Maps versus its users in the digital era: interpretation, cognition, and memory

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Abstract. Recently, a rising need to understand (novice) users of digital cartographic products has surfaced: how do they interpret and process the visual information, and how is this retrieved and used later on? A user study was conducted that combined several techniques to investigate these cognitive processes: eye tracking, thinking aloud and sketch maps. In total, 24 participants took part in the study, from which 12 were experts in the cartography. All participants had to study (learn) the content of four different topographic maps depicted on a screen. After studying each map, the participants were instructed to draw this map from memory (retrieve information), using paper and pencils. The results indicate that both user groups address the same cognitive processes, but these are positively influence by the expertise and background knowledge of the experts.

Keywords: Cartography, Eye Tracking, Thinking Aloud

1 Introduction

1.1 Background

Although cartographic products have evolved drastically over time, their main function still remains the: communication of geographic information. However, the possibilities and limitations inherently linked with screen displays have an impact on how maps can be presented to the user, and thus on how the information is perceived and thus used later on (MacEachren, 1995; Matlin, 2002). As a consequence, there is a rising need to understand the map user: how does he interpret and process the visual information on the maps, and how is this retrieved and used later on (e.g. Fabrikant & Lobben, 2009; Harrower, 2007; Montello, 2002, 2009; Slocum *et al.*, 2001). The users' level of expertise (knowledge already stored in memory) could also have a significant influence of this (e.g. Gilhooly *et al.*, 1998; Hambrick & Engle, 2002).

1.2 Studying the map users' cognitive processes

Using eye tracking, the position where a user is looking (Point of Regard, POR) is registered at a certain sampling rate. This gives insights in the user's attentive behaviour, which is an essential step in object recognition and thus in the interpretation process. Besides the position of the POR, other usable metrics (such as fixation duration) can be derived from the eye movement data, which are closely linked with the user's cognitive processes (Duchowski, 2007; Jacob & Karn, 2003; Poole & Ball, 2006).

Other methods are more suitable to investigate the retrieval of information from memory. Thinking aloud is, as such, a well integrated method in psychological research. During a thinking aloud study, participants are typically asked to say out loud every thought that comes into mind. The verbal protocols obtained during concurrent verbalisation correspond to the content of the working memory at that moment. As a consequence, these verbal protocols are direct and unfiltered (Nielsen, 1993; Trickett & Trafton, 2007; van Someren *et al.*, 1994). Furthermore, sketch maps could also be valuable tools to study the users cognitive processes. Huynh and Doherty (2007, p.286) defined sketch maps as “the extraction of information from a mental map through drawing”.

2 Study Design

2.1 Participants

Two groups of participants were selected to take part in the study, containing each 12 persons, with an equal share of males and females. The first group consisted out of experts in map use and cartography. All participants in this group had at least a Master degree in Geography or Geomatics and were employed at the Department of Geography at Ghent University. The second group consisted out of participants who did not receive any previous cartographic training and did not work with maps on a professional level.

2.2 Task and Stimuli

The participant was told he had to remember the general structure (e.g. roads, rivers, forests, etc.) of the map that would be shown on a screen. No time limit was set on this task to avoid influence from time pressure. While executing this task, the participant’s eye movements were registered. After studying the map, the participant took place at another table with a blank A3 paper, colour pencils, a gum, and a headset. During this second phase of the test, the participant had to draw the map he had just studied from memory. While drawing, the participant was instructed to ‘think out loud’. Also in this case, no time limit was set to avoid biases due to time pressure. Finally, at the end of the experiment the participants had to fill in a questionnaire to obtain background information: age, sex, experience, familiarity with the stimuli, etc.

This task of remembering and drawing a map was repeated for all four stimuli presented on a screen (see *Figure 1*). These are based on topographic maps on 1 : 10 000 created by the Belgian national mapping agency (IGN-NGI). The stimuli were presented in the same order to the participants. Only half of the participants (within each group) saw Map3a, the other half the mirrored version Map3b. Consequently, the influence of recognizing the map content is eliminated. This is not the case for the mirrored maps Map1 and Map4, which were displayed to all participants. Finally, the colours of Map2 are adapted: the water bodies are depicted in red instead of cyan; the background colour of the villages is presented in purple instead of yellow. These adaptations in the map image could also influence the user’s cognitive processes while reading, interpreting or retrieving the map’s content.

