Expertise in a Map Reading Task: The Role of Schemas in the Processing of Topographical Relief Information

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Abstract

Earlier studies have suggested that proficient map readers employ cognitive strategies such as information chunking and schemas to aid information processing. In this paper experienced and non-experienced map readers studied and reproduced firstly a town map and then a topographical map. No group differences were observed for the town map task. When the topographical map was recalled the experts had better recall for contour related data. They also combined contour related data with individual features more often than less experienced map users and employed specialist procedures during encoding and recall. These findings are consistent with Template theory and schema based accounts of information processing.

Keywords: Expertise; Map-reading; Information chunking; Schemas; Protocol analysis.

Introduction

Expertise and information processing. The nature of expertise has been studied within a number of domains. Early work by Chase and Simon (1973) identified superior task-relevant memory skills in chess Masters and attributed this ability to a process of information 'chunking'. Similar studies have shown that experts perform better than novices when engaged in problem solving tasks incorporating electronic diagrams (Egan & Schwartz, 1979), basic electricity circuit diagrams (Cheng, 2002), medical diagnosis (Groen & Patel, 1988) and schematic engineering diagrams (Moss, Kotovsky, & Cagan, 2006). In such comparisons participants reportedly employ cognitive strategies in which information is processed in perceptual chunks. Within each chunk the information contained is consistently greater for experts than for novices.

Experts also appear to employ highly organised memory structures such as schemas (Gobet, 1998), templates (Gobet & Charness, 2006; Gobet & Simon, 1996) and retrieval strategies (Ericsson & Kintsch, 1995). By the employment of such schemas, information processing during encoding into short term memory and retrieval from long term memory is facilitated by the early identification of commonly occurring prototypical configurations and patterns within their domain knowledge. Each of these patterns and configurations may then be processed as single units of information although they may represent a number of individual components.

Expertise in map reading and comprehension is highly dependent on the efficient processing of visually presented information. In addition, the wide variety of tasks associated with topographic (terrain) map usage often require a number of associated skills including, efficient spatial memory performance, an ability to mentally rotate internal and external representations and a familiarity with task-specific map presentations to facilitate the generation of 3D mental representations from 2D displays. At a fundamental level, however, it is probable that for experts the visual information studied on a map is processed both more efficiently and at a deeper level of comprehension than for novices. Since capacity for spatial information in short term memory is limited it is again highly probable that experts employ some form of information chunking and associated cognitive schemas to facilitate rapid and efficient information processing.

Information chunking strategies and map reading. Three studies have directly addressed the employment of 'information chunking' strategies in map reading tasks. In the first of these Thorndyke & Stasz (1980) examined individual differences between experts and novices when studying a map in a recall task. Experts were observed to employ two distinct attentional procedures - partitioning (restricting study areas to sub-sets of map information) and dedicated sampling methods. The sampling methods were further sub-divided into four categories – a) Systematic sampling (directed by subject defined rules or criterion); b) Stochastic sampling (shifting to an adjacent area but with no systematic control; c) Memory directed sampling (guided by the last inspection of the map) and; d) Random sampling. Experts were further distinguished from novices by their adoption of different encoding strategies such as relational encoding (linking features by their spatial relationship) and labelling (to generate a verbal cue to assist recall). The results from this study suggested that familiarity with maps was not of itself predictive of good performance for the task of memorising and reproducing information from maps. Instead, the employment of good learning strategies for the processing of spatial information and a good visual memory were more reliable predictors of accurate recall of map detail.

