Published as: Ooms, K., De Maeyer, P., Fack, V., Van Assche, E., Witlox, F. (2012), Interpreting Maps Through the Eyes of Expert and Novice Users. *International Journal of Geographical Information Science*, vol. 26(10), p. 1773-1788.

Interpreting Maps Through the Eyes of Expert and Novice Users

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The experiments described in this paper combine response time measurements and eye movement data to gain insight in the users' cognitive processes while working with dynamic and interactive maps. Experts and novices participated in a user study with a 'between user' design. Twenty screen maps were presented in a random order to each participant, on which he had to execute a visual search. The combined information of the button actions and eye tracker reveal that both user groups showed a similar pattern in the time intervals needed to locate the subsequent names. From this pattern, information about the users' cognitive load could be derived: use of working memory, learning effect, etc. Moreover, the response times also showed that the experts were significantly faster in finding the names in the map image. This is further explained by the eye movement metrics: experts had significantly shorter fixations and more fixations per second meaning that they could interpret a larger part of the map in the same amount of time. As a consequence, they could locate objects in the map image more efficiently and thus faster.

Keywords: cartography, eye tracking, usability, cognitive map

1. Introduction

Usability Engineering (UE) and *User Centered Design* (UCD) are well-known themes in the domain of software development. UCD involves the user in the subsequent stages of the product's development to enhance the usability of the final product. By involving the user in the production process, the effectiveness of the product – or its quality towards the user – improves drastically. ISO 9241-11, *Guidance on Usability*, defines usability as 'the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use' (Earthy, *et al.*, 2001, p.554). In this context, *effectiveness* is related to how well a user can accomplish a certain task: the accuracy and completeness. *Efficiency* is related to how fast a user can accomplish a task: learning time and completion time. Finally, *satisfaction* is related to the user's preferences.

A frequently used UE-technique to examine, among others, the layout of user interfaces and websites is eye tracking (e.g., Djamasbi*, et al.*, 2010; Fleetwood & Byrne, 2006; Goldberg, *et al.*, 2002; Jacob & Karn, 2003; Schiessl*, et al.*, 2003). This technique allows 'tracking' the movements of the participant's eyes: his Point of Regard (POR) is registered at a certain sampling rate. From this long list of (*x, y*) positions, eye movement metrics such as fixations and saccades can be derived. A *fixation* is a stable POR during a certain time span and indicates that the user is interpreting the content at that location. A *saccade* is a rapid eye movement between two fixations. The velocity of these saccades (up to 500 degrees/s) is such that the user cannot interpret any content at these moments. A *scanpath* is a succession of fixations and saccades (Duchowski, 2007; Poole & Ball, 2006; Rayner, 1998).

The use of eye movements in user studies is not a new method. One of the first experiments dates from the end of the 19th century. These initial techniques differ significantly from the ones used today. They were rather invasive with direct contact to the participant's eyes. The first application of eye movement studies in the field of UE is described in the work of Fits *et al.* (1950), who used motion picture cameras to study the movements of pilots' eyes (Jacob & Karn, 2003). Also in cartography, the use of an eye tracking method to study the user's attentive behaviour is not new. Inspired by the systematic use of eye movement recordings in research fields that involve graphical communication, such as psychology and art, Jenks (1973) studied the scanpaths of users looking at a dot map. Based on this initial study, a number of follow-up studies were conducted during the 1970s and the first half of the 1980s (e.g.,Castner & Eastman, 1984, 1985; Dobson, 1977; Steinke, 1987).

After these first studies, researchers recognized the method's applicability, but concluded that no new knowledge could be derived from it. Consequently, the use of eye movements almost disappeared in cartographic user studies after 1985. Jacob and Karn (2003) give three main reasons why the use of eye movements in usability research did not get widely accepted. First, the technical problems related to capturing the actual eye movements were very challenging in the past and produced rather inaccurate and thus unreliable results. Second, eye trackers produced huge amounts of raw data from which meaningful metrics need to be extracted. This labour-intensive, and often manual data extraction complicated and slowed down the analysis significantly. Third, the interpretation of the extracted data was very difficult. Furthermore, some doubts emerged regarding the link between a person's eye movements and his spatial attention during a visual search: we can all move our attention without moving our eyes (Montello, 2002; Rayner, 1998).

More recent studies, however, show that eye movements are critical to interpret visual information efficiently while performing a complex visual and cognitive task (Duchowski, 2007; Henderson & Hollingworth, 1998). The eye tracking systems have also evolved drastically during the last decades with new and more accurate techniques that have a smaller impact on the participant himself. Moreover, the cost of the eye tracking devices has decreased considerably during this period. The software packages that come with these eye trackers today allow more flexible extractions of meaningful metrics related to fixations and saccades (Duchowski, 2007;

Goldberg, et al., 2002; Jacob & Karn, 2003; Poole & Ball, 2006; Rayner, 1998). Not only what a user is looking at but also how long, how often, the length and speed of the saccades, etc. can be discovered. As a consequence, more detailed insight in the user's cognitive processes can be derived from these measurements in comparison with the initial eye movement studies. Even more, during these last decades psychological research on cognitive processes linked with visual search has received much attention, which resulted in new and more detailed theories regarding cognitive cartography (e.g., Harrower, 2007; MacEachren, 1995; Slocum*, et al.*, 2001).

At the same time, also the maps have experienced a tremendous evolution during this period: from a static, analogue format to highly dynamic and interactive digital maps. In 2001, Kraak defined a rough web map classification based on how the map is or can be used. He distinguished between static and dynamic maps on the one hand and between view-only and interactive maps on the other hand. Kraak (2001, p.3) noted that 'The most common map found on the WWW is the static view-only map.' Today, however, almost every map on the Internet is 'clickable' and produces dynamic responses such as animations or videos.