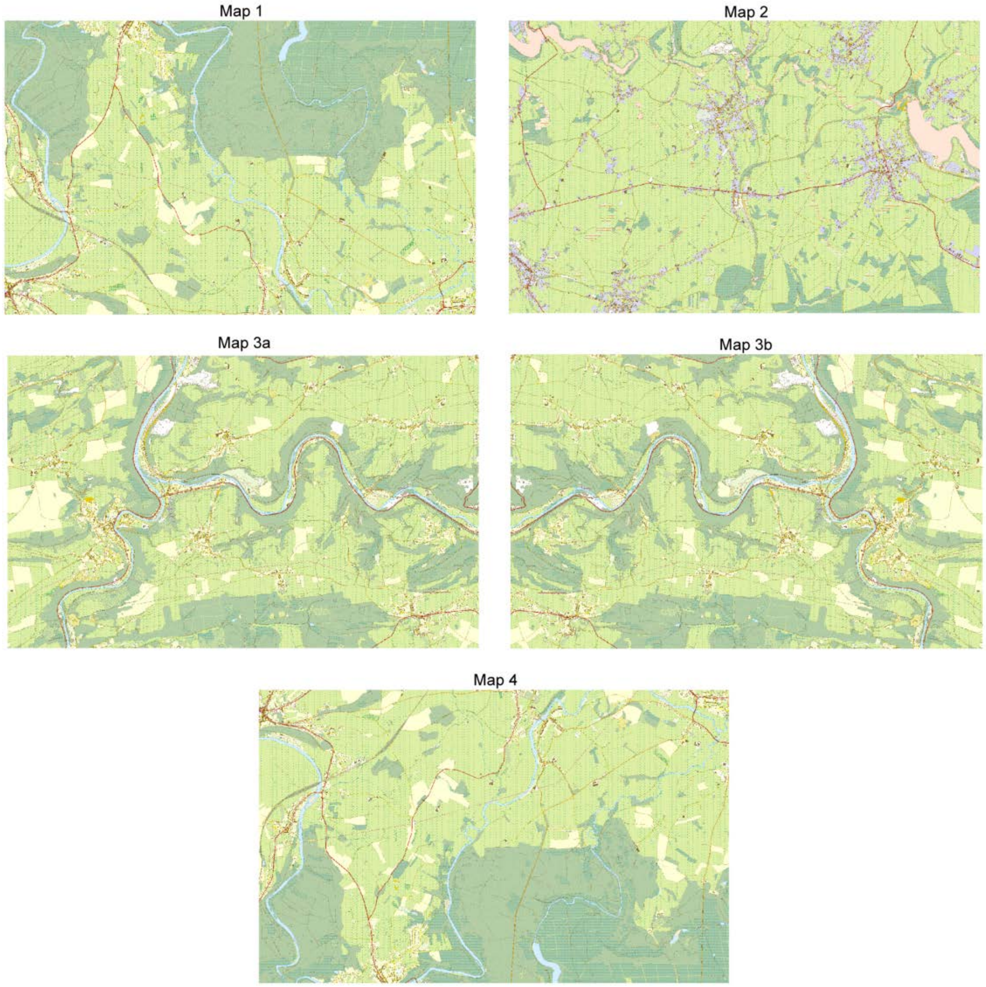

Figure 1. stimuli that were used during the test

2.3 Apparatus and Recordings

The user study took place at the Eye Tracking Laboratory of the Department of Experimental Psychology (Ghent University). This lab is equipped with an *EyeLink100* from *SR Research*. The stimuli were depicted on a 21 inch monitor. The software *DataViewer* (*SR Research*) was used to aggregate the raw data into meaningful measurements, such as fixations. Detailed information regarding these metrics can be obtained for indicated Areas of Interest (AOIs): the number of fixations, the total dwell time and the average duration of the fixations.

