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Cartographic design of thematic polygons: a comparison using eye-movement metrics analysis

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Master thesis, 30 credits, in *Geomatics*

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Abstract

Cartographic design of thematic polygons: a comparison using eye-movement metrics analysis

Map design research has strongly come into the agenda with the extensive use of GIS and maps in geoportals. Geoportals are used to find, access and display geographic data via the Internet. Novel opportunities and techniques for displaying geographic data in viewing services also introduce new challenges and issues in cartographic design. Specifically, thematic polygon layers (foreground) will obscure information in the background. Also, discriminating extents and locations of thematic polygon layers, that overlap each other is an issue. The aim of this thesis is to compare different cartographic design principles for thematic polygons and to utilize the eye-tracking methodology for solving cartographic design problems. Those suggestions are supported by empirical data collected from eye-movement metrics from subjects who performed inference tasks using maps of restriction areas.

In this study, 32 participants with knowledge in cartography/geography/GIS were asked to solve practical map reading tasks in a controlled experiment. Cartographic design can be studied with eye-tracking, which is a commonly utilized method to study visual search problems and provide design guidelines to improve usability. To compare different cartographic design principles for polygon objects in a geoportal, four design techniques (boundary lines, transparency, hatches and icons) were empirically tested on 16 physical map areas. These designs are provided by a Swedish standardization project in web cartography (SIS/TK570).

Empirical results show that to interpret the extent of the polygon on the conditions created in this study, the hatches design gave better results. As the hatches had the shortest scan path, one could interpret that this design was good for this particular map task solving experiment. Also, the hatches had the shortest fixation duration, thus meaning the design was good for this particular task. Furthermore, since the fixation count was smallest with the hatches design, one could assume that this map stimuli or layout was easily interpreted. An improved design technique for polygons that are on top of each other and on top of the base map in geoportals would be a design that includes elements combination from various designs. It is important that geoportals enable various design properties to manipulate by the users and more than one default design option, because all tasks can’t be solved with the same design. Eye-tracking offers additional information, more than just reaction time and correctness of answers. From the eye-movement data it is possible to conclude why the reaction time and quality of inference are different between designs. The results can be generalized for similar thematic polygons and map reading tasks as used in this study.

Keywords: map design research, cartographic design, thematic polygons, eye-tracking, geoportal, cognitive cartography.

Supervisors: Lars Harrie, Marcus Nyström

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Preface

The thesis was written by Andreas Kiik and supervised by Lars Harrie, Department of Physical Geography and Ecosystem Science at Lund University. Work with the eye-tracking equipment at Lund University Humanities Lab was supervised by Marcus Nyström. All experiments with human participants were conducted in Lund University Humanities Lab. I would like to thank the participants and acknowledge the good work they made.

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1. Introduction

1.1 Background

Geographic data are used by broad audiences for solving many difficult problems. Access to geographic data is mainly by maps, which are visual interfaces to information stored in spatial databases. Today, these data are mainly managed, visualized and analyzed with interactive mapping applications. These applications combine data from various datasets and sources, allowing users to see many datasets at once.

A common concept of finding, accessing and displaying geographic data via the Internet is by viewing services, in geoportals. Such applications are located in a public web portal and combine geographical information published by many data providers. Geoportals provide the user with more flexibility and simplicity, thus introducing it to wider audiences. Geoportals help to use GIS more effectively and are the key elements in a Spatial Data Infrastructure (SDI).

Novel opportunities and techniques for displaying geographic data in viewing services also introduce new challenges and issues in cartographic design. From this aspect, geoportals differ from common interactive map products by the lack of a cartographer, who selects and optimizes data presentations according to the map purpose. As the information visualized in geoportals is coming from many services and in an automated way, not designed to be shown on top of each other, visual conflicts between map elements will occur (Toomanian et al., 2012). Specifically, operational data on thematic polygon layers (foreground) will obscure information in the background. Also, discriminating extents and locations of thematic polygon layers, that overlap each other is an issue. These issues greatly affect the readability and usability of the geographic data viewed in geoportals. The relevancy of this becomes into agenda from the fact that many EU countries are now setting up the geoportals, to comply with the INSPIRE directive and struggling with the appropriate design of their geographic data (Bernard & Kanellopoulos, 2005).

Cartographic design can be studied with eye-tracking, which is a commonly utilized method to study visual search problems and provide design guidelines to improve usability. The methodology based on experiments which include visual stimuli (graphics on external display e.g. maps), stimuli relevant questions or tasks and recording user eye-movements behavior while solving tasks on visual stimuli. To analyze eye-movement data, various eye- movement metrics, like fixation duration and eye-movement scan paths are measured with an eye-tracker device. Results give objective and quantitative indications about user's cognitive processes while completing difficult visual search tasks and show where user visual attention is directed during a certain task.

Cartographic designs can be compared by using an eye-tracking methodology, an eye-tracking experiment; the tests will reveal how map readers perceive visual information from maps and perform visual search. These experiments, within map design research field, are framed within cognitive theories and combine cognitive science with cartographic visualization. In recent years the use of eye-tracking in cartographic design research has increased (Fabrikant et al. 2008, Çöltekin et al. 2009, Brodersen et al. 2001, Fabrikant et al. 2010, Li et al. 2010). This is due to availability as well as development of both eye-tracking software and hardware, also this technology is now more cost-effective. Furthermore, perceiving information efficiently and effectively is risen into the research agenda because graphical environments are turning more complex, overwhelming with data and visualization (Ooms et al., 2012a).

Previous studies investigating cartographic design with eye-tracking experiments, especially those focused on interactive map services, introduce new methods that help to solve challenges and issues with cartographic design (Ooms et al., 2012a; Coltekin et al., 2009; Fabrikant et al., 2010; Fabrikant et al., 2008; Steinke, 1987; Brodersen et al., 2001 and others). But none of these experiments have explicitly studied thematic polygon layer design. Empirical evidence for optimal thematic polygon design principles are not presented, particularly when layers overlap each other and are combined on top of a background map. By creating the similar conditions in test environment as appearing in actual geoportals and conducting experiments with real data, tasks and users, generic guidelines which are applicable in any working geoportal can be presented.

1.2 Problem statement

Combining several polygonal datasets on top of each other, defined as overlaying, cause a known problem in cartographic design. Polygon layers obscure the information available in the background map, causing loss of information from the map reader's point of view. Also, these layers commonly overlap each other, thus making it difficult to determine their extent and location. Several cartographic design techniques for overlaying thematic polygons, such as transparency (Figure 1), patterns (Figure 2), only boundaries (Figure 3) and icons (Figure 4) address this problem. However, there is a lack of user evaluation of these designs.

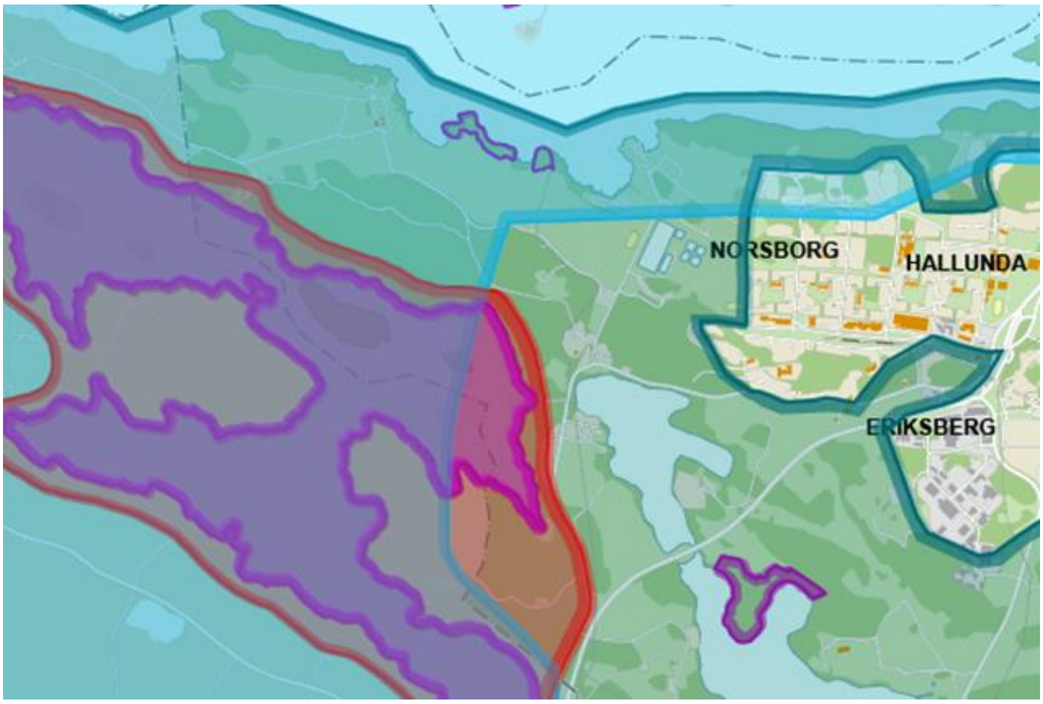


Figure 1. Designing thematic polygon layers with transparency. (The maps are made by Karin Willis, (c) Botkyrka kommun and Länsstyrelsen Stockholm).