Gilhooly et al. (1988) addressed the inconclusive results reported by Thorndyke & Stasz and suggested that map reading expertise had not been demonstrated by all the experts in their study because planimetric (non-contour) maps had been used. By including both planimetric and contour maps into their experimental design, Gilhooly et al. demonstrated that experts' memory for map detail in the contour maps was superior to that of the novices. However, this advantage was not observed for information recalled from the non-contour maps. The authors further reported that the two groups of experts and novices did not differ significantly in the methods they employed to study the maps nor in their use of non-specialist schemata. During recall however, the experts employed more specialist schemas and paused less often than novices. Experts also recalled more of the non-specialist schema information than the less experienced group despite the equal use of 'lay' schemas by both groups during encoding. These results supported the authors' contention that expert map-readers employ a 'rich repertoire of schemata' (p107) to encode information from a map. Since the experts paused less often than novices during map study (measured by recording pauses longer than one second from the videotape record) it was suggested that this might have reflected processing of larger information packages during both encoding and retrieval. This pattern was consistent with the 'information chunking' mechanisms employed by experts in the studies of expertise already cited.

In the third study of map-reading and expertise, Chang, Lenzen & Antes (1985) examined the eye movements of participants engaged in a map reading exercise and found that although both groups did not differ significantly in the number of fixations, experienced map users had shorter fixations on contour related features suggesting easier processing during the integration of contour data into the experts evolving schemas. Experts also performed better on their recall of absolute and relative heights. The authors attributed this superior performance to the experienced participants' ability to process larger chunks of information relating to contour information during the limited available study time. Experts, the authors suggested, may have been more adept at transforming a two-dimensional representation in the form of a map into a three-dimensional mental image of the terrain depicted. When confronted with irregular topographical information or random contour lines the experts' visual search times increased as they struggled to make meaningful patterns from atypical representations.

This result mirrored the additional cognitive processing required by chess masters when recalling random piece positioning and unstructured board layouts in the Chase & Simon (1973) literature.

Summary. Chunking theory and its more comprehensive successor, Template theory provide highly credible accounts of how information processing may be facilitated in expert map users by the employment of schemas containing familiar patterns. In a map reading task where the map corresponds to a known landscape, experts might be expected to encode it not just as separate 'chunks', but within an overall template that incorporates the relationships between the groups of objects viewed (Davies, 2005; McGuinness, 1994). Specifically experts may be: 1.Focussing on the distinctive features of a display to establish how it may differ from the norm; 2. Identifying what is familiar and typical and which therefore requires minimal processing; and 3. Performing spatial feature-matching of either the geometric or symbolic information provided on the map with geographic feature-matching in the landscape being represented (Chang et al., 1985).

The present study. The experiment reported here employed a similar experimental design to the Gilhooly et al study. However in the earlier study participants were provided with a map, which they viewed for five minutes, before recalling the information in the form of a sketch. In this study, in addition to a videotape and audio record of verbal protocols, a detailed record of the pen strokes and pauses between pen strokes was obtained using an electronic drawing tablet during production of the recalled sketch map. Earlier studies of participants engaged in handwriting tasks, e.g. Cheng & Rojas Anaya (2007) have shown using Graphical Protocol Analysis that the duration of a pause prior to a pen stroke correlated with the amount of processing relating to the planned action. The processing time in turn correlated with the differences between low-level procedural versus conceptual components of a written phrase and provided a method of identifying the boundaries of chunked information. Pauses during the processing of intra-chunk information were shown to be reliably shorter than those observed between individual chunks. Accordingly it was hypothesized that overall the experienced map users would record a higher number of short (intra-chunk) pauses between pen strokes than the novice group since more remembered items would be held in each information chunk. Similarly the experts were anticipated to record fewer long (inter-chunk) pauses than the novices. It was further anticipated that these group differences would be evident only for the more complex task characteristics of interpreting and remembering information from the contour map

Method

Participants: Eight experienced map-readers and eight novice map-readers were recruited from students and staff at the University of Sussex. The experienced group comprised two lecturers with the Informatics department who were skilled map users and six students currently completing a BA in Landscaping Studies in the Centre of Continuing Education. Three of the group were female. The non-experienced group comprised post-graduate students in the Department of Informatics with a balanced distribution of females and males. All participants were volunteers and were paid ten pounds.