Two cameras and a headset were used to record the auditory and visual components for the thinking aloud study. The headset was connected to a laptop which webcam recorded the front view of each participant: face and A3 paper on which they were drawing. This was an *Acer Crystal Eye Webcam* that captured HD videos, including the audio recorded with the headset.

A second HD camera (*Sony HandyCam HDR-CS115E*) was placed on a tripod and captured the drawing process on the A3 page from a top view. The coloured post-it placed next to each A3 page was visible in all recorded videos. Furthermore, the code assigned to each participant was written on the post-its and could thus be read from the top view videos (from the HandyCam). The synchronisation of the recordings from the two cameras (webcam and HandyCam) was based on the moment in time when the post-it was placed. The software *ELAN* was used to manually synchronise the videos and prepare them to be able to analyse the derived verbal protocols.

3 Methodology and Results

3.1 Studying the Map

The registered eye movement data was analysed both quantitatively and qualitatively. This combination ensures to obtain the most complete view on the users' cognitive processes and the differences between the two user groups.

3.1.1 Quantitative Analysis

Table 1 lists the mean values (*M*) and standard deviations (*SD*) for the average fixation durations, the number of fixations per second and the duration of the trial, both for the expert and novice users. The last column in this table shows the results of a one way ANOVA between the two user groups. From this table it can be derived that the expert users have significantly shorter and consequently more fixations than the novice users. These findings are in correspondence to the results of Ooms *et al.*, 2012, where the eye movement metrics resulting from a visual search on a very basic map design were described. This indicates that experts can interpret the same map more efficiently than novices.

Table 1. Statistical comparison (average fixation duration; number of fixations per second; duration of the trial) between expert and novice map users

	Experts		**Novices**		**ANOVA**	
	M	***SD***	***M***	***SD***	***F***	***P***
AvgFixDur(s)	.308	.046	.339	.062	7.578	**.007**
Fix/s	2.804	.467	2.566	.469	6.235	**.014**
TrialDur (s)	335.7	128.0	205.7	128.5	10.516	**.002**

3.1.2 Qualitative Analysis: Gridded Visualisations

A grid of 640 AOIs (40x32) was placed over each map image. In *Figure 2*, this grid of AOIs is depicted in yellow; the cyan circles represent the participant's fixations. The AOI-report from *DataViewer* was restructured as such that every AOI was located on its correct location on the map image. Furthermore, the obtained values (fixation count, total dwell time, average fixation duration) were normalised to correct for the varying trial durations (see also *Table 1*, bottom row). It was decided to use a uniform trial duration of 300 s (or 5 minutes), which corresponds closely to the average over all users.

Next, a classification and colour ramp to effectively and objectively visualise the obtained data in the grid had to be chosen, taking into account the fixations' characteristics (e.g. the link between the fixation count and dwell time) and using a colour scheme based on *ColorBrewer* (Brewer, 2012) (see *Table 2*). *Figure 3* shows examples of the obtained results, with a comparison between both user groups: Map1 and Map2 depict the average fixation count; Map3 and Map4 depict the maximal fixation count. The same methodology can be applied to visualise the distribution of the users' average and maximum dwell time or fixation duration. The main advantage of using this gridded visualisation, in comparison to the often used heatmaps, is the level of control (and thus objectivity) with which the data can be represented.