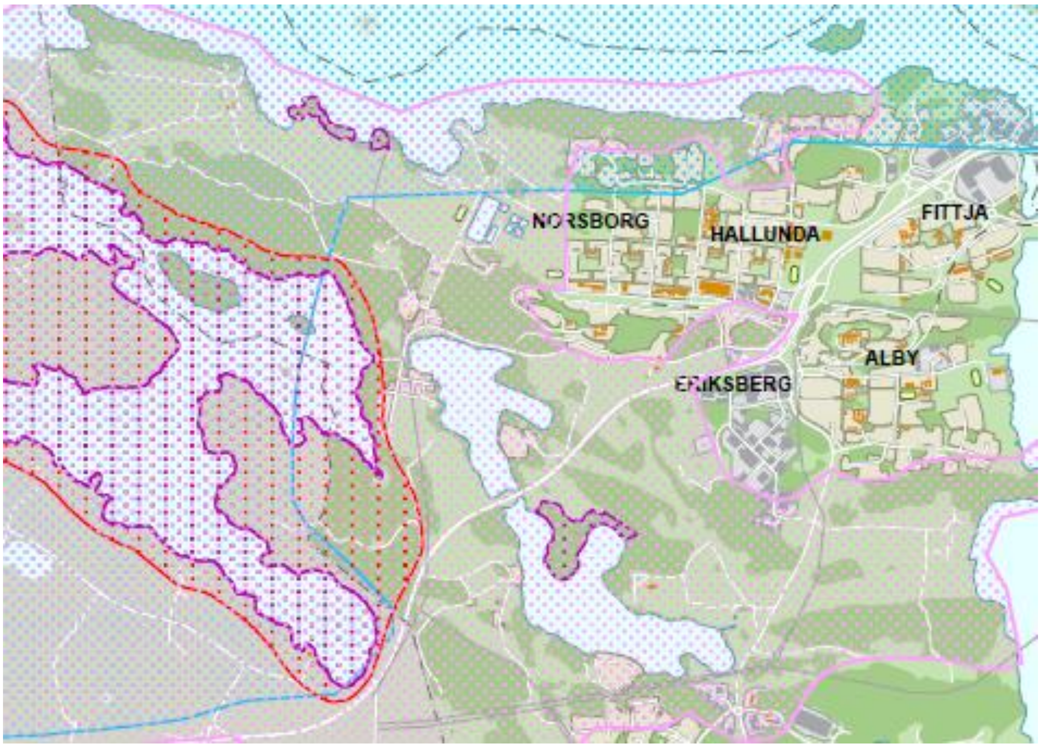


Figure 2. Designing thematic layers with patterns. (The maps are made by Karin Willis, (c) Botkyrka kommun and Länsstyrelsen Stockholm).

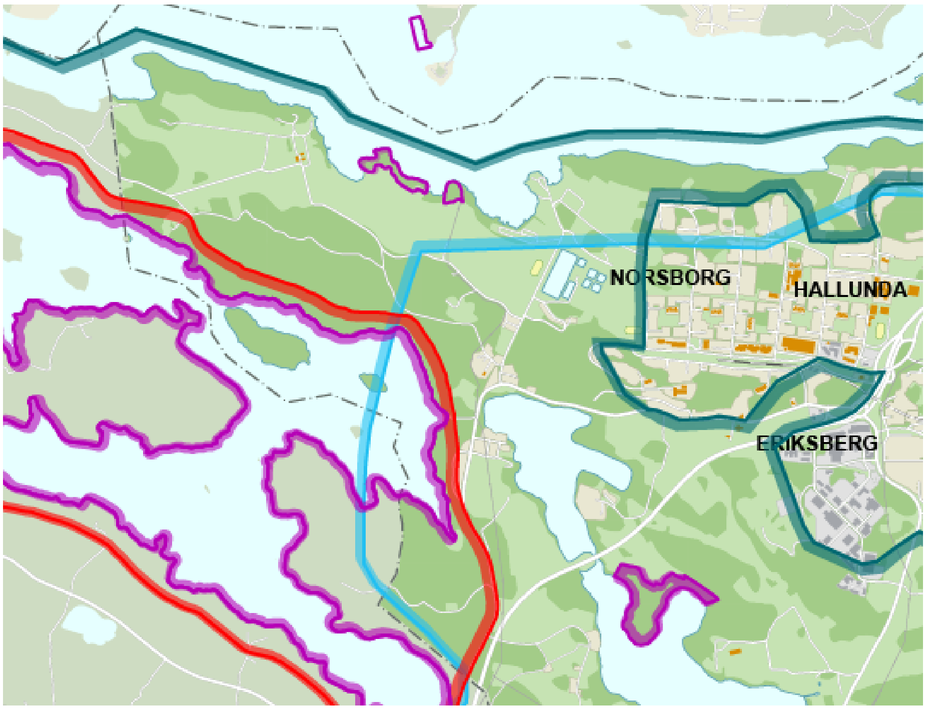
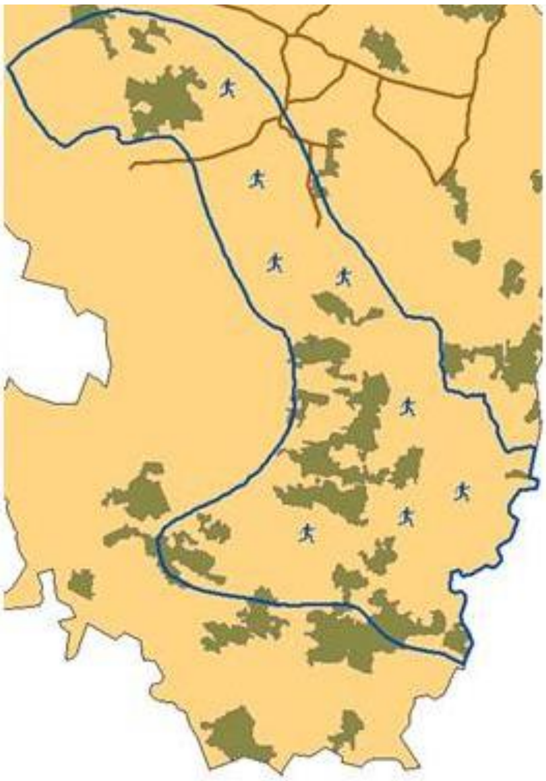


Figure 3. Designing thematic layers with only borders. (The maps are made by Karin Willis, (c) Botkyrka kommun and Länsstyrelsen Stockholm).



(b)

Figure 4. Designing thematic polygon layers with icons. (Toomanian et al., 2012, p.9).

Swedish Standardization Agency coordinates an ongoing (2015) project in web cartography, (SIS/TK 570) which among others, include design recommendations for thematic polygons. To verify the best design principles in geoportals, empirical experiments and evidence are needed.

1.3 Aim

The aim of this thesis was to compare different cartographic design principles for thematic polygons and utilize the method of eye-tracking for solving cartographic design problems. In this study, the research objectives are the following:

1. Improve the efficiency and effectiveness of cartographic map design, particularly when adding thematic polygons on top of a background map. This part results in design guidelines and recommendations.