The recent evolutions in cognitive cartography and the improvement of the eye tracking method has resulted in a renewed interest in eye movement research in the field of cartography during the past few years, but so far, only a few studies have been conducted. Brodersen *et al.* (2001), for example, investigated the symbology of analogue (paper) topographic maps. Fabrikant, *et al.* (2008) and Coltekin *et al.* (2010; 2009) recorded participants' eye movements to evaluate animations and interactive interfaces related to the presentation of maps. These initial eye movement studies (using the improved eye tracking techniques) prove the suitability of eye movement research to investigate how users perceive these highly dynamic and interactive maps of the current digital era. Montello (2009) also recommended the recording of eye movements as a future method for cognitive GIScience research.

The goal of this paper is to extend these eye movement studies to obtain insight in the user's cognitive processes while working with these dynamic and interactive maps: construction of the mental map, cognitive load, learning effect after interactions, etc. These observations can be compared with the Cognitive Load Theory, that Harrower (2007) and Bunch and Lloyd (2006) described in relation to the interpretation of map animations.

The Cognitive Load Theory distinguishes between two main memory types: working memory and long term memory. The *working memory* is used when new information is processed. It cannot contain large amounts of data or store it for a long time. In this case, the user's *long term memory* is addressed. Consequently, information has to be transferred from the working memory to the long term memory. This learning task is achieved by linking the current (active) information in the working memory with knowledge and skills already stored in the long term memory. When necessary, information stored in the long term memory can be retrieved and used again in the working memory. The Cognitive Load Theory describes three types of cognitive load that have an influence on the working memory and the learning task. The *intrinsic cognitive load* is related to the complexity of the visual information: complex information is more difficult to process and results in a higher cognitive load. The second type of cognitive load, the *extraneous cognitive load*, will increase due to distractions or a poor representation of the information. Finally, the *germane cognitive load* is closely linked to the learning task itself: a part of the working memory is used to link the active information (in the working memory) to previous knowledge in the long term memory so that the active information can be passed on to the long term memory (Bunch & Lloyd, 2006; Harrower, 2007).

What is more, different users may interpret and process the same information in a different way. Consequently, map users cannot be considered as one homogeneous group but as different categories of users and individual user differences have to be taken into account. Different user characteristics of interest are: gender, age, experiences, background knowledge, etc. (Aykin, 1989). Important and interesting differences between users are the background knowledge and the level of experience they have with the topic under investigation, maps in this case (MacEachren, 1995; Nielsen, 1989). Since the interpretation process is closely linked to the structure and use of the user's memory, it is influenced by previous knowledge. As a consequence, designers of user studies often differentiate between expert users (high level of experience) and novices (low level of experience) (Duchowski, 2007; Nielsen, 1993; Rubin & Chisnell, 2008).

This paper gives an overview of the results from an experiment conducted both by novices and experts. Since the same stimuli – screen maps in this case – are presented to two different user groups, the study has a 'between user' design (Duchowski, 2007; Nielsen, 1993). The comparison of the results allows detecting whether experts (persons with cartographic training and experience in interpreting maps) can interpret maps more efficiently. A combination of response time measurements and eye movement data is used to obtain insight in the participants' cognitive processes while working with dynamic and interactive maps.

2. Study Design

2.1. Participants

The participants of the expert group were at the moment of the study employed at the Department of Geography at Ghent University. They obtained at least a Master degree in Geography or Geomatics and received, both theoretical and practical, cartographic training. In their daily job they use paper and digital maps on a regular basis. Consequently, the expertise of this group is two-fold. On the one hand, they have a substantial level of background knowledge of cartographic syntax and semiotics, on the other hand, they are highly experienced in working with paper and digital maps.

The group of novices were Bachelor students of the Faculty of Psychology and Educational Sciences at Ghent University. None of them received any previous training in cartography. The group of expert users counted 16 participants, whereas the group of novices 15. All participants co-operated on a voluntary basis and were Dutch-speaking (the language in which the test was presented).

2.2. Stimuli

Twenty demo maps were presented to each participant in a random order on a screen. An example of a demo map is presented in Figure 1a. The design of these maps was very basic and controlled. The next sections explain the reasons for this specific design.

First of all, the design had to be homogeneous within one map, without any deviating regions in it. Secondly, the design of all maps had to be very similar in order to avoid users being distracted in any way. The cognitive load related to processing the information on these maps needed to be limited, equal for all maps and equal for all participants. In this way, the design prevented that certain users considered a specific area on a map more interesting or that a certain map would be more interesting than the others.

In order to keep the extraneous cognitive load limited and equal for all maps, the same simple background image was used for every map. The simplest background image of a map consists of a small number of polygons (for example three), filled with a non-obtrusive pastel colour. These polygons can present, for example, countries or thematic regions. Adding extra objects to this background (such as lines or more polygons) would increase the complexity of the map, resulting in a higher intrinsic cognitive load for the user. Using one or more striking colours could distract the users, resulting in a higher extraneous cognitive load. Too many or different map elements across the twenty trials would distract the participant from the actual task. The complexity of the information presented on the foreground also needed to be limited and balanced across the twenty maps. The number of elements, types of elements and their distribution on the map contribute to the intrinsic cognitive load of the user: the complexity of the visual information. Therefore, only point objects and their associated labels were depicted, which may represent cities or points of interest. The number of labels depicted was similar for all the twenty maps. The actual visualisation of these objects has an influence on the extraneous cognitive load. In order to keep this load low, all labels were visualized in the same colour (black) and only a limited level of hierarchy in the labels was present. Some labels were presented in capitals, but most were depicted in a normal font. The names in the task were rather short (consisting of, on average, five characters) and not written in capitals. What is more, the distribution of cities (points) and their names originated from existing regions in order to present realistic situations to the participants. However, these regions were selected in such a way that none of the Belgian participants was likely to recognize one of the regions. Familiarity of a participant with a certain region would mean that the participant has already stored some information about that region in his long term memory. The germane cognitive load for this participant is influenced differently when viewing the familiar regions: he can make a direct link between the working memory and the long term memory.