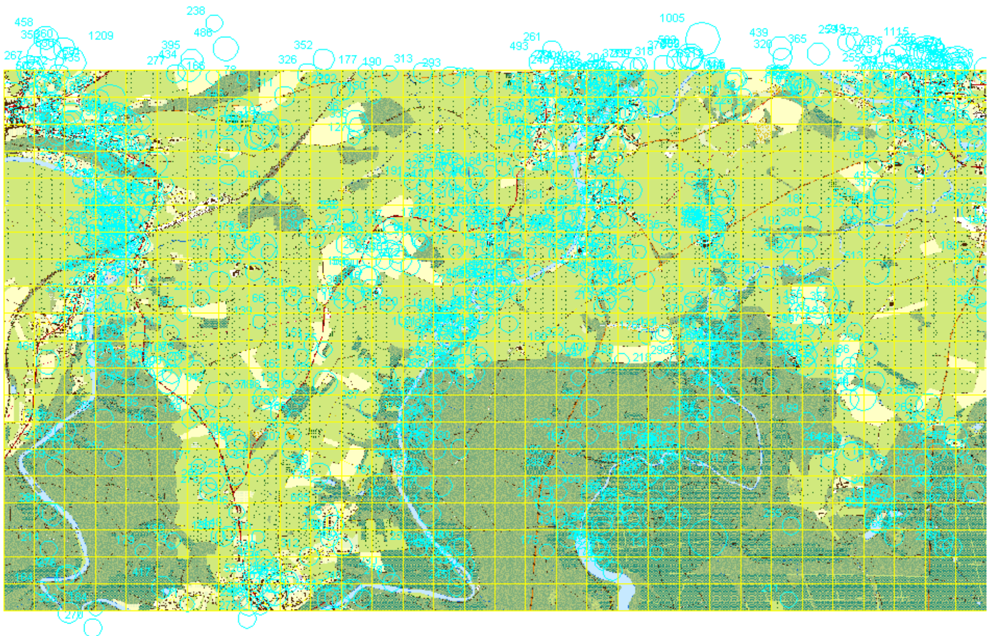

Figure 2. Grid of AOIs placed over each map image (yellow) to visually analyse the users' fixations (cyan)

Table 2. Classification and colour scheme for fixation duration

Variable	Classification and colour schemes							
FixCount	[0-1[	[1-2[	[2-4[	[4-6[	[6-8[	[8-10[	[10-20[	[20-...]
FixDur	[.000-.325[	[.325-.650[	[.650-1.300[	[1.300-1.950[	[1.950-2.600[	[2.600-3.250[	[3.250-6.500[	[6.500-.........]
Colour (RGB)	255	247	217	189	150	99	37	0

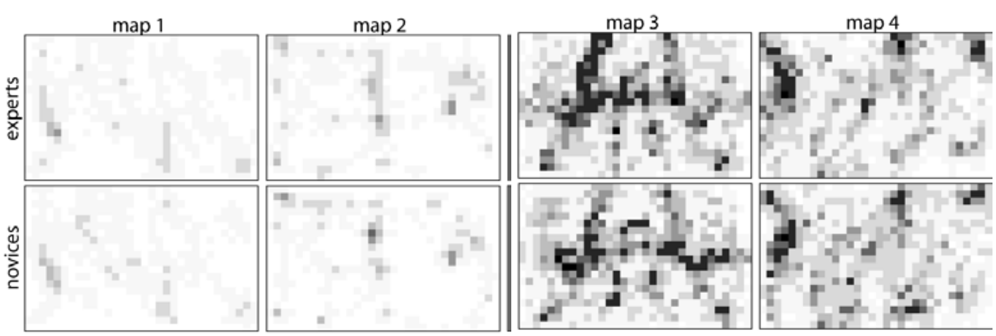

Figure 3. Grid of AOIs depicting the average and maximal fixation count for experts (top row) and novices (bottom row) for the stimuli (left to right)

Based on these 2D grids, statistical ANOVA tests between all corresponding cells of different grids can be executed. This method has been applied to the mirrored map equivalents: Map1 vs. Map4 and Map3a vs. Map3b. On the top row of *Figure 4*, a comparison is made between the original data. On the bottom row, the registered eye movements of the mirrored maps (Map4 and Map3b) are mirrored again and then compared with the original maps (Map1 and Map3a). Dark cells indicate a high significant difference; white cells show no significant difference. This allows investigating 'how well' the registered eye movement data is reflecting the main structuring elements on the map.

