judge gradients and journey times for various routes presented on the maps and interactive animated terrain displays. Although results are not yet available one important factor expected to impact on performance is level of expertise in both map reading and route-finding in the field. As these new mapping systems are becoming more accessible and commercial, research of this kind will provide an important resource for future developments.

INTRODUCTION

The human facility for spatial reasoning in the environment (e.g. navigation) is essentially cognitive, and the desire to seek the support of external representations (normally map-like objects) may be an intuitive human response. Changes in the design and production of these cartographic representations have reflected changes in user requirements and been influenced by the emergence of new technologies. Today, however, we find ourselves in a period of transition. Paper maps, the legacy of the printing era, are now being supplemented and even replaced by the products of new computer-related technologies. Using static maps for route-finding is primarily an image interpretation process. Making sense of elevation contours, for instance, requires special knowledge to recognise and interpret the patterns, associate them with specific landforms and, perhaps, even create intermediate mental models as a further stage towards anticipating the appearance of the real landscape. This internal thinking/modelling process can now be enhanced by use of on-screen interaction which allows users to query, modify and animate the displays on the more recent generation of computer-based map-related products. Vera and Simon (1993) have referred to this as the interleaving of "…internal and external states in order to achieve naturalistic behaviour". Solid models perhaps similar to those pictured mentally by some experts can now be created more effectively and reliably as computer 3D terrain models, thus offering less experienced users some of the advantages of those with skill and training in map reading.

The research programme described in this paper is considering the design and potential value of these new cartographic products, and also seeking answers to psychological questions about the nature of the interaction between them and mental representations – largely ignored by current theories of human working memory[1]. Initial experiments are addressing, first, the relative effectiveness of interactive, animated 3D terrain models, and traditional contour maps as external aids in the task of estimating the gradients and time taken to complete mountain walking routes. The second experiment will test recognition memory for 2D and 3D representations.

SOME HISTORY

The history behind digital terrain modelling is characterised by two traditional graphic forms, topographic maps and landscape panoramas. Since the 18th century, national mapping agencies have sought to provide topographic map coverage with effective representation of the physical landscape. The latter was achieved using hachure symbols,

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[1] The part of the brain that provides temporary storage and allows manipulation of the information being used in complex cognitive tasks such as learning, and reasoning.

contours and hillshading, but only through skilled craftsmanship (as on Swiss maps) could the desired impressions, of sunlit landscapes viewed from above, be produced. Despite their attractive style, maps such as these are still complex documents which can challenging to users who lack expertise in contour map reading. Thus even when high-quality graphic design solutions are offered they may not necessarily provide the visual breakthrough to understanding required to help meet the needs of truly general and novice users.

Panoramas had different origins. Although related to landscape painting, they first appeared in the late 18th century as large works of art mounted on the interior walls of rotunda buildings, offering city dwellers experiences they could only otherwise obtain from high buildings and mountain tops! Later, especially in the Alps, this graphic product (now in much smaller format and more conveniently folded form) achieved huge commercial success with the growth of mountain tourism in Europe (Wood, 2003). The work of the late Austrian artist, Heinrich Berann, represents the zenith of this art form (Wood, 2000). However some features of these images, such as their fixed view-points, long production time, and 'artistically-licensed' small adjustments and distortions (such as vertical exaggeration, progressive perspective, widening of valleys to accommodate names and road/river symbols, and exaggeration of lakes and settlements) introduce problems of inconsistency which reduce their value as general-purpose visualisation tools.

APPLICATION OF TERRAIN MODELLING SOFTWARE

Despite the specific nature, artistic qualities and popularity of these two graphic media, neither satisfied the criterion of outstandingly effective 'visual-friendliness' required by unskilled map readers to support spatial-reasoning tasks such as wayfinding/navigation. Of course by the 1980s digital terrain modelling software packages were becoming available for the production of fixed views, but not until the 1990s were they sufficiently accessible, and offering graphically acceptable output. Research with two such earlier systems – LaserScan Horizon and Arc/Info - laid some of the ground-work for the present investigative programme. In the first study (Wood & McCrorie, 1993) 3D graphic images were created as support in map-reading experiments using geography undergraduates as subjects. Results suggested that the views could offer some help with contour-reading, but a more significant (and unexpected) discovery was of the considerable difficulty encountered by many of the students when trying to interpret contour patterns from the maps themselves. Reduction of map-based school-work in an increasingly crowded curriculum may be the source of this problem. If it represents a more common condition in the wider population then the need for new and more powerful geovisualisation tools will certainly be an advantage. In the second study (Wood & Goodwin, 1995) static 3D views were again created, this time using Arc/Info, and incorporating draped naturalistic colours and selected vectors (paths and streams). Test subjects were grouped by level of knowledge and experience into 'real experts' (serious amateurs, rescue teams), 'regular leisure walkers', 'occasional walkers', and 'opportunists' (e.g. motor tourists who reach a mountain car park in good weather and decide to take a walk!). Difficulties obtaining sufficient subjects for each experimental group curtailed the main research but a pilot study with real experts (serious mountaineers) led to the following observations about the potential value of 3D views of topographic maps:

- Useful for many of the preliminary tasks of route planning but less popular for on-going navigation.
- Provided that the degree of realism in surface rendering could be improved it was believed that in some circumstances such views might provide sufficient information without the support of a map.
- There was modest recognition of the possibility that high quality views could be of benefit to the improvement of mountain safety.

The outcomes of these investigations were only tentative. A more rigorous programme of experiments would have been preferred.

Used imaginatively, the new generation of terrain-modelling software can offer the degree of visual-friendliness required to support effective external cognition, with their facilities for more realistic surface rendering (where required), interactivity and animation. Looking back over the emergence of these exciting new tools it is interesting to observe that what began before and during the 18th century as separate graphic forms - topographic maps and panoramas - have now become, effectively, different options of a single fully-functional digital geovisualisation system. With it the data can now be viewed as a flat orthographic 2D map, or, with its terrain modelling features, it can offer a 3D landscape (as bird's-eye view or low-angle panorama) with possibilities for rotation, zooming and directed 'flythros'. These were truly the developments which would offer us maximum flexibility for our proposed experimental design.

THE CURRENT PROJECT: BACKGROUND AND EXPERIMENTAL STRATEGY

The term 'wayfinding' refers to navigation through spatially complex environments (Zimmer, 2001). If the environment is unfamiliar some form of external representation is often necessary for successful route-finding. The increasing availability of the above-mentioned computer-based visualisation and multimedia technologies, collectively referred to as Geovisualisation (MacEachren and Kraak, 2001), to supplement or even replace conventional printed maps has been driven by the assumption that dynamic 3D representations can provide more effective support than the 2D maps alone. Few studies, however, have examined whether this assumption is correct (Scaife and Rogers, 1996). The majority of previous findings on perception and cognition in wayfinding are based on static paper maps, and much less is known about the cognitive and perceptual issues associated with 3D and dynamic displays (Slocum et al, 2001). It is well documented that mental representation of environments produced by 2D maps are quantifiably different from representations produced by direct experience (e.g. Thorndyke and Hayes-Roth, 1982; Moeser, 1988). It is therefore important to investigate whether learning, using 3D terrain models, produces different or superior memory than learning using 2D maps of equivalent geospatial data. Another neglected area of research is on effects of expertise in the use of 2D and 3D representations. A diverse user group ranging from serious mountaineers to casual weekend walkers regularly visit wilderness areas such as the Scottish Cairngorm Mountains. Recent theories of expert cognition in orienteering (e.g. Eccles et al., 2002) are based solely on the use of 2D maps. Davies (2002) has reported no expertise differences between use of digital (on-screen) and paper maps. However her test maps presented 2D views of urban rather than wilderness environments, and expertise was not defined in terms of wayfinding experience. The majority of previous studies has largely ignored direct comparison of 2D and 3D representations, and has focused on urban/man-made settings rather than wilderness environments, or on development and application of the technology for implementing such representations for prospective users (Moore et al., 1999; Morrison and Purves, 2001). The social, economic and environmental importance of mountain regions in many countries have been steadily increasing over recent years, with an associated increase in the use of such areas for recreational activities. The purpose of the current project is to provide a source of data on whether 3D terrain models do provide better cognitive support than traditional static 2D maps, and produce empirical evidence that could allow better evaluation of the potential impact of geovisualisation tools for mountain environments.

The main objectives being addressed are (1) how expertise interacts with the ability to interpret and make use of 2D maps and 3D computer terrain models, (2) the effectiveness of 3D models as planning and navigation aids in comparison with 2D maps of the same geospatial data, and (3) whether encoding of spatial environments using 2D maps and 3D models produces different types of mental representation in memory. Two experiments are planned. The first tests the interpretation of 2D and 3D geospatial data. The second tests recognition memory for 2D and 3D representations, using the same expertise groups as in experiment 1.

Experiment 1

The subjects: The expertise groups are: novices (little of no experience of mountain environments), intermediates (casual weekend walkers), and experts (extensive orienteering-style experience). Each group will contain 24 subjects.