After a fixed interval of fifty seconds, a user interaction was simulated: a horizontal pan operation to the right. As a consequence, a part of the initial view remained visible on the left side of the screen and a new part of the map emerged on the right. This fixed time interval ensures that all users will look at the initial map for the same amount of time. Figure 1b depicts such a view after the interaction.

It was chosen to use a basic map design in the test to avoid as many influencing, possibly confounding factors as possible. This map design also implies that the value of expertise, related to the expert users, is limited. Using very complex maps with multiple layers of information might be prejudicial for the novice map users because they do not have the same background knowledge and level of experience. In extension to this study, new experiments can be designed with an increased level of map complexity, related to the objects themselves or to the visualisation of the objects. This way it can be discovered which elements or what level of complexity has a profound impact on the different types of users: novices and experts. However, this extension is beyond the scope of this paper.

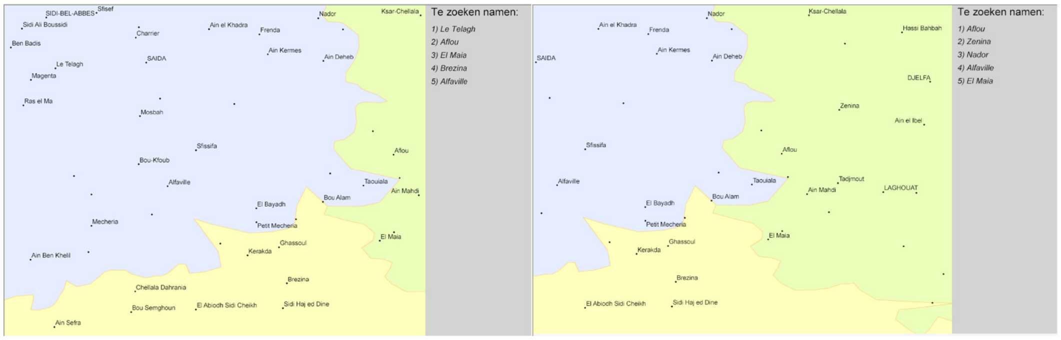


Figure 1: Initial (a) and final (b) view of a demo map

2.3. Procedure

On the right side of each map, a list of five names was presented (see Figure 1a). The participant was asked to locate these names in the map image and to push a button each time a name was located. The participant could use any of the buttons at the bottom of the joystick in order not to distract him from the task or to discriminate between left and right handed people. Each of these button actions resulted in a response time measurement. In order not to disturb the cognitive processes of the participants, they were free to choose in which order they wanted to locate the five names. According to a previous (unpublished) study by the authors it was found that most participants could locate these five names within 50 seconds. Therefore, the horizontal pan operation was simulated on the screen after this time interval. As a result of this design users can anticipate when and how the interaction will occur, which is considered a positive element: when users perform an interaction 'in real life' they also know in advance when and how this will occur. Unexpected changes in the map view, both in terms of time and direction may confuse the user.

During the simulated pan operation, the list of five names also changed (see Figure 1b). Three of the initial names reappeared in the new list (on a different position) and two were new. The user had to locate these names in the map image again and push one of the two buttons at the bottom of the joystick to confirm he found one. When all names were located, the user could end the trial by pushing one of the buttons on top of the joystick.

Before the actual start of the test, two demo trials were presented to the participant. The goal of these demo trials was two-fold. First, the participant could practise on the assignment allowing him to ask any additional questions before the start of the actual experiment. Second, he was able to familiarize with the background and general structure of the maps used during the actual tests.

The task described above corresponds to a visual search on an image. A visual search is a very realistic and natural operation for a map user. He is trying to find locations, such as cities, on a map of which he only knows the name. When exploring the surroundings of these locations, the user will use a pan operation to visualize a larger part of the map. After the pan operation, the user tries to orient and explore the map by locating new names and relocating known names from the view before the interaction.

2.4. Apparatus

The study was conducted in a controlled environment: the Eye Tracking Laboratory in the Faculty of Psychology and Educational Sciences (Ghent University). An EyeLink 1000 eye tracking device (SR Research, Ontario, Canada) was used to record the participant's eye movements during the study. This system can sample the participant's Point of Regard once every millisecond. Each participant received a joystick (Microsoft Sidewinder Plug-and-Play Game Pad) from which two button-clusters could be used. The stimuli were presented on a 21inch monitor with a resolution of 1280 by 1024.

2.5. Recordings

During this study, different types of recordings were obtained and combined. First, response time measurements were obtained from the button actions. With these button actions, the participant indicated that he found a label. However, a user could push the button without finding a correct name. Therefore, these absolute response times were compared with the eye movements. If a user was not focussing on a name from the list, the measurement was removed from the dataset. In the analyses, the relative response times are used: the time interval between locating two subsequent names. Hence, locating a wrong label influences the relative response time of the next label. Consequently, these measurements, related to the subsequent label, were also removed from the dataset.