2. Evaluate eye-movement metrics data for studying the usability and readability of cartographic design.

1.4 Method

The method in this study includes three main parts: preparation of the experiment, conducting the experiment and collecting data and finally, analyzing the data. The first step in this study was to prepare maps and experiment. Based on the collected information and knowledge from supervisors, the experiments were designed using maps and questionnaires. Then, the experiment was tested during a pilot study carried out by the author, supervisors and other pilot test subjects. The results and findings from the pilot study were used to improve the preliminary study. Potential test participants, who formed a selection of GIS users, were reached by e-mail. Most of them were related to the Department of Physical Geography and Ecosystem Sciences. Participants performed various tasks, which can be completed with the help of information available on the maps given. Metrics like fixation duration, scan path length, fixation count and net dwell time in AOI (area of interest) were considered. Eye-movement data from participants were collected during actual experiment, while participants solved map reading tasks. Finally, the data were analyzed to investigate any statistically significant difference between designs.
The workflow from the first step to the last step was not straightforward, some steps were redesigned in the form of trial and error.

From statistical analyzes and comparing different designs, eye-movement metrics and tasks performed by participants, recommendations were given for optimal design. The thesis focused also on the experiment design and capabilities of using eye-movement data for investigating cartographic design.

1.5 Disposition

In the introduction section, necessary information and background to understand the purpose and goals of this study are given. Also, explanation of the problem is stated.

The theoretical part of the thesis includes overview of the problem, a survey of previous relevant studies and a description of eye-tracking methods. Overview of map design research and common cartographic principles are given. Geoportals are introduced and capabilities of these viewing services are explained, including technical details about how maps are designed in geoportals. Cognitive theory for visual information perception and understanding, as well as those aspects in cartographic design and map reading are outlined. As the problem of visual conflict between map layers and elements is common in cartography, map research design studies offer possible solutions and insights. In this thesis, inference making from maps is defined as understanding the information presented on the map quickly and answering given questions about the map correctly. Also, critics about empirical experiments and map design research overall is presented. Information about experiment design using the eye-tracking techniques and possible problems that can occur are reviewed. The chapter for eye-tracking provides background to applying this method.

The practical study section of the thesis includes: designing the experiment, choosing the right devices for eye-tracking, selecting appropriate eye-movement metrics to record, conducting the experiment and analyzing the outcomes of eye-movement data. This also includes conducting the pilot experiment. The results chapter is the main part of this thesis, by providing statistics from eye-movement metrics with cartographic design. It ends by explaining efficiency and effectiveness in perceiving information from maps with different designs in the light of eye-tracking results. That is, empirical evidence collected in this study give new information of how good map design can enhance inference making from complex thematic maps. Discussion and conclusions are provided in the last chapters, also cartographic recommendations for combining data from several datasets and guidelines for conducting similar studies are given.

2. Theory and related work

2.1 Cartographic design principles and research

Cartographic design includes two main processes: mental and physical and these are divided into smaller steps, which then formats the map communication model (Slocum et al., 2004). The design process is not finished until the map is completed and could be repeated iterated multiple times. There are two main goals for cartographic map design, first, the map must serve the required information for the specific audience and second, the information on the map must be displayed in an efficient, simple and clarified manner (Slocum et al., 2004).

Maps consist of graphical elements, visual variables (Krassanakis, 2013). These are used for visual search or to "see" the maps. There are techniques to make important features on the map more visible and create a visual hierarchy. Task relevant and map purpose oriented thematic information is designed to be more perceptually salient than other information presented on the map. In this way the map reader's attention is focused on important elements in the map. This can be achieved by manipulating contrast, figure – ground relationship and balance. Contrast is the visual difference between map objects and provides graphical variety to show which objects are more important on the map (Slocum et al., 2004). Wolfe (2002) points out several of these, for example: color, orientation, shape, size, scale. MacEachren (1995) explains figure – ground relationship as grouping combined information considering perception, visual attention and significant map elements. Figure – ground method enables cartographers to manipulate the perception that some features appear closer to the map reader and in front (on top) of other map elements.

Cartographic design determines efficiency and effectiveness of the map, which is how map users perceive information presented and how it is understood it. Effective maps can represent complex data and still be easily legible by the user (Ooms et al., 2012a). Selecting appropriate polygon design for presenting thematic information on maps is a fundamental cartographic design task.

Cartographic design is affected by the results from map design research and from graphic design. Most of the map design research, especially empirical research, is done in the field of thematic maps (Board, 1981 and Castner, 1983 described in Montello, 2002). Montello (2002) describes critics by Petchenik (1983) towards map design research, claiming that map design research is not helpful because humans use maps differently than test subjects during experiments. For example, ordinary map users do not have a single absolute question when they look at maps. She also argued that results from the empirical studies are context-dependent. Other critics, according to Montello (2002), include map users individual differences and that experiments focus mainly on low-level map reading tasks, like size detection.

A common problem is that thematic polygons in the foreground obscure important information in the middle and background (Toomanian et al., 2012). One of the map designs used in this study is the polygon overlay method. The polygon overlay method investigated in this study is one possible solution for this problem; it is based on representing a polygon with icons that are placed semi-randomly in good locations, thus not hiding any vital information on the background.

2.2 Geoportals

The European Commission established the Infrastructure for Spatial Information in Europe (INSPIRE) directive in 2007 (European Commission, 2007). This directive supports availability of spatial information through European Union. To meet the objectives of INSPIRE, the Spatial Data Infrastructure (SDI) concept was made to encompass policies, organizational field of work, data, technologies, standard delivery mechanisms, finance and necessary human resources. In order to discover and use existing spatial information offered by EU countries, a concept of electronic portal for searching, viewing and downloading information, called the EU Geoportal, was proposed (Bernard et al., 2005). This thesis focuses on viewing services.

The spatial data in geoportals are visualized through Open Geospatial Consortium (OGC) Web Map Service (WMS). WMS displays spatial data from a geographic information database as a raster image map (OGC, 2006). WMS is an international standard that offers three operations: information about metadata, displaying map image and give information about specific feature on the map. With this standard, the design and style of the map image sent to user, is predefined. However, OGC offers another specification mechanism, Styled Layer Descriptor (SLD), to enable user-defined symbolization of feature data, so users can apply their own explicit styling rules (OGC, 2006). This method offers better design capabilities for datasets that are published by different providers and thus not meant to be displayed together.

This viewing service offer new opportunities to display rich and personalized geographic data. However, displaying multiple data sources at once raises new challenges, especially for automating methods for presenting data in geoportals. Harrie et al. (2011) argues that, solving these presentation issues is essential for the success of geoportals as viewing services in the future and for making right conclusions from the data. As viewing services should offer quick and certain answers for relevant spatially directed questions, the designs aspect, which affects usability the most, is in the main focus (Harrie et al., 2011). Also, with the latter in mind, it is difficult to predict the purpose and usage for the users, so here readability is a more appropriate measure than usability. The degree of readability is the main argument for cartographic quality and is defined as to what degree the map user can visually read the map (Harrie et al., 2011). The methods offered in this study to improve design were compiled with this understanding in mind.

2.3 Cognitive cartography

Cognitive cartography uses cognitive theories and methods to understand, produce and read maps (Montello, 2002). Montello (2002) explains that cognition and cognitive processes in cartography include several aspects: perception, learning, memory, thinking, reasoning, problem-solving and communication. Map reading consists of all these aspects and thus can be explained as a complex cognitive process. If the map reading can be explained as a cognitive process, then to be able to design better maps, this fact must be considered and followed in cartographic design research. Montello (2002) defines cognitive map design research as the purpose of getting to know map users cognitive processes to be able to enhance cartographic map design.

Current understandings for improving visual attention on maps imply that both processes, bottom-up (stimulus driven and pre-attentive) and top-down (task dependent, cognitive and semantic) should be combined together (Fabrikant & Goldsberry, 2005). With bottom-up processing, user's visual attention is selecting the object and elements from the map to cognitively solve the task and this is done in working memory. During top-down processing, the user visual attention is influenced by prior knowledge about the task and the map and this comes from long term memory (Bunch & Lloyd, 2006). To make correct inferences, both concepts of processing, bottom-up and top-down, are used simultaneously. Another important aspect for improving visual attention and designing maps to be easily understood, is to maintain the map readers' cognitive load during this process.