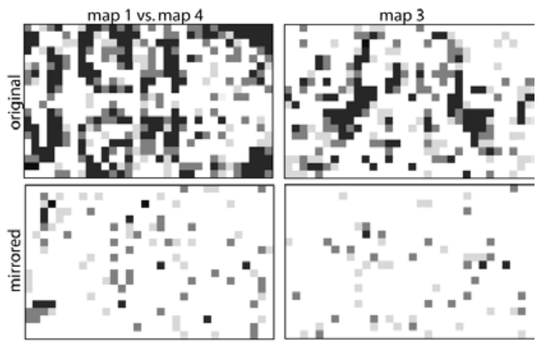

Figure 4. Statistical comparison of the number of fixation between two mirrored maps

3.1.3 Discussion

When combining the obtained results, similar patterns in all users' attentive behaviour can be discovered. They focus on the main (linear) structuring elements on the map, such as rivers and road. These elements are clearly reflected in the 2D gridded visualisations, on the one hand, but significant proof can be found in the statistical grids. The two grids on top of *Figure 4* (the original grids) show a high number of dark cells, whereas the grids at the bottom (re-mirrored data) show high corresponding values.

Nevertheless, the statistical tests also indicate a significant difference in how experts and novices interpret the data. Experts are significantly more efficient in their attentive behaviour (less distracted by deviating colours, familiar objects or less important elements) and interpretation process (shorter fixations).

3.2 Thinking Out Loud and Sketched Maps

While drawing, the users had to say out loud every thought that came into mind. These verbalisations are closely linked to the active content of the participants' working memory and thus to the cognitive processes and strategies needed to retrieve the information from (the long term) memory. The obtained verbal protocols were segmented in two ways to contribute to the validity of the results. The sketched maps also provide important information regarding the users' information retrieval processes.

3.2.1 Counting and Comparing Word Use

All words that were verbalized during the thinking aloud sessions were counted, ordered based on its frequency, and compared between both user groups. Not surprisingly, the words that are most frequently used, correspond a lot between both user groups as these are very general words, like 'the', 'it', 'a', 'has', etc. However, when investigating the words that are less frequently used (e.g. 30-50% of the ordered list), a clear distinction is noticed. Novices use more descriptive terms for the shape, colour and location of the map objects (e.g. line, red, middle, circle, etc.) , whereas the experts used their correct names (meander, major road, north, field, etc.).

3.2.2 Analyzing the 'Full Thought'

The participants' verbalised full thoughts (sentences) were analysed according to the scheme depicted in *Figure 5*. A psychological model was developed, based on which a coding scheme constructed that has four levels: map level, item level, confidence level, and actions (see *Table 3* to *Table 6*). Four codes were thus assigned to each of the segments to obtain the coded protocols. The duration of each full thought (and its associated code) is expressed as a ratio between zero and one, relative to the full length of the thinking aloud session.