3. Results

3.1. Response Time Measurements

The relative response time measurements indicate how fast a certain user could find each subsequent label. The overall (all labels, all users) mean (M) relative response time was 5.472 seconds ($SD = 1.605$ s). A one way ANOVA shows that the experts were significantly faster at finding the subsequent labels ($M = 5.227$ s, $SD = 1.433$ s) than the novices ($M = 5.595$ s, $SD = 1.673$ s), with $F = 7.056$ and $P = .008 < .01$. When considering only the time intervals before the simulated interaction, a marginal significant difference could be found in the response time measurements ($F = 3.000$; $P = .084$). During this time interval the experts' mean relative response times were shorter ($M = 5.619$ s, $SD = 1.462$ s) than these of the novices ($M = 5.965$ s, $SD = 1.648$ s). After the simulated interaction, the experts were also significantly faster at locating the names than the novices ($M_{\text{nov}} = 5.235$ s, $SD_{\text{nov}} = 1.622$ s, $M_{\text{exp}} = 4.836$ s, $SD_{\text{exp}} = 1.297$ s, $F = 4.594$, $P = .033 < .05$).

In Figure 2, the mean response times (with their associated 95% confidence intervals) are represented for each subsequent label. If the code of the labels starts with a 1, it means that this is one of the labels the participant had to locate before the interaction. For example, 13 corresponds to the third label the participants found before the interaction. A code starting with a 2, corresponds to labels that had to be located after the interaction: 23 is the third label the participants found after the interaction. Figure 2 indicates that the mean response time measurements for the experts were always lower than those of the novices, but they follow the same pattern. This pattern can also be derived from the actual values in Table 1. Both before and after the interaction, the shortest time interval was linked to the second label (label number 12 and 22). After this label was found, the relative response times grew with each subsequent label, also both before and after the interaction. The time needed to locate the first label before (label 11) and after the interaction (label 21) was always higher than for the second label. Furthermore, the response times before the interaction were always longer than after, compared with the corresponding label (e.g., label 13 vs. label 23, label 14 vs. label 24).

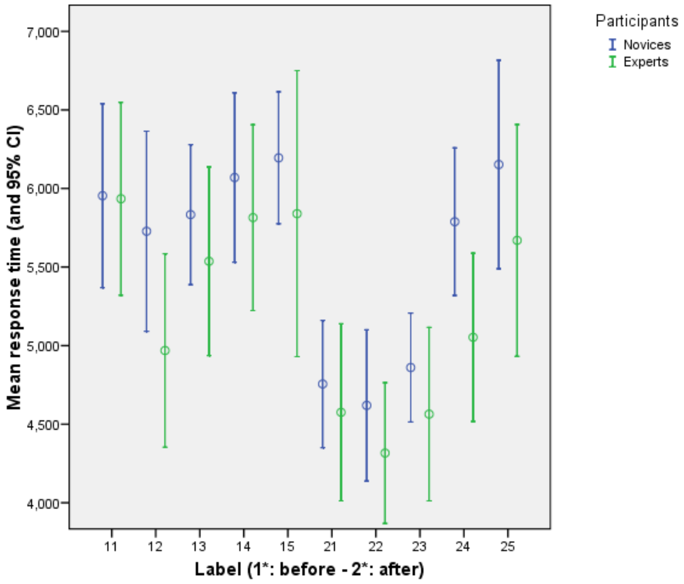


Figure 2: Error bars (mean values with 95% confidence interval) of the relative response times (s) for locating the subsequent labels

Table 1: Mean values for the time intervals (in s) for locating subsequent labels and their statistical comparison

Label	**Before (1*)**		**After(2*)**		**ANOVA**	
	M	***SD***	***M***	***SD***	***F***	***P***
***1**	5.954	1.805	4.756	1.265	11.722	.001
***2**	5.728	1.991	4.619	1.504	7.894	.006
***3**	5.834	1.392	4.860	1.082	12.187	.001
***4**	6.069	1.685	5.789	1.469	.631	.430
***5**	6.195	1.313	6.152	2.074	.012	.913

a. novices

Label	**Before (1*)**		**After(2*)**		**ANOVA**	
	M	***SD***	***M***	***SD***	***F***	***P***
***1**	5.934	1.311	4.576	1.203	11.657	.002
***2**	4.969	1.315	4.316	.957	3.218	.081
***3**	5.537	1.283	4.564	1.179	6.234	.017
***4**	5.815	1.264	5.053	1.145	3.987	.053
***5**	5.840	1.945	5.670	1.575	.093	.763

b. experts

A one way ANOVA shows for both user groups a highly significant difference in the mean response times before versus after the interaction ($F_{nov} = 19.372$, $P_{nov} < .001$; $F_{exp} = 16.071$, $P_{exp} < .001$). The last columns of Table 1a and 1b show the results from the statistical comparison between the corresponding intervals. These *P* values indicate that, for both user groups, only the three first corresponding intervals are significantly different. For the experts, the intervals related to the fourth label showed a marginal significant difference, whereas no significant difference was detected for the novices. The last corresponding time interval showed no significant difference for the two user groups. According to Figure 2 , both the expert and the novice map users show a steep increase in the response times for each subsequent label after the interaction, which is not the case before the interaction (see Figure 2). Furthermore, this increase is more pronounced for the novices than for the experts. As a consequence, the fourth and fifth corresponding intervals show no significant difference for the novices, but a marginal significant difference is detected in the fourth corresponding interval of the experts.