Cognitive load can be understood as a work effort needed to obtain and use information perceived. This applies well for geographic information presented on maps (Bunch & Lloyd, 2006). The amount of cognitive processing needed, information presented, expertise of the map reader and the design of the information, contribute to the cognitive load. If the cognitive load is rather high for a certain map reading task, the task tend to be more difficult, thus will result in less correct answers and take longer time to complete (Bunch & Lloyd, 2006).

Bunch and Lloyd (2006) point out three assessment factors to measure cognitive load: mental effort, mental load and mental performance. Mental load is mostly related to the specific task and its difficulty, which map readers must complete on the map. Mental effort is the whole amount of cognitive capacity used during this task, which can include learning new information or remembering already known information. Mental performance ties those two together and reflects their common aspects.

The cognitive load can also be divided into three categories: intrinsic, extraneous and germane (Bunch & Lloyd, 2006). The first one, intrinsic, describes the amount of working memory and long term memory needed to learn new information and store this information for later use. The second part of cognitive load, extraneous, is interfering map user learning capabilities, and is affected by the way how task instructions and information on the map is presented. The previous component is the main opportunity that cartographers can use to reduce cognitive load; this is done by eliminating any information from the map that the map user does not absolutely need for the process. Germane component is used to improve learning, with generating patterns, models and experiences of how to solve or explain a task for information presented. It is also affected with the design of the information.

Based on Mayer and Moreno (2003), Bunch and Lloyd (2006) adapted the cognitive theory of multimedia learning to map reading and explain how humans learn and make conclusions from the map. The process, in a simplified way, is as follows: visual stimuli (e.g. map) is presented to the user, with eyes as primary sensors the information is acquired for the working memory and processed as a cognitive map, then it is integrated with all previous knowledge from long term memory to make final conclusions.

Simon (1978) presented the concept of informational and computational equivalency of representations. He showed that two map representations can contain the exact same information, but can be very different concerning the amount of cognitive load and effort needed to understand the information presented and make correct conclusions from it. Two representations are informationally equivalent if it is possible to get the same information from both and one can be made from the information of the other. For computational equivalency it defines that, two representations are computationally equivalent if informational equivalency applies and all conclusions that can be easily and quickly made from one can be made explicitly from another with the same amount of effort. Thus, it can be implied that computational efficiency is determined by the map design and can be improved by enhancing the design.

2.4 Eye-tracking

Eye-tracking offers various methods and measures to investigate eye-movement data. The main tool for collecting these data is the eye-tracker, which records the eye-movement coordinates on a computer display. Eye-tracking software and hardware technology has developed very quickly. Also, the price and learning curve has decreased. The software is very intuitive and easy to use, both for building and conducting the experiment, as well as analyzing and exporting the necessary results. There is a wide selection of measures, but for the simplicity and goals of this study, most typical and common measures are utilized. These measures are: fixation duration, fixation count, scan path length and total dwell time in area of interest (AOI). The following terminology is used in this study (Holmqvist et al., 2011):
Fixation – a state, when the eye remains still over a period of time on a specific area.
Fovea – a part of the eye, which is responsible for our sharpest vision.
Fovea, foveate – in order to see objects sharply, light must fall directly on the fovea, thus enabling to foveate.
Gaze – point on the stimulus screen, where the user looks.
Saccade – rapid motion of the eye from one fixation to another.
Dwell time – the amount of time, from entry to exit, during which the gaze remains inside the AOI, including fixation duration and saccades.

Total dwell time – the amount of time, over the whole trial, that was spent inside the AOI, the sum of all dwell durations.
Saccade amplitude – is the distance travelled by a saccade from its onset and to the offset, given in visual degrees or pixels.
Scan path – the route of eye-movement events through space within a certain timespan; the path has a beginning and end, and therefore a length.
Scan path length – the sum of all saccadic amplitudes in a scanpath.
Fixation duration – a period of time when the eye is relatively still in the same position.
Fixation count – or number of fixations, the amount of fixations during a trial, over the whole of the stimulus.

Scan path length as a measure is used to evaluate interfaces; ideal scan path would be a straight line from the first fixation to a desired target, longer scan path would mean a non-meaningful representations or poor design (Holmqvist et al., 2011). Studies (Goldberg and Kotval, 1999 and Renshaw et al., 2003, described in Holmqvist et al., 2011) have shown that there is a significant difference between scan path lengths for good and poor user interfaces, and also that there is a significant difference in scan path length for poor and good visual design for graphs. For both cases, the design which is better has a smaller total scan path length.

Fixation durations vary between tasks and stimuli. Findings show one general pattern, that longer fixations indicate deeper processing and increased effort for cognitive processing (Holmqvist et al., 2011), but there are many exceptions. For example, Unema and Rötting (1990, described in Holmqvist et al., 2011) found that participants had longer fixations when they did more difficult mental calculations than when they made simpler ones. Also, Goldberg and Kotval (1999, described in Holmqvist et al., 2011) and many other researchers interpret that longer fixation duration means that understanding information from a display is difficult for the participants.

The measure of fixation count or number of fixations has also been widely investigated. The results indicate that as the amount of fixations increase, the search efficiency is lower and also a high number of fixations could mean difficulty of interpreting the fixated stimuli or layout

(Holmqvist et al., 2011). Fixation count could also be affected by experience, age, glasses, sex and memory built-up (Holmqvist et al., 2011).

The rationale of recording eye-movements, as empirical approach to map research, during map viewing, comes from the knowledge that map readers look at the places on the map that they wish to attend (Montello, 2002). From this, researchers can see where the map reader is trying to acquire information visually. The eye-tracking device records the position of fovea on the map and the fovea has the greatest number of visual receptor cells, thus places on the map that are foveated, are visually perceived with the best resolution (Montello, 2002). To get the full capabilities from this method, the location of the fovea is recorded with accurate time measurement, to enable temporal and spatial patterns of eye-movements.

A study made by Irwin (2004) examines the various issues considering the two main measurements of eye-tracking: fixation duration and fixation location. Eye-movements can be recorded unobtrusively because they are natural and frequently occurring human behavior. From this, it can be suggested that the eye fixation position is a good dependent variable and humans usually look at something when they want to gain more information about it (Irwin, 2004). From this, Irwin (2004) concludes that fixation location is happening on the same place that is cognitively processed at this moment and fixation duration is the time while cognitive processes are happening for the fixated material. Irwin (2004) points out that there are several issues concerning interpretation of eye-movement data, which are especially evident for studies about visual search and those measures would not provide completely precise and accurate information in all circumstances. These problems include: the cognitive processing can be happening on much wider areas than only fixation location, cognitive processing can be happening without certain fixation location, eyes can be moving without direct cognitive control and cognitive processes can be evident during eye-movements.

Eye-tracking devices record the fixation location from the center of fovea, and from this, the duration is measured by the time fovea is directed at this location (Irwin, 2004). But Irwin (2004) also argues that cognitive processes are not happening only in the center of fovea; rather there is a functional field of view surrounding the fixation location, where information processing during any visual task is done.

The size of functional visual field depends on various factors: the amount of items displayed at once, the similarity and detail of the items, the task being performed, cognitive load demand and on individual differences (Irwin, 2004). From this, it can be implied that solely the position of fovea is not sufficient to precisely analyze what information is being processed and how effectively the cognitive processes are interpreted (Irwin, 2004). He also suggests that when discriminating different objects, the accuracy is only high when the fovea is directly towards the target object location. From the map reading point of view, Irwin (2004) explains that some cognitive operations are suppressed during eye-movements and are executed only during eye fixations. One of those is mental rotation, which is a visuospatial process happening during a map reading task.