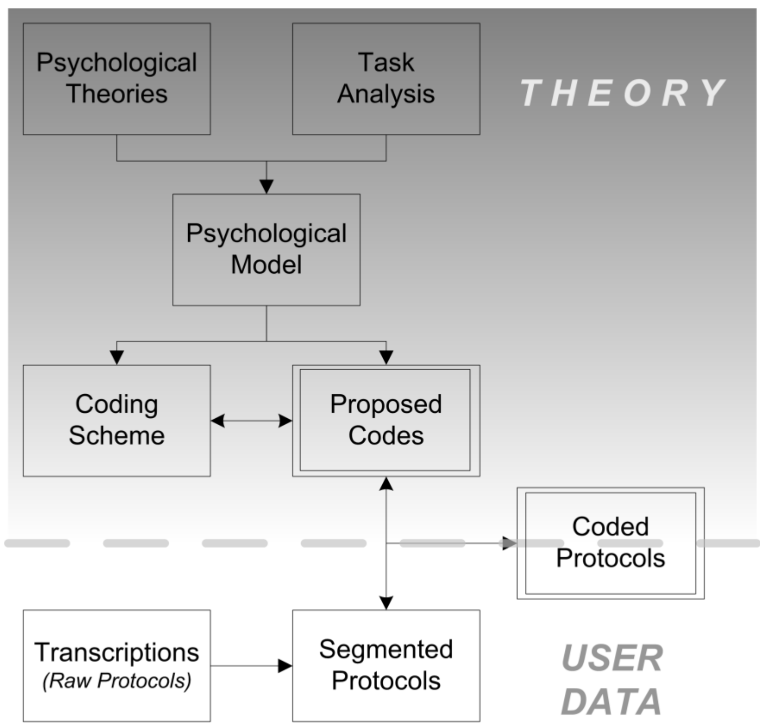

Figure 5. Analysing verbal protocols obtained from a thinking aloud study (after van Someren *et al.*, 1994)

Table 3. Proposed codes related to the map level (Level 1)

psych. model	**category**	**code**	**description**
Orientate	orientate	or1	*before the start of the task execution, gather thoughts, check tools, assignment, ...*
Execute Assignment	execute	ex1	*drawing, talking, explaining, correcting items, ...*
Evaluate Result	evaluate	ev1	*check if everything is on the map (count objects, check size, relative positions,...); not the correction of individual items when drawing them*
OK?	evaluate	ev1	

Table 4. Proposed codes related to the item level (Level 2)

psych. model	category	code	description
Consult WM	gather thoughts	gt2	*participant is clearly thinking, gathering thoughts, finding links between items, consult previous knowledge, similarity between objects*
Next Item	gather thoughts	gt2	
LTM to WM	gather thoughts	gt2	
Draw Item	draw	dw2	*items are draw on paper,* colour *pencil was taken, ...*
Evaluate Item	evaluate	ev2	*check correctness of item that was drawn, or items related to it*
OK?	evaluate	ev2	
Adapt Item	correct	cr2	*correct items which were evaluated (drawing, erasing)*

Table 5. Proposed codes related to the participants' level of confidence (Level 3)

confidence	category	code	description
Confident	confident	cf3	*participant is sure that it is correct*
Neutral	neutral	nt3	*level of confidence is not expressed*
Not Confident	not confident	nc3	*participant is not sure that it is correct*

Table 6. Proposed codes related to the participants' actions (Level 4)

action	category	code	description
Draw	draw	dw4	*participant draws an item*
Take Pencil	take pencil	tp4	*participant takes a pencil*
Correct	correct	cr4	*participant corrects item that was drawn previously*
Erase	erase	er4	*participant uses the eraser*
Fill Colour	fill colour	fc4	*participant is filling up items with* colour
Checking	checking	ck4	*participant checks drawing*
Talking	talking	tk4	*participant is only talking*

The graphs in *Figure 6* show a very similar structure for the experts and the novices. This indicates that the same cognitive processes were addressed while solving this problem, which is in this case remembering and drawing the information from a map that was studied previously.