The stimuli: Three stimuli were presented to each subject, one on-screen topographic map and two versions of the terrain model of the same area. Using ESRI ArcGIS software, models were created of twelve separate 10km² tiles, selected from different high-level mountain regions in Scotland. Ordnance Survey 1:25 000 scale digital data was used. Both models had shading from oblique illumination, and one had a draped image – the raster version of the 1:50 000 Ordnance Survey map (see Fig 1). The stimuli were presented on a notebook computer. Routes were established on each of the maps /models and depicted by a line located 10m above the surface to avoid visual confusion with underlying symbols. Each route was subdivided into 5 segments, each with different gradient characteristics, and depicted in a different colour (red, green, purple, blue, yellow). The models were interactive through mouse and keyboard allowing the viewer to zoom from the whole scene into selected areas at will, although the extent of zoom would be influenced visually by the increasing courseness of the raster elements. It was also possible to rotate the model and fly through it in any direction and at any height above the terrain surface.

The experimental procedure: The procedure begins with an introductory session which includes 1) the recording of certain personal details such as age, and any knowledge and experience of walking, orienteering and map-reading., and 2) familiarisation with the laptop computer, the processes of interacting with the computer screen and the nature of the experimental tasks.

The subjects are then asked to judge the gradients of each section of the routes displayed. This is indicated as an angle between zero and ninety degrees. They are also asked to give a qualitative indication of the degree of difficulty for each section. Next they are asked to judge how long the total route would take to walk, excluding stop time.
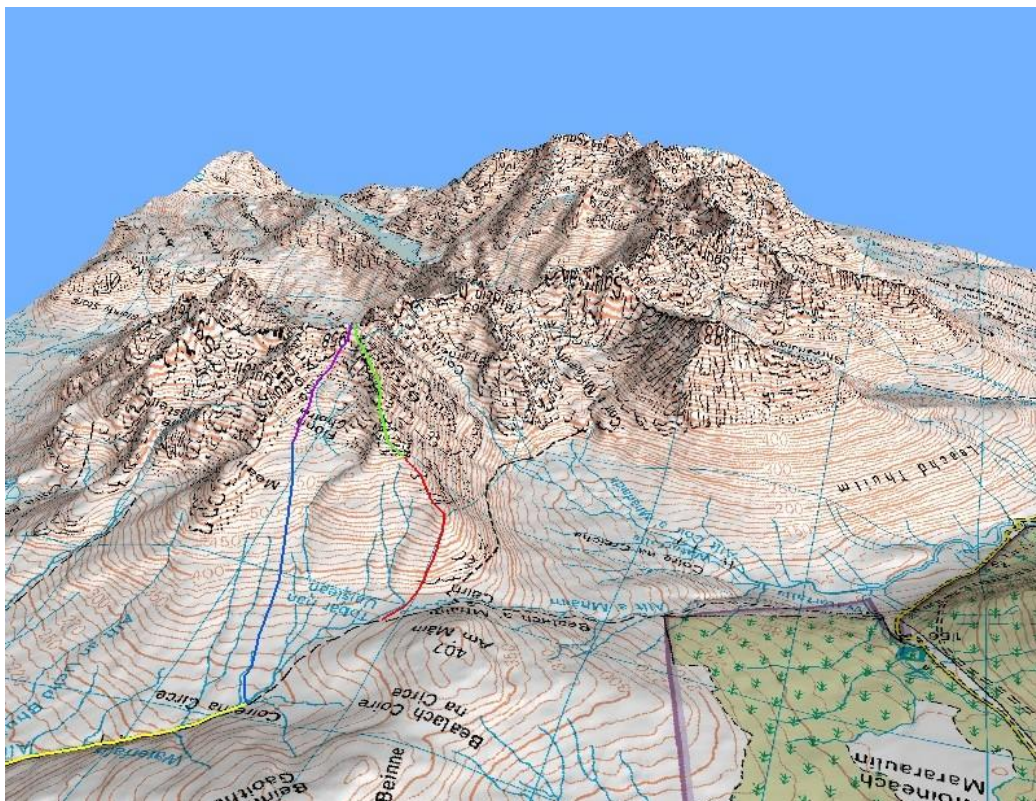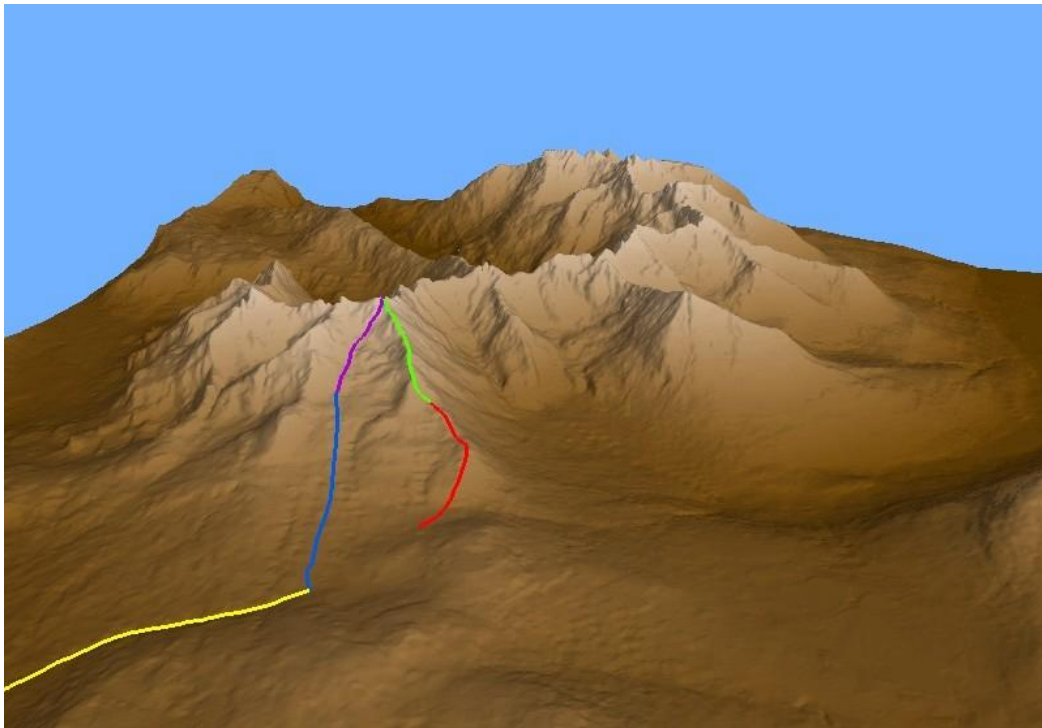