3.2. Fixation Duration

Longer fixation durations can give insight into two elements: the user has more difficulty with interpreting the visual input or the user considers the visual input more interesting. In this study, the latter explanation is not considered. Because of the basic design of the maps, it can safely be assumed that both user groups look at all maps with the same level of interest. The longer fixations measured during this study thus indicate that the user needs more time to process the (visual) information. The overall (all labels, all users) mean fixation duration was .225 s (*SD* = .086 s), with .249 s (*SD* = .080 s) for the expert group and .265 s (*SD* = .094 s) for the novices. A one way ANOVA shows that these eye tracking metrics differ significantly ($F = 44.176$, $P <$

.001). Before the interaction, the mean fixation duration linked to the expert group was significantly shorter (M = .249 s, SD = .081 s) than these linked with the novices (M = .260 s, SD = .090 s), with F = 9.315 and P = .002. After the interaction, the experts had significantly shorter fixations (M = .248 s, SD = .077 s) than the novices (M = .270 s, SD = .097 s), with F = 39.858 and $P < .001$.

These measurements also indicate that, for the novices, the mean duration was numerically longer after the interaction than before. A one way ANOVA shows that this difference is significant (F = 6.119, P = .013). For the expert users, however, the mean fixation durations were very similar during both intervals (F =.123, P = .726). An overview of the fixation durations related to finding the ten labels is listed in Table 2. The distribution of these measurements is depicted in Figure 3 and reveals that the mean fixation durations diverge between the two user groups with each subsequent label that was found, both before and after the interaction. Interval 21 is an anomaly in this trend: the fixation duration of the novices was very high, but no deviation was noticed in the expert group.

Table 2: Mean values for the fixation durations (in s) for locating subsequent labels (*1 to *5) (1*: before the interaction - 2*: after the interaction)

		11	**12**	**13**	**14**	**15**	**21**	**22**	**23**	**24**	**25**
Novices	***M***	.257	.255	.263	.252	.272	.295	.265	.260	.251	.282
	SD	.070	.095	.100	.082	.101	.081	.105	.088	.079	.121
Experts	***M***	.260	.251	.240	.242	.253	.255	.244	.248	.238	.257
	SD	.100	.092	.067	.063	.080	.071	.089	.081	.061	.082

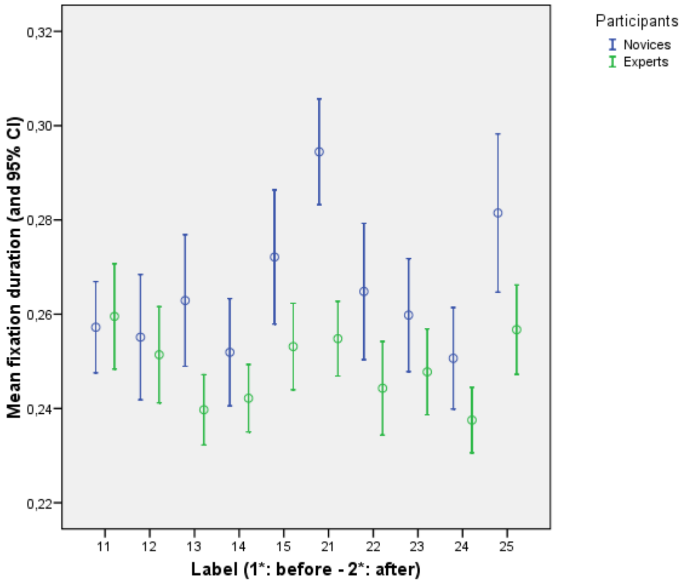


Figure 3: Error bars (mean values with 95% confidence interval) of the fixation durations (in seconds) related to each subsequent time interval

3.3. Fixation Count

The number of fixations a user can have per second is closely related to the duration of the fixations. If the duration of the fixation is very long, the number of fixations per second will decrease. However, the combined results of the fixation count and duration provide a better insight in the user's cognitive processes. Other elements that have an influence on the fixation count are the saccades. Shorter saccades may increase the number of fixations per second. The mean fixation counts for each subsequent label are listed in Table 3 and their distribution is depicted in Figure 4. The overall (all labels, all users) mean fixation count was 3.658 fixations per second (*SD* = .762 fix/s). Experts had a higher count (*M* = 3.694 fix/s, *SD* = .750 fix/s) than the novices (*M* = 3.605 fix/s, *SD* = .775 fix/s). A one way ANOVA shows that the measurements of both user groups differ significantly (*F* = 16.716, *P* < .001). As can be derived from Figure 4, the experts had significantly more fixations per second (*M* = 3.713 fix/s, *SD* = .736 fix/s) than the novices (*M* = 3.597 fix/s, *SD* = .754 fix/s) before the simulated interaction, with *F* = 14.726 and *P* < *.001*. The same goes for after the interaction: a significantly higher fixation count for the experts (*M* = 3.675 fix/s, *SD* = .764 fix/s) than for the novices (*M* = 3.613 fix/s, *SD* = .796 fix/s), with *F* = 3.940 and *P* = .047 < .05.

Table 3: Mean values for the fixation counts (fix/s) for locating subsequent labels (*1 to *5) (1*: before the interaction - 2*: after the interaction)

		11	**12**	**13**	**14**	**15**	**21**	**22**	**23**	**24**	**25**
Novices	***M***	3.805	3.600	3.552	3.573	3.450	4.003	3.542	3.497	3.540	3.488
	SD	.617	.797	.722	.730	.849	.605	.826	.776	.767	.864
Experts	***M***	3.746	3.622	3.723	3.718	3.758	3.610	3.713	3.654	3.662	3.738
	SD	.654	.834	.702	3736	.740	.795	.777	.797	.693	.751