Materials: One planimetric map and one contour map each measuring 23 X 18 cm were used. The planimetric map was a reproduction of the Thorndyke & Stasz (1980 pp.141) Town Map. The Contour map was of an area approximately 3sq. miles around the Devon village of Yeoford. The area was selected from Ordnance Survey Explorer Series Map (no.113), scale 1 : 25,000, and provided a similar density of information as the town map but with features located in undulating terrain.

Participants' sketch maps were recorded using specially designed software, TRACE (Cheng & Rojas-Anaya, 2004), and a Wacom Intuos 2™ graphics tablet with an effective working area of 30 x 22cms. This provided a detailed record of the commencement and completion of every pen stroke in the compilation of the sketch map during the recall phase. Information from the graphics tablet was relayed to a monitor, resolution 1280 x 1024 pixels, beside the participant. Sketch map production was recorded from the monitor using a Canon MV850i video camcorder, which also provided a synchronous record of participants' verbal protocols.

Verbal Protocols were obtained using the 'think aloud' technique described by Ericsson & Simon (1993) and analysed using the HyperRESEARCH™ software programme. A total of twenty descriptions of cognitive processes or memory strategies were selected from the codes originally identified in the Gilhooly et al. and Thorndyke & Stasz studies and are listed in Table 1.

Table 1: Codes for procedures employed during encoding and recall of map data.

Code	Definiton
Counting	Counting number of features
Feature Description	Identifying particular aspects of features
Inferring Height	Attributing values of altitude or rates of change of altitude.
Lay Schema use	Use of memory aids during encoding
Memory directed sampling	Returning to specific map locations to identify partially remembered features or their relative locations
Metacognition	Analysis of personal performance on aspects of cognitive processing.
Negative evaluation	Critically evaluating performance or results
Partitioning	Dividing the map into sub units to facilitate the memory task
Pattern encoding	Using geometric or familiar shapes to identify spatial relationships
Positive evaluation	Evaluating personal performance positively
Random sampling	Unstructured identifying of features
Reading Heights	Merely reading as opposed to inferring heights
Reading Names	Reading names as a unitary task
Rehearsing names	Repeated reading of names
Relational encoding	Describing feature location as it relates to other features
Specialist schema	Employment of specialist knowledge to provide enhanced comprehension of the information studied or recalled
Stochastic Sampling	Search pattern partially determined by previous search and not entirely random
Systematic sampling	Directed searching for specific or classes of features
Task reference	Incorporating features of the designated task into the search and encoding processes
Verbal association	Use of word association as a memory aid

Procedure: Participants were tested individually and completed in turn: a ten-item Familiarity with Maps questionnaire; a question Paper Folding test (French, Ekstrom & Price, 1963) and; a Rey-Osterrieth Complex Figure copying task (Meyers & Meyers, 1995). The Familiarity with Maps Questionnaire was purpose-designed to provide an objective measurement of participants' map skills. The Paper Folding and Rey Complex Figure tasks provided measurements of spatial ability and spatial memory. Participants were then provided with written instructions for the Town Map task. These stated:

''You are about to begin studying a town map. The map will be made available for inspection for one minute, after which it will be removed and you will be asked to reproduce as much as you can remember in the form of a sketch. The map will be available for a further 4 inspections, again for one minute each, until all of the information has been recalled. The aim is to produce a sketch map of sufficient detail to provide a stranger with the information needed to locate facilities within the town. You are asked to 'think aloud' and provide a commentary on what you are attending to as you study the map and again when you copy the information onto your sketch map.''

When the participants had completed five inspections of the map and their sketch maps had been completed they answered eight questions related to information presented on the map. After a two minute break, the full procedure was then repeated for the Contour map. Here the task instructions included:

''The aim is to produce a sketch map with place names suitable for identifying the general layout of the area but which also includes information for walkers of differing fitness levels some of whom may wish to avoid steep hills.''

On completion the participants provided answers to eight questions relating to the contour map studied.