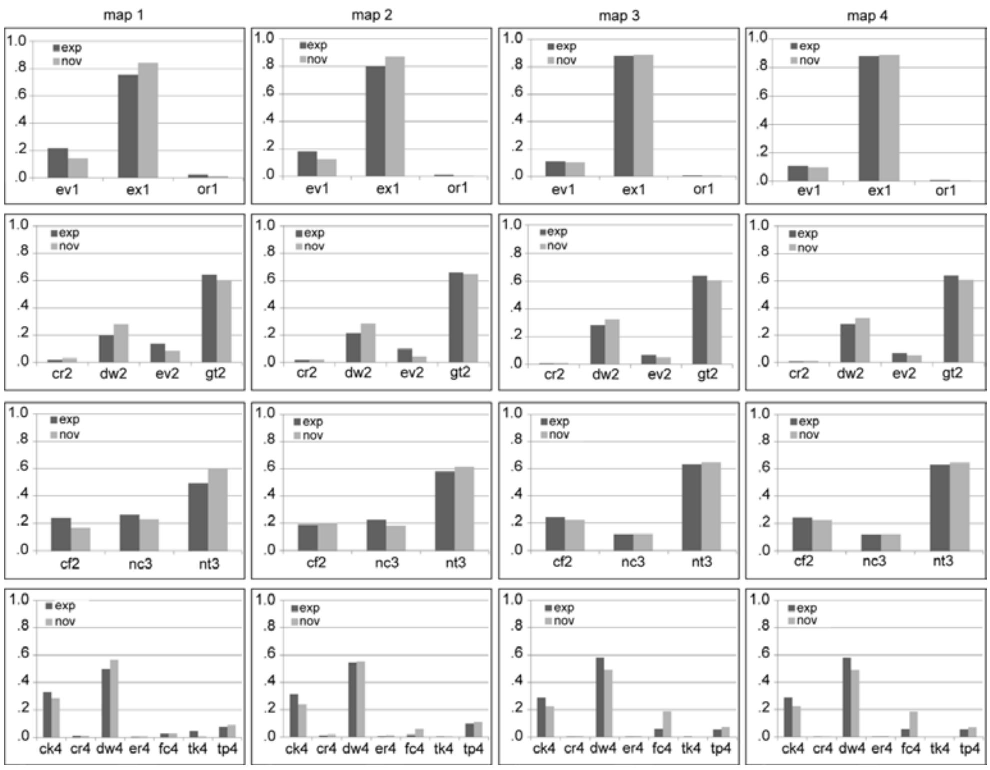

Figure 6. Overview of the segmented protocols (full thought) per level and map

3.2.3 Sketched Maps

The maps that were drawn by the participants were compared with the original screen maps. Based on how well these maps were drawn, a score was assigned to them. The aesthetics of the sketched objects or drawing skill of the participants were not taken into account. A similar scoring system as used by Kulhavy and Stock (1996) and Thorndyke and Stasz (1980) was applied to obtain a score for each map. If the object was present and drawn on the correct location a score of one point was assigned to it. If the object was present, but drawn on a considerably wrong location, only half a point was assigned to it. The results are presented in *Figure 7*.

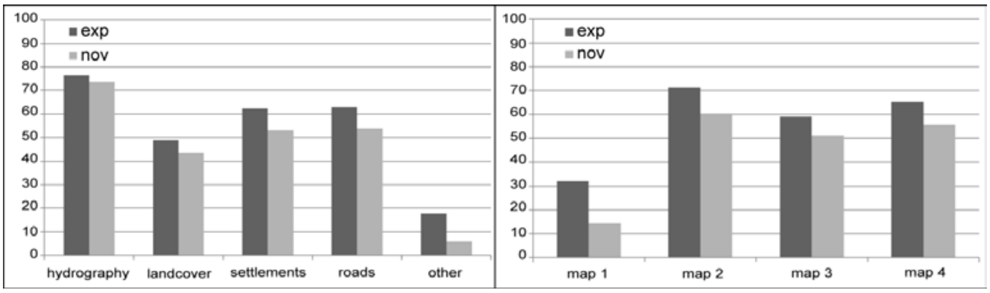

Figure 7. Overview of the scores (%) on the drawn maps, per theme (left) and per map (right)

The order with which the different structuring elements on the map were drawn can give insights in how these elements were stored in the users' memory. Huynh *et al.* (2008) argue that this sequence gives insights in the hierarchical structure of the users' cognitive map: a basic framework in which lower level elements are subsequently placed. This hierarchical structure is closely linked with the perceived importance of objects by the user.

For each map, eight categories of elements were identified (see *Figure 8*). These categories contain structuring map elements and are an extension of the four categories used to present the map scores: electrical wire (other), field (landcover), forest (landcover), settlement, hydrography, meadow (landcover), railroad (other), and road. A 'score' was assigned to each category based on the order with which the first element of that category was drawn: 100 for the first element, 50 for the second, 25 for the third, 5 for the fourth, 4 for the fifth, and so on. If a certain element was not drawn, no score was assigned. The three categories that are associated with the highest scores are the forests, roads and hydrography.