2.5 Eye-tracking in cartographic design research

Jenks (1973) was one of the first cartographers who experimented with eye-movement techniques in cartographic design. Jenks and his students recorded eye paths for map readers studying a dot map. The results were not accurate, but demonstrated that using eye-movement data in cartography and broadly in map design research is achievable. Eye-tracking enables to record differences in actual map using (reading) behavior and to compare these between different design methods. This method offers understanding of the interactions between the map reader and the map, defining not only the best designs that work, but also why they work. It is important to know how users process visual map content (Ooms, et al. 2012b). Coltekin et al. (2009) argues that with traditional methods, only recording time and correctness of answers, it is not clear if users do the same what they say they do or not when processing a map. Also, the eye-movement data provides objective and quantitative indications about user cognitive behavior (Ooms et al., 2012a; Krassanakis, 2013, Fabrikant et al., 2010).

Henderson and Hollingworth (1998) suggest that there are many advantages for eye-tracking experiments, compared to traditional methods. One of them is that data are collected without attracting the test subjects attention and discreet manner. Also, it provides researchers information about cognitive processing and real-time visual attention during map reading process. MacEachren (1995) points out that, cartographic design principles lay on limited empirical evidence. Bertin (1967, described in Montello, 2002) created a most widely used cartographical design recommendations, based on data characteristics and symbol characteristics, but presents no empirical data. Thus investigating different designs with empirical studies can add support for using (or not using) them.

There are several reasons why eye-tracking has had limited success in cartography, Montenello (2002) suggests that experiments were difficult and expensive to perform. He also says that, for some cartographers this kind of data collecting would not give them any new information. Furthermore, he points out that cartographic design research, especially cognitive cartographic research, is difficult and time-consuming. According to Brodersen, Andersen and Weber (2002), one of the reasons could have been that most studies focused on where users looked on the map, but did not relate eye-tracking metrics results with specific inference tasks. Ooms et al. (2012) argues that some concern about this method comes from the knowledge that there is no direct relation between eye movements and attention, map users can shift their notice without moving eyes. This again is refuted by Duchowski (2007) who claims that when solving complicated tasks (as inference making from maps), the direct link between eye-movements and attentive behavior is evident.

Fabrikant et al. (2010) conclude that in order to interpret eye-movement metrics on maps correctly and understand why some cartographic designs work better than others, researchers need to frame their studies within cognitive theories. In order to make effective cartographic map designs, researchers need to understand how map users store and process information presented on maps (Ooms et al., 2012a). She also argues that, to evaluate or investigate map design, user experiments or studies must be conducted. Ooms et al. (2012a) and Coltekin et al. (2009) chose eye-tracking, because this method records changes in the map readers attentive behaviors and cognitive processes unobtrusively while solving tasks on a map. The eye-tracking technology and movement metrics analysis have developed during recent decades, thus experimenting with these is accessible (Coltekin, et al. 2009).

Fabrikant et al. (2010) investigated how thematic relevance and perceptual salience are related to visual attention in weather maps. They used eye-tracking to reveal changes in map users viewing patterns when task relevant items were made more eminent through design. Also how users' attention was drawn on different map elements. One of the aims was to answer fundamental questions of which way and how cartographers can enhance maps to improve efficiency and effectiveness for inference making. Experimental methods from psychology and cognitive science were used to study these questions systematically and with an interdisciplinary approach. Fabrikant et al. (2010) conclude that the correctness of response is not affected by different designs. When analyzing the eye-tracking data, it is evident that users viewing behavior and response time are influenced. They also suggest that findings from empirical research, like eye-movement analysis, provide evidence that known design principles in cartography are justified.

Ooms et al. (2012a) present a new label placement method which has improved algorithmic efficiency. As this method influences the label placement on maps, researches questioned whether efficient algorithms create more usable maps. From the gathered data Ooms et al. (2012a) concluded that no difference in response time and other eye-movement metrics exists between the two map designs. Results show that it is possible to improve map algorithms without affecting the way users look at a map and the cognitive load. They also improved map efficiency but did not alter with effectiveness on map usability and readability. Ooms et al.

(2012a) claims that eye-tracking is an appropriate method for investigating users' cognitive processes during map reading tasks.

Coltekin et al. (2009) combined traditional usability methods with eye-movement recordings to evaluate two interactive map interfaces. These interfaces were equivalent from the information point of view but differed in design. Apart from traditional metrics they used eye-tracking to reveal if and how map display provides information for correct inference. Another aim was to conduct research based on cognitive theory and to study eye-tracking as a method in this domain. They also suggest using a combination of traditional methods with eye-movement analysis to empirically test maps. In their study eye-tracking data revealed micro level usability issues. They conclude that eye-movement analysis is complex, first it produces large volumes of data, which is time consuming to handle. Another issue is how to interpret eye-movement behavior correctly.

Brodersen et al. (2001) conducted a study to evaluate eye and head movement tracking as a new method to investigate the usability of topographic maps. They concluded that eye-movement data were most informative, because this enables researchers to follow the subject eyes exactly and draw conclusions from that.

Krassanakis (2013) examined pre-attentive vision in map reading and used eye-tracking as a method of experimentation. Two cartographic experiments were conducted, selectivity of a visual variable shape from sequence of maps and optimal values for change and duration. The results show that participants start looking at the map from the point where the answer was located on the previous map. Participants found the correct symbol faster when it was located at the center of display. From the second experience it was evident that users' reaction is faster when the point symbol location changes less in a sequence.

2.5.1 Eye-movement metrics analysis

Various eye-movement metrics are analyzed in cartographic design research. Fabrikant et al. (2010) measured eye fixations to derive scan paths and see how users viewing patterns are changing. They defined certain AOI-s (areas of interests) on the map, which were then divided to task related and task irrelevant. Fixation times (duration) in selected AOI-s were measured. From that they investigated how participants' visual attention changed with different map modifications.

Ooms et al. (2012a) recorded several elements (eye-movement metrics and mouse clicks) at the same time, after the study elements were combined. They combined results from eye-movement metrics and button clicks to identify which label was found at a given moment. Eye fixations were recorded to see how much time users need to process a view. Ooms et al. (2012a) claim that synchronization has to be perfect when combining different sources of measurements and preferably would be processed in the same software. Fixation duration and number were recorded, indicating how difficult it is to process visual information. Because the number of fixations is strongly related to the duration of a certain trial, number of fixations per second was used. According to Ooms et al. (2012a), maps that are not efficient have longer fixation durations, meaning that users are confused. Scan paths were also analyzed to understand test subjects' search behaviors.

Coltekin et al. (2009) enhanced traditional usability metrics with additional measures from eye movement recordings. This was needed to reveal the amount of cognitive processing load during map reading and where cognitive complexity is demanded. Gaze plots and fixation patterns were recorded in specific AOI-s. The AOI-s were selected before the test and enhanced after the recording process.

Brodersen et al. (2001) recorded fixations and analyzed the areas where fixations were concentrated. They advise caution, because it requires full insight of relating eye movements, task and visual behavior needs. Fixation duration was also analyzed to understand areas with greater complexity. From this they derived the sum of map viewing time, to see on which map subjects perform faster.

Krassanakis (2013) examined how test subjects search a shape that has a hole in it. Eight test subjects were asked to search a point symbol with this property among other pictorial and geometrical symbols placed on a map. They used 16 different maps, half with pictorial symbols and others with abstract symbols. In the second experiment, 32 test subject's eye-movements were recorded while they observe moving point symbol on a simple blank background and a topographic map. He used fixations, saccades and scan paths to analyze visual search. Conclusions are that, when the target is located in the periphery of the map, the scan paths are more complicated. Also, scan paths are more complicated when the target is missing from the map. The location of the point symbol changes through scenes, but the background remains the same.

2.5.2 Performance measures

For evaluating cartographic design, there are two commonly (or traditionally) used measures in usability testing: efficiency (response time) and effectiveness (accuracy of response)

(Coltekin et al., 2009). According to Fabrikant et al. (2010), these can also be explained as inference speed and quality of inference.

Ooms et al. (2012) also recorded response time, to indicate how fast participants found the labels. Measures were compared between map designs, effective map design would result faster response times, because users process information easily. Coltekin et al. (2009) measured three traditional usability metrics, user satisfaction, efficiency and effectiveness. These are widely used in usability engineering when users are given a certain set of tasks based on a particular usage scenario to investigate map designs. Brodersen et al. (2001) defined three main measures to evaluate map reading. These were: efficiency, effectiveness and visual behavior during map reading task.