Results

Group means were examined by ANOVA. All α values were adjusted to avoid cumulative type 1 errors. All reported p values < .01 remained significant after bonferroni correction where necessary. Detailed results for each test are provided in table 2.

Scores for the Familiarity with Maps Questionnaire showed that participants in the experienced group were more frequent map users and displayed a deeper knowledge of map symbols than the less experienced group. The groups did not differ, however, in their general spatial abilities when measured by the Paper Folding task nor in their spatial memory performance when measured by the Rey-Osterrieth tracing task.

In the Town Map exercise the groups did not differ significantly in either the quantity of data they recorded from the five map inspections nor in their knowledge of the map when providing verbal answers to the Town Questions on completion of the copying task.

However, in the Contour Map task the experienced group recorded significantly more data than the less experienced group during the recall task $F(1, 14) = 13.6$, $p < .003$.When the information was sub-divided into information relating to 'features' and information relating to 'contours' the expert group reproduced more information than the novices relating to contours $F(1,14) = 5.25$, $p = .038$ but not relating to features $F(1,14) = 3.449$, $p = .084$

Unexpectedly, although the experienced group did perform marginally better than the less experienced group on the contour map questions, this difference was not significant. This result was surprising because the experts had displayed superiority in their recall of data for contour features and might therefore have been expected to have a greater comprehension of their final sketched map. Further examination of the contour questions revealed that the level of difficulty might have contributed to the generally poor performance of both groups thereby possibly introducing floor effects.

Table 2: Group Differences for each task. Group Means, (SDs) and Significance

Task	Expert	Novice	Sig
Familiarity with maps Q	14.3(1.5)	9.5(2.7)	**
Spatial Ability	5.9(1.9)	6.1(1.4)	
Spatial Memory	25.7(3.4)	24.5(5.4)	
Town Map Data	28.2(3.8)	24.6(3.4)	
Town Map Questions	20.6(11)	14.5(8)	
Contour Map Data	28(4.0)	22(2.4)	**
Contour Map - Features	19.5(4.2)	16.3(2.6)	
Contour Map - Heights	9.0(3.0)	6.0(2.1)	*
Contour Map Questions	8.9(5.5)	6.2(5.4)	

*sig p < .05 **sig p <.01

Analysis of the verbal protocols was conducted using the Hyperware™ Software. The video and audio recordings were examined for each participant and all instances where the coded procedures listed in Table 1 were employed were identified and entered into the data set by two analysts with an inter-rater reliability of .80. Group scores for both map exercises are provided in Table 3.

In the Town Map exercise participants from both groups frequently employed the aide-memoir of 'reading names aloud' when encoding and recalling information. While the expert group recorded a lower mean number of instances (M = 42, SD = 3.46) compared to the less experienced group (M = 50.6, SD = 10.6), these differences were not significant. Similarly the use of 'relational encoding' in the town map task was employed by both groups with almost equal frequency. The experienced group (M = 20, SD = 11.2) recorded more instances than the novices (M = 18.6, SD = 13.3) but again these differences were not significant. For the remaining codes in the Town Map task, there was some evidence of 'metacognition' and 'lay schema use' in some participants' protocols but no group differences were evident for these or the remaining codes. It was noted, however, that for both the 'lay schema' and 'metacognition' individual scores across members of the group were not equally distributed leading to large standard deviations. Group comparisons, therefore, were not considered fully reliable for these codes as they reflected large individual differences within each group.

However, with the examination of the verbal protocols for the Contour map a different picture emerged. When the experienced group encoded and recalled the contour data, the participants employed the 'relational encoding' strategy more than twice as often (M = 21.8 SD = 10.1) than the less experienced group (M = 9.7 SD = 4.6) and this difference was significant F (1,14) = 9.43, p < .008.

Similarly, examples of 'inferring height' occurred in the protocols of the experienced group almost twice as often (M = 27.6 SD = 8.4) as in those of the less experienced group (M = 14.5 SD = 4.5). Again the group differences were significant F (1, 14) = 15.07, p < .002.