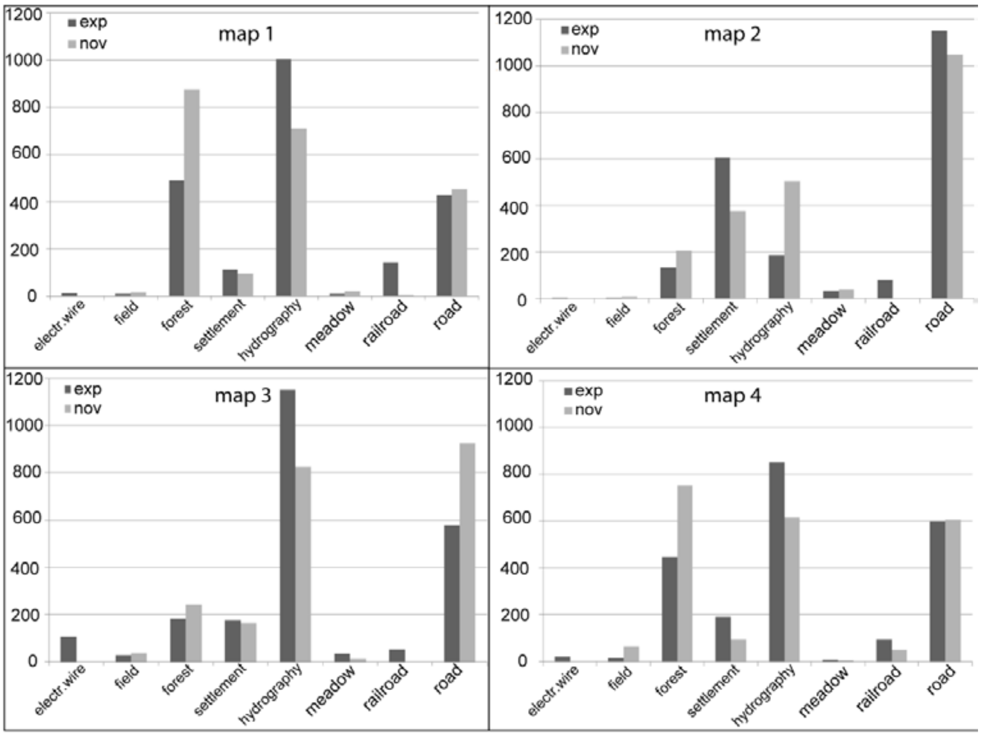

Figure 8. The order with which the objects were drawn for each map

3.2.4 Discussion

Using thinking aloud and sketch maps, it can be discovered how users structure the information in their memory (previously gathered from a digital map). The protocol analyses on the full thoughts indicate that both user groups address the same cognitive processes to retrieve the information. However, a significant influence of expertise (amount of background knowledge) was found regarding how the retrieved information is structured and consequently how much information could be retrieved. Experts could retrieve much more information, because they could link the newly gathered data with information that was already present in their memory. Because of the available background information, they actually have to remember less and can structure is more efficiently. Consequently, it is better accessible during information retrieval. Novices, on the other hand, lack this background information. All perceived information has to be stored, in a rather unstructured, descriptive way making it harder to retrieve later on.

4 Conclusion

By combining different methods, it was possible to the study complete cartographic communication process. Attentive behaviour and interpretation was investigated through quantitative and qualitative analyses of eye tracking data, but also how much information was remembered and how this is structured in memory. The latter elements were studied using thinking aloud and sketch maps.

It was found that the main cognitive strategies that were addressed are very similar for both expert and novice users. While studying the map, they focus their attention on the main structuring elements on the map to create a reference frame in which all other elements can be placed. However, experts can interpret the content significantly more efficiently and are less distracted (by deviating colours, familiar objects, less important objects, etc.). As a consequence of this and in combination with extensive background knowledge, the experts could structure the interpreted information more logically through links with the existing information in memory. This also allows easier retrieval of the information.

It is thus important that experts in cartography, when creating cartographic products, are aware of the novice map users' cognitive limits. The visualisation of the map elements should be keyed to the novice map users cognitive structures and processes so that they can interpreted more efficiently and effectively. This would facilitate the storage of the information in memory, making easier accessible during information retrieval.

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