Stigmar (2010) also describes which are the measures of "good" or "better" map designs. She claims that a map should give quick and certain answers to relevant questions and presents three traditional metrics: time taken to solve the task, identified behavior (is the map used correctly and what happens during map use) while solving the tasks and the number of correct answers.

2.5.3 Experiment design

Fabrikant et al. (2010) used weather maps in their study, because inference making from those is complex. Also weather maps are commonly used and popular. They chose thirty novice participants from an undergraduate geography class to evaluate interpretations of wind direction from the maps. Participants used two different maps, one was designed for mass media and the other had cartographically designed task related elements. They were shown two series of thirty maps, with true/false answer possibilities. All participants had six practice trials, to become customed with the task and eye-tracking device. During the test, eye-movement and response data were collected.

Research done by Ooms et al. (2012a) tested thirty participants while working with dynamic and interactive map displays. Participants were shown two sets of maps. On the first set labels were placed with an old algorithm, on the second set, labels were placed with the new algorithm. None of the test subjects had any previous cartographic knowledge. Also they were not familiar with the geographic locations presented. Each participant saw ten maps from two sets. The task was to find five names on the map and click a button when each name was found. To prevent learning effect, the same region was not shown twice to a single participant. Ooms et al. (2012) made a pilot study to test the time scale and methods before the actual test. Each participant had two demo trials, this made the subjects familiar with the test. When all 20 trials were completed, users answered questionnaires about background information and feedback. Answers help to eliminate biases and give reasoning for distortions in data.

Coltekin et al. (2009) made an experiment with thirty participants. Participants were selected as average users with no domain knowledge. Half of them had college level geography background and the others had non-geographic education. All participants had some experience with using graphics and spatial data. Test subjects solved three typical map use tasks, using two different interface designs. Questions were map usage related. Eye and mouse movements were recorded while participants performed tasks. After the experiment participants answered some questions for preference feedback.

Brodersen et al. (2001) combined several measures in the research. Eye and head movement, think aloud protocol, questionnaires, interviews and video analyses. They used ten participants from various age groups and backgrounds. The experiment was carried out on two topographic paper maps. The test subjects answered 11 questions in total and the experiment lasted about one hour for each person. The maps were from the same location, but had different cartographic design. Questions were practical and related to the specific map function.

Bunch & Lloyd (2006) describe a cognitive overload scenario, for test experiments, which happens when map readers have to remember task instructions while completing map reading tasks, because this can affect performance. Recommendations for it, is to not ask participants to remember questions asked during the experiment, thus reducing cognitive load on working memory. This can be done by presenting the instructions (questions) on the map and also simplifying the map task.

The most common eye-movement metrics, from the previous studies, are fixation duration, scan paths and fixation count. The amount of participants', for map design studies, are usually around thirty. It is also important to select participants that are the intended user group for the maps tested. From traditional measures, response time (efficiency) and correctness of answers (effectiveness) are mostly used. Participants do better when demo trials are included in the experiment. The tasks and questions in the experiment must be related to actual map usage.

3. Methodology

In this study 32 GIS users were asked to solve specific tasks on static map stimuli. Eye-movement and response data were collected from participants while they performed the tasks. The step-by-step structure of the experiment is displayed in Figure 5.

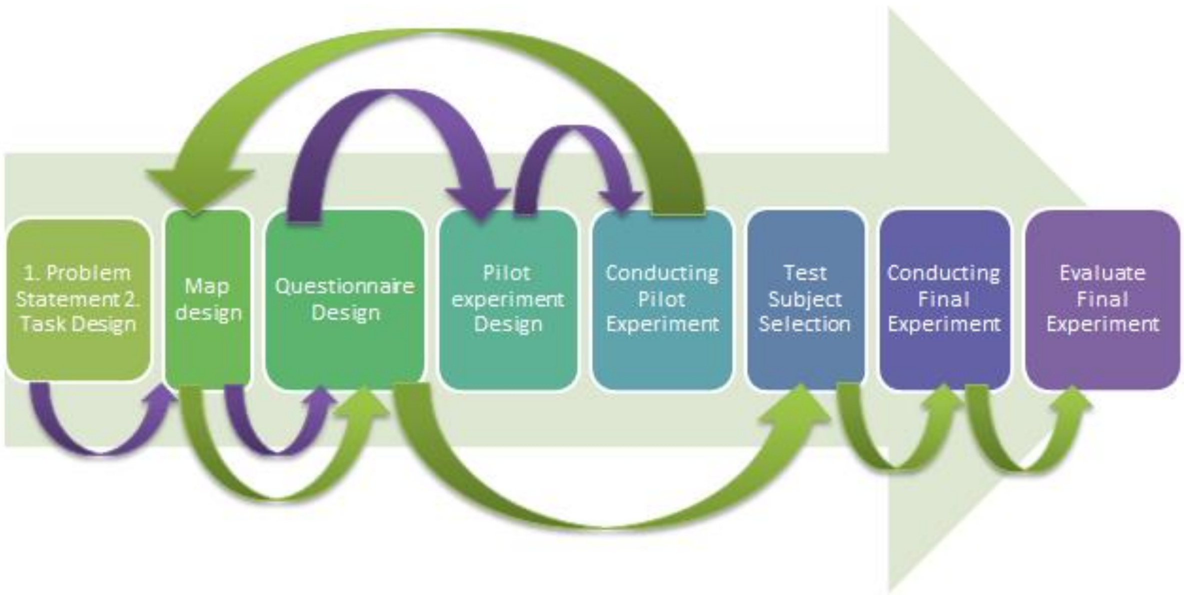


Figure 5. Experimental design workflow.

First, the experiment follows the purple arrows on the chart. The problem to be examined was stated and tasks that are common scenario of map usage were designed. To complete this task, a set of maps were created with task relevant thematic information. To be able to verify that users completed the tasks, a set of questions were designed. After this, a pilot experiment was designed and then conducted. Secondly, following the green arrows on the chart, from the results of conducting the pilot experiment, map design and questionnaire design were improved. After this, test subjects for the final experiment were selected. The last step was to conduct and evaluate the final experiment.

There were two main visual properties of cartographic design for thematic polygons to investigate in this experiment. First, a polygon identification task was created to find out which design is better in the case of understanding where exactly the thematic layer is located and what is the extent of it. Ideally, the map reader understands which areas or spots are overlapped by a certain thematic polygon and which are not. The map reader must understand which areas are inside the polygon and which areas are outside. A background search task was created to investigate the other property affected by design. Layers that are under the thematic polygons would be obscured, thus covering valuable information on the background map. To understand which map objects are within a certain area, map reader has to be able to visually locate the objects. Ideally, background map is fully visible and not obscured, when covered by thematic polygon layers. In other words, when users complete visual search tasks, thematic layers should not disturb finding target objects from the background map. Also, there was an additional interest to find out, how a particular design technique affects the utilization of the border and inside area. This was investigated by adding additional information to only boundary lines design technique. All designs used in this study share a common feature, the faded border line. Representation of the inside area varies between designs and helps the user to understand correct overlapping. The selected designs are all proposed by the SIS/TK570 web cartography project.

The eye tracking experiment, that is carried out in this study is similar to other in this field, and follows the same procedure and steps. In order to present results, for the questions raised in the aim sections and above, independent and dependent variables were defined. Independent variables were the map designs. These were categorical independent variables, with four possible values. An independent variable is a constant or a controlled variable that can be altered during the experiment to see expected changes in dependent variables.

Dependent variable is an output or effect and depends on other factors, this is the event studied. Dependent variables in this experiment were correctness of the answers, fixation duration, fixation count, net dwell time and saccadic amplitude (scan path length). These are all depending on the map design. The experiment is created in the way that independent variables are kept constant or altered on purpose so that these would not influence the results and would be comparable. Ideally, only variables that affect dependent variables are the map manipulations (designs).