Table 3: Frequency of occurrence of procedural strategies in Group Verbal Protocols. Mean & (SD)

Town Map

Procedural Code	Expert	Novice	Sig
Reading Names	42.0(3.5)	50.7(10.7)	-
Relational Encoding	20.0(11.2)	18.7(13.3)	-
Lay Schema	10.0(11.3)	5.0(5.3)	-
Metacognition	8.0(2.6)	7.7(8.9)	-

Contour Map

Procedural Code	Expert	Novice	Sig
Reading Names	21.2(9.2)	23.4(8.0)	-
Relational Encoding	21.8(10.1)	9.7(4.6)	**
Inferring Height	27.6(8.4)	14.5(4.5)	**
Metacognition	5.9(2.3)	4.0(2.0)	-
Lay Schema	2.7(1.6)	2.2(1.6)	-
Specialist Schema	4.8(5.4)	.38(.74)	**
Task Reference	2.6(2.8)	1.37(.92)	-
Negative evaluation	2.7(2.8)	1.1(1.5)	-
Positive Evaluation	1.5(1.4)	.13(.35)	-
Partitioning	.76(1.75)	.13(.35)	-

*sig p < .05 **sig p <.01

The experts appeared to differ in one further encoding and retrieval strategy by their use of 'specialist schemas'. This verbal protocol code had been defined as 'employing specialist knowledge to provide enhanced comprehension of the information being studied'. Examples included 'we have a spur running down between these two areas of high ground' and 'there are a couple of re-entrants (small valley at the head of a stream) from the East'. The experienced group averaged nearly 5 examples of specialist schema use per participant (M = 4.75 SD = 5.4) while in the non-expert group only two participants employed specialist knowledge and then only on a total of three occasions (M = .375 SD = .74). Accordingly the groups differed significantly, F (1,14) = 5.0, p < .043. Of interest here however, were the large individual differences as illustrated by the associated high values of standard deviation within group scores. These reflected a large variance in specialist knowledge within the experienced group and highlighted the difficulties in consistently capturing the complex nature of specialist knowledge within a protocol analysis dialogue alone.

The remaining codes occurred infrequently and only in some of the participants' verbal protocols. Accordingly the cumulative scores were too low to provide reliable statistical evidence of group differences.

The low occurrence of the memory strategies of 'partitioning', 'stochastic sampling' and 'memory directed sampling' had been anticipated since the incorporation of five study periods of one minute into the experimental design had provided a more continuous cycle of information encoding and recall. Where Thorndyke & Stasz had employed a two minute study time and Gilhooly et al a single period of five minutes it could be argued that the task characteristics of these earlier experiments were more suited to a study of spatial and verbal memory rather than an examination of the nature of information processing strategies employed in map reading.

Inspection of the Graphical Protocol Analysis (GPA) data provided detailed values of elapsed time between each pen stroke and a record of distance between completion of each pen stroke and the commencement of the next.

It had been hypothesised that the more experienced map-readers might employ 'information chunking' during information encoding and retrieval and that this might result in faster processing of information during the recall of map data. Accordingly it was expected that experts would process more items of information within chunks and would be expected to have a higher number of short pauses (intra-chunk) and a lower score of long pauses (inter-chunk) than the less experienced group.

Detailed inspection of the GPA data was conducted by setting thresholds for pause values in eleven increments between .05 and 20 seconds to identify the frequency distribution of each pause length. The histograms revealed large individual differences between the members of each group but no reliable between-group differences when the individual results were averaged and compared. This result was disappointing since the expert group had transposed more information onto their contour maps than the novices within similar time frames. This suggested that they had processed the information more fluently. Yet, while the experts did not appear to reproduce the sketched data with measurably shorter pauses, examination of the move distance data revealed that the experienced group made significantly more additions to their maps at a distance of 500 pixels (approx 15 cms), or more from the previous pen-stroke ($M = 7.9$, $SD = 2.9$) in comparison to the less experienced group ($M = 4.0$, $SD = 2.5$), $F(1,14) = 8.05$, $p < .01$. One interpretation of this result might be that the experts were encoding features that were related spatially or semantically but not necessarily proximally. This explanation would be commensurate with either schema based or 'chunking' theories of expertise.