Figure 1: Undraped (upper) and undraped models of Bruach na Frithe, Cuillin, Skye, Scotland, showing Route 6.

The experimenter kept a record of how participants interacted with the software; i.e. number of rotations, number of zooms etc. This will allow greater insight into any expertise differences in how participants responded to the different forms of representation. Finally each subject is asked if they have any first-hand experience of any of the geographical regions depicted in the models. If they do then their responses are discounted. Each experimental session takes about one-and-a-half hours to complete.

Each subject will view all twelve model/regions; four through sight of the map alone, four with the undraped model, and four with the contour map drape. The experiment will adopt a repeated measures counter-balanced design that will ensure that each of the twelve model/regions will be presented an equal number of times across participants as a map, undraped model, or contour map drape. This will allow a direct comparison of participants' performance using 2D maps and 3D models generated from the same geospatial data.

CONCLUSION

At time of writing 24 of the 72 subjects have been tested. Although results are not yet available observations can be made, for instance, about the question on gradient estimation. Supporting information is more explicit in the terrain model/3D imagery than on the 2D map, but the impact of this on performance may interact markedly with level of expertise. In an earlier less formal pilot study carried out with undergraduate students studying psychology, gradient and journey-time estimations were made using the two terrain model stimuli only, i.e. without the topographic map. The results showed no significant differences in responses made from either of the models. Distinct lack of expertise in this subject group may help explain these results.

Although some research has been done on the value of animated and interactive terrain modelling in support of various tasks, most have not followed a rigorously experimental approach. In view of the rapidly growing popularity of leisure walking (e.g. walkingworld.com) and growing anecdotal evidence of the attractiveness and popularity of these new animated and interactive cartographic products (e.g. Memory-Map, Anquet Maps), the authors of this paper advise that their nature and use should be examined with some scientific rigour. Only through such methods can a suitably rich and dependable source of empirical evidence be assembled which can be of value to:

1. Product designers seeking to assess the degree of realism or symbolic support required from the displays
2. Psychologists seeking to extend their knowledge of visuo-spatial cognition and mental imagery
3. Those responsible for giving advice and training to different categories of mountain visitor
4. Environmental managers and planners.

This could also lead to new and valuable Internet resources and further opportunities to offer advice and pass on information about techniques for planning leisure journeys and for use with PDAs (or new-generation mobile phones!) in the field.

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