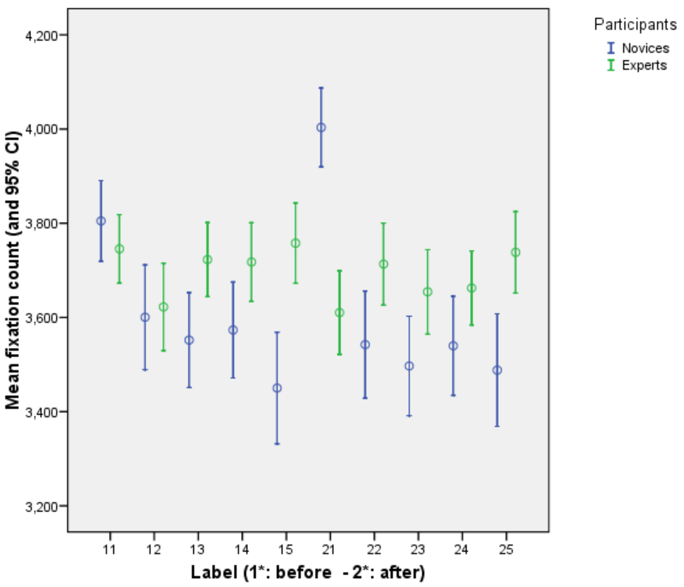


Figure 4: Error bars (mean values with 95% confidence interval) of the fixation counts (fix/s) related to each subsequent time interval

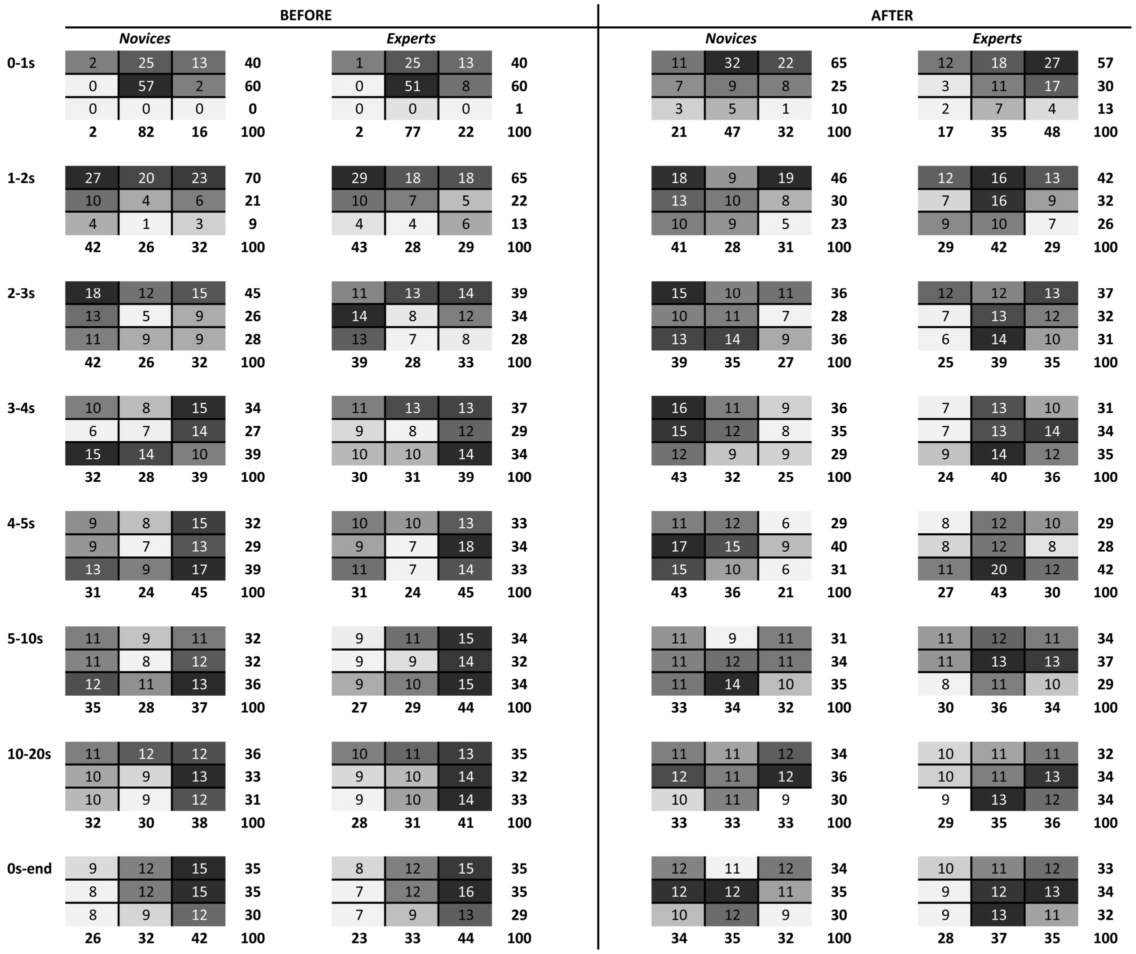
Similar as with the fixation durations, the number of fixations per second diverged between novice and expert users with each subsequent interval. Equally, interval 21 of the novice group showed a deviation in the measurement: a much higher number of fixations per second. When comparing the measurements within both user groups, no significant difference could be detected between the intervals before and after the interaction ($F_{nov} = .223$, $P_{nov} = .637 > .05$ and $F_{exp} = 1.902$, $P_{exp} = .168 > .05$).

3.4. Fixation Distribution

Analyzing the eye movement data qualitatively and visually reveals spatial patterns in the search behaviour of users. The location of fixations indicates which part of visual stimuli (map in this case) is of most interest to a user at a certain moment. Since this experiment focuses on two types of users, differences in these patterns might be noticed. In Figure 5, a number of intervals are depicted for each user group, presented by a grid of nine areas of interest (AOIs) that cover the whole map image. The number of fixations in each AOI during the mentioned time interval is presented in percentages. The darker the cell, the more fixations were registered. With this figure, the locations of fixations before the interaction can be compared with the corresponding intervals after the interaction on the one hand and between the two user groups on the other hand. Furthermore, evolutions in the user's search behaviour might be visible in the subsequent time intervals.