3.1 Participants

In this study, 32 participants with knowledge in cartography/geography/GIS were asked to solve practical map reading tasks in a controlled experiment. The number of participants selected aligns roughly with other previously described eye-tracking studies on map design research (Ooms et al., 2012a; Coltekin et al., 2009; Fabrikant et al., 2010; Fabrikant et al., 2008). As geoportals are mostly used by GIS specialist, our test subjects were selected with this demand in mind, also to ensure consistency and objectivity of their results. The age of the participants was between 20 and 55, this selection represented appropriate cross-section for actual geoportal users. Participants were told what the study is about, the general purpose and the task, but not anything about expected results or scientific purpose. A Doodle poll was created to set an appointment with each participant.

Due to poor data quality of the recording, the results from eight participants were excluded. For four participants the tracking ratio was under 80%, so there was many gaps in the data, other excluded participants had very low fixation accuracy and precision. Of the remaining 24 participants were 14 female and 10 male. Their mean age was 38 years and they were from various age groups. All participants received a small gift in return for their time. The participants registered to the experiment on a voluntary basis.

3.2 Apparatus

The Humanities Laboratory of the Faculty of Humanities and Theology (Lund University, Sweden) is equipped with eye-tracking hardware and software produced by SensoMotoric Instruments (SMI). Participants' eye-movements were recorded using iView X 2.7 software with default settings and the RED 500 (500 Hz) eye-tracker by SMI. The experiment was run on a Windows XP 2002 Shuttle PC, using Experiment Center 3.5 by SMI to display the instructions, map stimuli and question dialogues. These were presented on a 22-inch color monitor, at 1680 x 1050 pixel spatial image resolution, with a refresh rate of 60 Hz. A standard mouse and keyboard were used to answer questions. Fixation data were visualized and then extracted from BeGaze 3.5 (SMI) with default settings to Excel, to make the final analysis and graphs. Answers to questions were recorded by the software and were analyzed in Excel.

The map stimuli were created with Environmental Systems Research Institute's (ESRI; 2014) ArcMap. The stimuli consisted of full color maps.

3.3 Materials and design

3.3.1 Experiment design

To test dependent variables, the experiment was divided into the polygon identification and discrimination task and background search task (Figure 6). The background search task included two separate tasks, finding villages and finding lakes from the map. All tasks included test trials and actual experiments, the questions and tasks remained same through all tasks. This structure was selected to reduce participant cognitive load. The polygon identification task consisted from four test maps and eight different experiment maps, with four design techniques (Figure 6). The background search task had two test maps and four experiment maps. Before each task, there was a brief description about the task, the question and the structure of the following experiment (Appendix 4). The tasks were designed in a way that all traces of natural environment and actual user cases are not removed from the experiment, thus making it totally artificial. The experiment is within-subjects, every participant saw each condition.

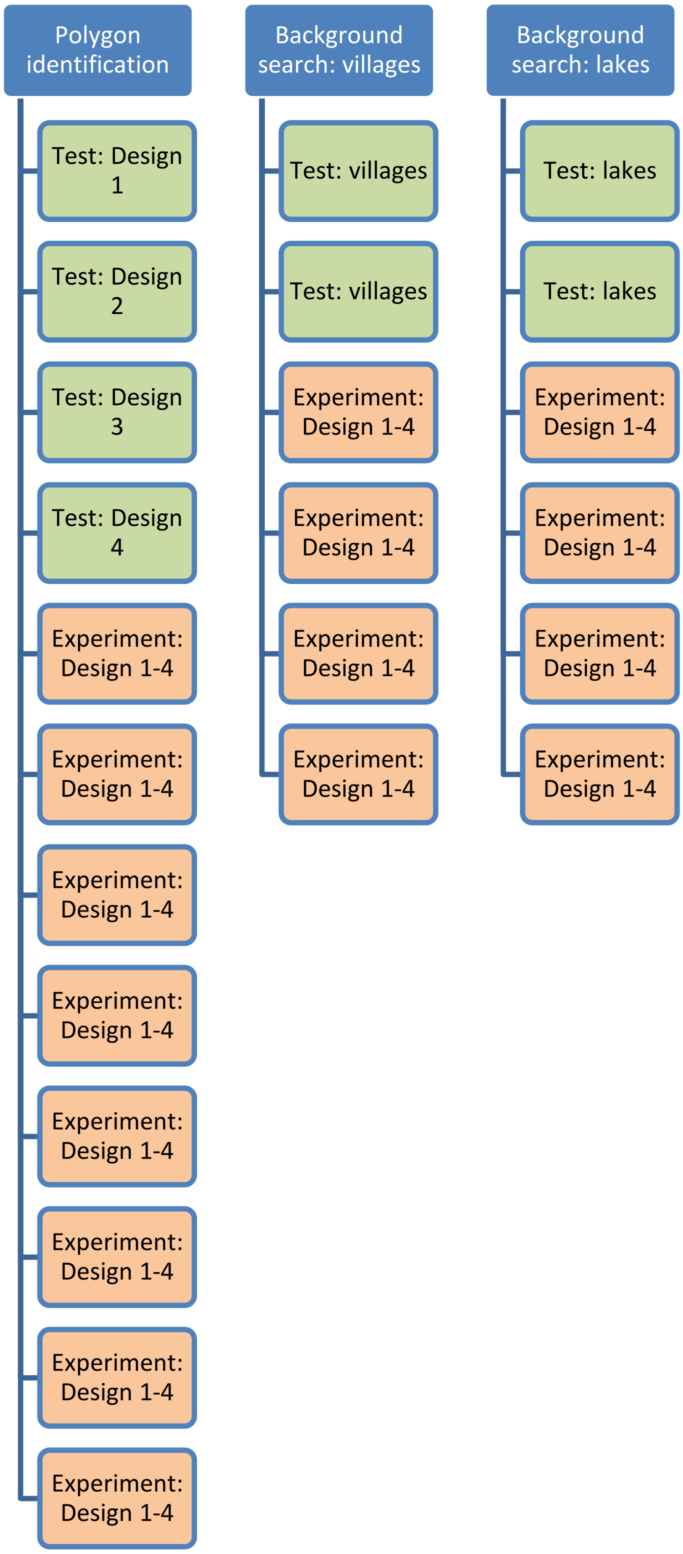


Figure 6. Overall experiment procedure.

Boxes on the Figure 6 represent maps; all are from different geographic locations. Experiment includes two main tasks. Before actual experiment, participants solve test experiments (marked with green), then they conduct actual experiments (marked with orange).

Participant saw each design four times, on different physical map areas. To solve these tasks, a set of maps were made, with task related thematic data (Appendix 5). Maps included in the experiment represent different design methods for thematic polygons. In order to prevent learning effect, participants did not see a map from the same geographic location twice. To verify that participants solved the prompted tasks, questions were asked for each map. In order to give empirical experimentation verification to our designs, these tasks were solved by the 32 participants that had previous geographic knowledge. Participants had eight trials maps overall, four for solving the polygon identification task and two each for solving the background search task.
Before the map stimulus was presented to the participants, a white image with a black dot was shown. This was done to concentrate participants gaze to the center of the screen.

To avoid any biased results from order effects and the way participants saw different designs, a premade structure for presenting designs was made (Figure 7). All participants were divided into 4 groups, each group consisted of 8 participants. This structure ensures that each physical map area would be used with four different designs and thus the results are not affected by the individual properties of a particular map area.

Task	Physical map area	Design (Group 1)	Design (Group 2)	Design (Group 3)	Design (Group 4)
PI	A	4	2	3	1
PI	B	3	1	2	4
PI	C	1	3	4	2
PI	D	2	4	1	3
PI	E	3	1	2	4
PI	F	2	4	1	3
PI	G	4	2	3	1
PI	H	1	3	4	2
BS: V	I	2	4	1	3
BS: V	J	1	3	4	2
BS: V	K	3	1	2	4
BS: V	L	4	2	3	1
BS: L	M	1	3	4	2
BS: L	N	4	2	3	1
BS: L	O	2	4	1	3
BS: L	P	3	1	2	4

Figure 7. The order of map deigns presented to participants. Each participant sees 16 physical map areas, from A-P, with four different designs. To compare only map designs and not the physical map areas, each area was presented with four designs. PI- polygon identification task, BS: V- background search (villages), BS: L- background search (lakes).