Discussion

The results replicated those of Gilhooly et al. (1988) in three important areas. The groups did not differ in their performances for the planimetric map exercise, nor did they differ for feature related information in the contour map task. However they did vary significantly in their processing of contour related information with the experts reproducing more information on their maps than the novice group. Thorndyke & Stasz (1980) had reported that when both their high and low spatial ability groups were taught effective procedures, only those participants with good visual memory ability improved in the recall task. However in this experiment the groups differed only in their levels of experience with contour maps. No differences between groups were found in the tests of spatial abilities and spatial memory. Similarly the groups performed equally well for all aspects of the town map task in which the lack of topographical data simplified the task. The superior performance of the experienced group in the recall of detail from the contour map task might therefore reasonably be attributed to differences in the information processing strategies employed by each group for contour related data. Also by incorporating five separate study periods of one minute each, immediately followed by the sketching of map data the experimental design had deliberately biased the task towards a continuous cycle of encoding and recall rather than that of an isolated test of spatial memory.

Analysis of the verbal protocols provided some insights into the differences in information processing evident in each group. While both groups employed the technique of 'relational encoding' in the Town map task, when the contour map was studied only the experts recorded similar levels of usage of this technique. In the novice group instances of 'relational encoding' fell to half those recorded in the planimetric map exercise. It was not clear from the verbal accounts whether or not the novices were affected by the unfamiliarity of the information they were processing or if the extra cognitive processing employed to interpret the map data resulted in a failure to adopt a strategy that had served them well in the earlier task. One confounding variable may have been introduced by the inclusion of three students in the novice group for whom English was not their first language. As the difficulty of the task increased these individuals may have suffered from the increased cognitive resources required to articulate their thoughts in English.

The experts' greater use of cognitive strategies in which they were identified as 'interpreting height' and 'employing specialist schemas' might be explained by their improved ability to integrate contour information with feature information to produce more complex propositional representations. Alternatively the experts may have been constructing a detailed 3D mental image of the area portrayed on their maps. By navigating around their mental images the experts would have had access to information gleaned from their height analysis that then provided another dimension in which to employ 'relational encoding'. This was evidenced in the verbal protocol statements which included descriptive elements of features imagined within their topographical context e.g. 'Lower Town is actually higher than Yeoford'. Use of this extra dimension may therefore have contributed to higher scores both for 'inferring height' and 'relational encoding' in the more experienced group due to their construction of a mental image somewhat richer in detail than the less experienced participants.

This view was further supported by the Graphical Protocol Analysis, which indicated that the experts were consecutively encoding and recalling some features more widely dispersed than those recalled by the novices. This again might be interpreted as the experts' ability to encode individual features not simply proximally related but also according to their topographical, semantic or spatial relationships. Similarly, the less experienced group may have been encoding features only in close proximity to one another and from more narrowly defined locations.

The failure to identify reliable between-group differences in the pause patterns prior to each pen stroke could be attributed to the large individual differences observed in participants of both groups or the variable nature of the sub-tasks within the map sketching exercise. Either or both of these factors may have been sufficient to induce overlapping of the temporal signal values associated with chunk boundaries such that meaningful comparisons between groups were not possible. Also, while the groups differed in their levels of experience as measured by the Familiarity with Maps questionnaire, the difference in levels of expertise was not of the same order as that reported between Chess Masters and novices in the earlier literature on information chunking. Accordingly large effect sizes for any group differences had not been predicted.

These findings nevertheless support the view that experienced map users employ cognitive strategies to process information about features and contours within prototypical configurations based on their familiarity with the information presented. These cognitive strategies are therefore consistent with Template theory and schema based accounts of information processing.

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