Before the interaction, the distribution of the fixations was very similar between the novice and expert users. During the first second of the map's display more than 50% of the fixations were located in the middle of the map due to the drift correction: the user had to look at a fixed point in the middle of the screen and the deviation was measured. This was executed after each trial to control the quality of the current eye tracker's calibration. During the next few seconds, the grid of AOIs shows a higher concentration of fixations in the top row. This indicates that the users tended to start their search in the upper part of the map. Only after three seconds, the fixations seem to be more homogeneously spread over the different AOIs and thus over the map image. During the remaining intervals, the AOIs in the middle seem to have the lowest count whereas the AOIs on the top right corner always have a rather high count. A possible explanation is the list with names located on the right side of the map, but outside the map image. When starting to search for the names, some of the fixations in the scanpath are located in the closest AOI.

After the interaction, no drift correction was executed, resulting in a more homogeneous spread of the fixation during the first second. Similarly as before the interaction, both user groups started scanning the upper part of the map whereas they focussed only in a later moment on its lower part as the higher concentration of fixations in the top row of AOIs reveals. However, in contrast with before the interaction, the novice users systematically had more fixations in the left column of the AOIs, thus on the left side of the map. The fixations of the expert users were concentrated in the middle and right column of AOIs and much less in the left one.



	BEFORE								**AFTER**							
	Novices				***Experts***				***Novices***				***Experts***			
0-1s	2	25	13	**40**	1	25	13	**40**	11	32	22	**65**	12	18	27	**57**
	0	57	2	**60**	0	51	8	**60**	7	9	8	**25**	3	11	17	**30**
	0	0	0	**0**	0	0	0	**1**	3	5	1	**10**	2	7	4	**13**
	2	**82**	**16**	**100**	**2**	**77**	**22**	**100**	**21**	**47**	**32**	**100**	**17**	**35**	**48**	**100**
1-2s	27	20	23	**70**	29	18	18	**65**	18	9	19	**46**	12	16	13	**42**
	10	4	6	**21**	10	7	5	**22**	13	10	8	**30**	7	16	9	**32**
	4	1	3	**9**	4	4	6	**13**	10	9	5	**23**	9	10	7	**26**
	42	**26**	**32**	**100**	**43**	**28**	**29**	**100**	**41**	**28**	**31**	**100**	**29**	**42**	**29**	**100**
2-3s	18	12	15	**45**	11	13	14	**39**	15	10	11	**36**	12	12	13	**37**
	13	5	9	**26**	14	8	12	**34**	10	11	7	**28**	7	13	12	**32**
	11	9	9	**28**	13	7	8	**28**	13	14	9	**36**	6	14	10	**31**
	42	**26**	**32**	**100**	**39**	**28**	**33**	**100**	**39**	**35**	**27**	**100**	**25**	**39**	**35**	**100**
3-4s	10	8	15	**34**	11	13	13	**37**	16	11	9	**36**	7	13	10	**31**
	6	7	14	**27**	9	8	12	**29**	15	12	8	**35**	7	13	14	**34**
	15	14	10	**39**	10	10	14	**34**	12	9	9	**29**	9	14	12	**35**
	32	**28**	**39**	**100**	**30**	**31**	**39**	**100**	**43**	**32**	**25**	**100**	**24**	**40**	**36**	**100**
4-5s	9	8	15	**32**	10	10	13	**33**	11	12	6	**29**	8	12	10	**29**
	9	7	13	**29**	9	7	18	**34**	17	15	9	**40**	8	12	8	**28**
	13	9	17	**39**	11	7	14	**33**	15	10	6	**31**	11	20	12	**42**
	31	**24**	**45**	**100**	**31**	**24**	**45**	**100**	**43**	**36**	**21**	**100**	**27**	**43**	**30**	**100**
5-10s	11	9	11	**32**	9	11	15	**34**	11	9	11	**31**	11	12	11	**34**
	11	8	12	**32**	9	9	14	**32**	11	12	11	**34**	11	13	13	**37**
	12	11	13	**36**	9	10	15	**34**	11	14	10	**35**	8	11	10	**29**
	35	**28**	**37**	**100**	**27**	**29**	**44**	**100**	**33**	**34**	**32**	**100**	**30**	**36**	**34**	**100**
10-20s	11	12	12	**36**	10	11	13	**35**	11	11	12	**34**	10	11	11	**32**
	10	9	13	**33**	9	10	14	**32**	12	11	12	**36**	10	11	13	**34**
	10	9	12	**31**	9	10	14	**33**	10	11	9	**30**	9	13	12	**34**
	32	**30**	**38**	**100**	**28**	**31**	**41**	**100**	**33**	**33**	**33**	**100**	**29**	**35**	**36**	**100**
0s-end	9	12	15	**35**	8	12	15	**35**	12	11	12	**34**	10	11	12	**33**
	8	12	15	**35**	7	12	16	**35**	12	12	11	**35**	9	12	13	**34**
	8	9	12	**30**	7	9	13	**29**	10	12	9	**30**	9	13	11	**32**
	26	**32**	**42**	**100**	**23**	**33**	**44**	**100**	**34**	**35**	**32**	**100**	**28**	**37**	**35**	**100**

Figure 5: Distribution of the fixations of both user groups on the map image (in percentage) during a fixed time interval

4. Discussion

The combined results of the response time measurements and eye movement recordings allow detecting how efficient and effective a user can perform a certain task related to map use. The response time measurements give insight in how fast the participant finds a name and the position of the eye movement at that moment reveals if he found a correct one. Furthermore, eye movement metrics (fixation duration and fixation count) give more detailed insight in the users' cognitive processes while performing a visual search. This insight explains the results of the response time measurements related to the Cognitive Load Theory. The 'between user' study design allows differentiating between both user groups: does the background knowledge and experience have an influence on the user's cognitive processes?

For both user groups, the same trend was visible in the response time measurements for each subsequent label. The smallest time interval was associated with the second label (12 and 22), not with the first label (11 and 21). This first longer interval may be explained by the orientation process. The moment when a map is presented to the participant, he has to orient the map and the list with names before he can start searching on the map. This orientation process will be longer in the initial view because the map is completely new to the user. After the interaction, however, only part of the map is new and thus the orientation time is reduced. After the second label, the response times increased with each subsequent label, which may indicate an equal increase in the cognitive load. On the one hand, the user is trying to locate a current label. This task requires the working memory to process the active visual stimuli and link this information to the previously gathered information (stored in the long term memory). On the other hand, the position of previously located labels is being processed. This process also addresses the working memory which may increase the germane cognitive load in order to be able to transfer this information to the long term memory. With each new label, longer response times were measured, which may suggest an increase in the (germane) cognitive load. The reduced response times after the interaction may be explained by a reduced germane cognitive load. Users may find it easier to create links with the long term memory. However, the response times related to the two last labels after the interaction showed a steep increase, which was even more pronounced for the novice users. This steep increase suggests an equally steep rise of the novice users' cognitive load.

The shorter response times after the interaction may indicate a learning effect: less time was needed after the interaction because the cognitive load of the user is lower. A part of the map the user was already familiar with, remained visible after the interaction: a mental map for this part of the map was constructed and stored in the long term memory. After the interaction, this mental map had to be completed with only a small part of the current view that could be linked with the former view. These elements suggest a reduction of the germane cognitive load after the interaction. This implies that the user could invest more of his working memory in processing the current visual stimuli. This investment could explain the significantly faster retrieval of the labels in the second view.

However, the reaction times of the experts were significantly shorter than these of the novices. Although these differences were less than a second, they have to be interpreted in the context of the study design: locating a name on a basic map. These differences may be explained by the eye movement metrics, providing insight in the users' cognitive processes while working with these dynamic and interactive maps. First, the duration of a fixation may indicate the degree of difficulty experienced when interpreting a certain (visual) content. The results from the experiment show that experts had significantly shorter fixations than the novices, both before and after the interaction. This suggests that experts had it easier to interpret the map's content than novice users. The background knowledge and experience of the experts might be the cause of this increased efficiency: previous knowledge and habit facilitate interpreting complex visual stimuli. Second, the number of fixations per second is considered. During a fixation the user interprets the visual input. The more fixations the more visual input the user can interpret. Consequently, the user can interpret more content, or a larger part of the map. The number of fixations per second is closely related to the duration of the fixation. The results of the experiment show that experts had significantly more fixations per second than novices, also both before and after the interaction. As a consequence, experts could 'scan' or interpret a larger part of the map image in the same amount of time and they can locate the names on the map more efficiently, resulting in shorter response time measurements.

The significantly longer fixations of the novice group after the interaction were mainly caused by the deviation of the measurement during interval 21. A peak is noticed in the measurements, which is not the case for the expert group. The results from the fixation counts show the same peak during interval 21 for the novices and not for the experts. Normally, longer fixations are typically associated with fewer fixations per second, but this is not correct for this interval. Since this interval is situated right after the simulation, it could be assumed that the novice map users might have been distracted of the presented pan operation. However, this simulation does not seem to have an influence on the response times of the experts.

The qualitative and visual presentation gives more insight in the distribution of the users' fixations, their evolution over time and differences between both user groups. The grid of nine AOIs with the associated fixation count (in percentages) gives an overview of the regions on the map that are of interest at a certain moment in time. Both before and after the interaction, both user groups start interpreting the upper part of the map. Gradually more fixations are found in the middle and the lower part of the map. Before the interaction, there was not much difference in the distribution of the fixations between the novices and experts. After the interaction, however, the novices tended to have more fixations on the left side of the map than the experts. The left side corresponds to the part of the map that was already visible during the initial view (before the interaction). The novice users seemed to be more attracted to this familiar part of the map whereas the experts had a remarkably low percentage of fixations in this region. This could be explained by a better structured cognitive map of the expert group, which would make it easier to determine whether a certain label is within the overlapping part after the interaction or not. They only searched on ('fixated') the left part of the map if a label (from the list) is located in this region. Novices experienced more difficulties in determining whether a label was already visible on the initial view or not, and consequently searched more often in the left part of the map.

5. Conclusion and Future Work

The analyses described in this paper reveal how users look at, interpret and search on maps, which is essential information to understand the users' cognitive processes while working with these maps. This understanding is crucial to be able to create more 'user friendly' or effective maps in the future, especially since animations and dynamic interactions are increasingly being added to the interface of maps on the Internet. Recent technologies allow and even support this evolution, but the limits of the end users' cognitive processes need to be considered. Users who are not that familiar with working on maps might not benefit from all the interaction and animation possibilities since they need more time to interpret the content. These technical possibilities could also be used to differentiate the map content according to the type of user. However, up till now very little practical knowledge is gathered about these cognitive processes related to (dynamic and interactive) screen maps.

The experiment described in this paper is part of a larger study to obtain more detailed insight in the cognitive processes of map users while working with dynamic and interactive maps. Since maps are essentially spatial objects, the statistical analysis will be extended with a more detailed visual analysis of the eye movement. The visualisation of the users' scanpaths might reveal patterns in the orientation and/or search behaviour, as well as influencing factors. Furthermore, new tests are planned, using topographic maps, that deviate even more between different user groups.

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