Each participant got an oral description (Appendix 3) and examples about the map designs before the experiment. The descriptions and instruction were the same for all participants, to ensure equal pre-knowledge. Also, this was done to confirm that each participant fully understood the designs and the results are not affected by any pre-knowledge or not knowing the meaning of design elements. Before the actual test, a pilot test was carried out.

This workflow allowed testing if or how those design methods improve cartographic quality, map usability and readability.

To avoid distractions from web environment, static images were used to compare the efficiency and effectiveness of the designs. From the information processing point of view by the user, performing tasks in an actual geoportal is not necessary.

When the experiment was completed, we collected answers for background information and feedback. Also, a preference questions for different designs were presented. Participants' eyes were monitored during the actual test and answers to map related questions collected.

3.3.2 Map Design

To evaluate different cartographic design principles for polygon objects in a geoportal, four design techniques were empirically tested on each of the 16 physical map areas. These designs are given in the SIS/TK570.

All the restriction areas appearing on the maps were selected from the Swedish restriction map portal (Länsstyrelsen, 2014). Cultural heritage conservation area is represented with red, natural conservation area is represented with green and outdoor activity conservation area is represented with blue. All maps contain each restriction type and there is a reference of the restriction areas presented by at least one part of the boundary. This makes it possible to discriminate different areas by the participants. That is, the physical map locations were selected in a way that no restriction area is covering the whole map stimuli. Also, areas that are located at the remote locations in Sweden were selected, to ensure that participants' were not familiar with the areas.

The specific location for the house symbol, were selected in a way, that there would be an appropriate distance between the symbol and border. This ensured the possibility to distinguish between the fixations on the border and inside area. Also, similar strategy was used to pick specific location for each iconic symbol for the icons and boundary lines design technique.

For the simplicity of the task, to reduce participants' cognitive load and to eliminate knowledge effect, restriction areas on the map are referred as green areas, blue areas and red areas. This allows them to use less previously known information and reduces the amount of new information. Also the boundary and icon polygon design uses geometrical icons, instead of pictorial icons for simplicity.

Swedish default topographic basemap with faded colors is used as the background map. The objects, needed to be discriminated by the participants from the background map, were selected to have similar size and visual properties. This ensures that the results are comparable, and objects are not saliently different. Also, to eliminate random choosing, more than one target object are present on the map. For the background search task, participants had to find a group of houses or a lake from the map, there were 12 houses in each group, to ensure similarity between target objects. For some areas, a number of houses and lakes were artificially drawn.

On each map, there were targets to be found, in order to solve the task and answer questions correctly. Ideally, targets are distributed evenly on the screen and targets for different designs have the same advantages to be found. This ensures that, the time it takes to find closer objects to the center and objects further from the center is balanced. So, targets for every design are located closer to the center and far from the center equally. The target distribution in this study is presented in the Figure 9.

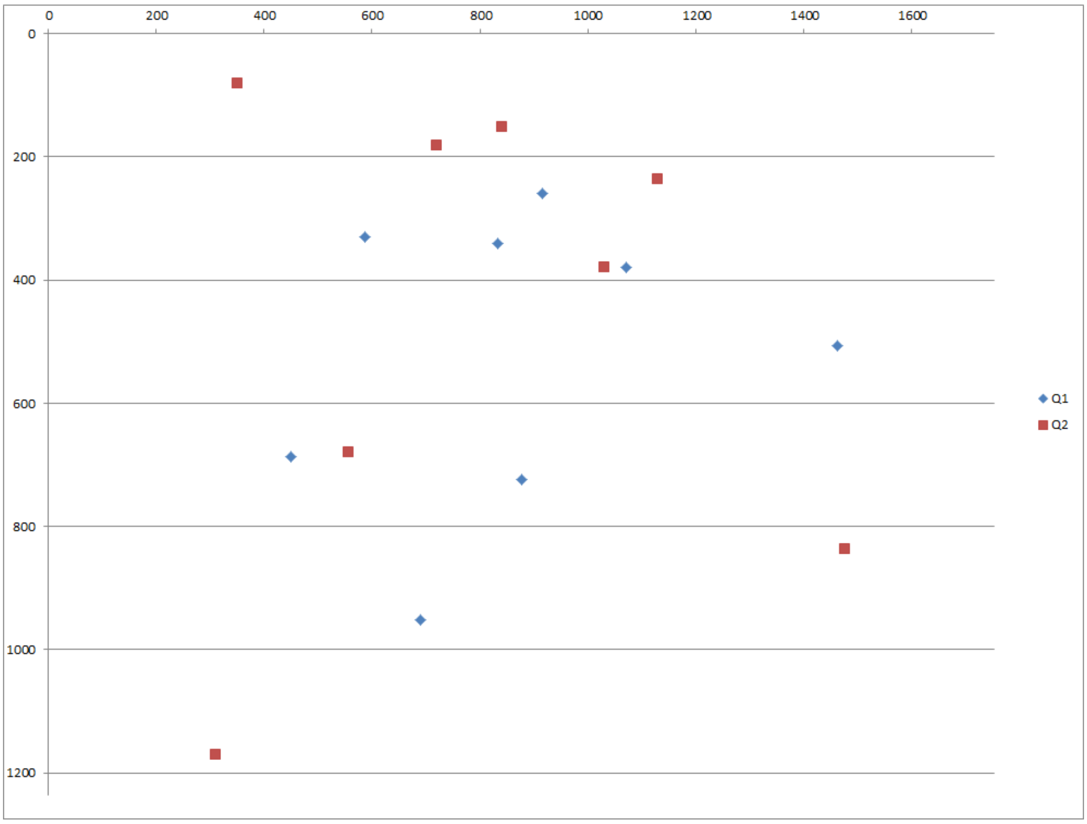


Figure 9. Target distribution according to screen coordinates (pixels). Targets for question 1 (house) are marked with blue and targets for question 2 and 3 (group of houses and lakes) are marked with red.

Four different thematic polygon designs were compared in this study as independent variables. These designs were the following:

1. Thematic polygons are represented only by boundaries, with faded line style towards inner region of the polygon (Figure 10).

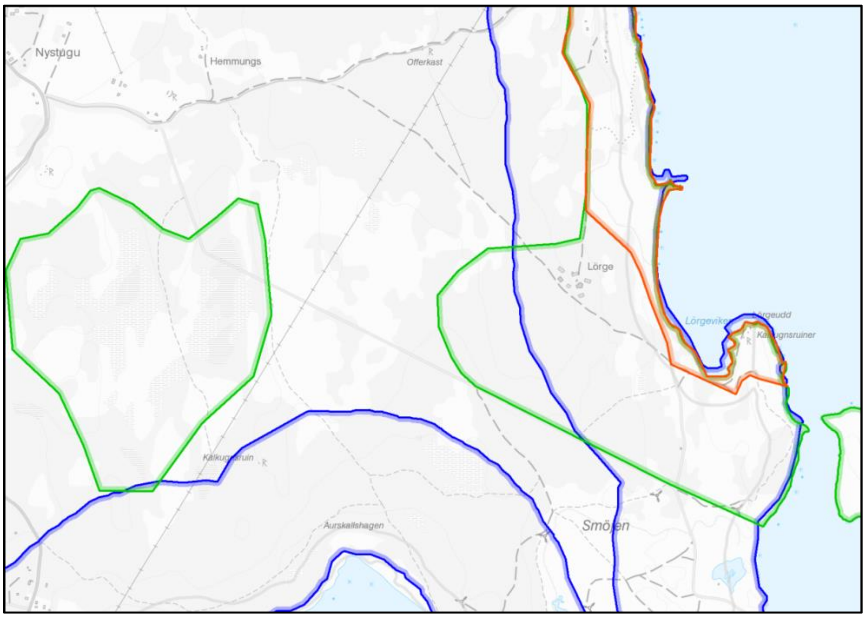


Figure 10. Thematic polygons are designed with only boundary lines. (*Source: Länsstyrelserna and Lantmäteriet, © Lantmäteriet, Dnr: I2014/00579)*

2. The polygons are filled by transparent color of 80% and outlined by boundaries with fading line style towards inner region of the polygon (Figure 11).

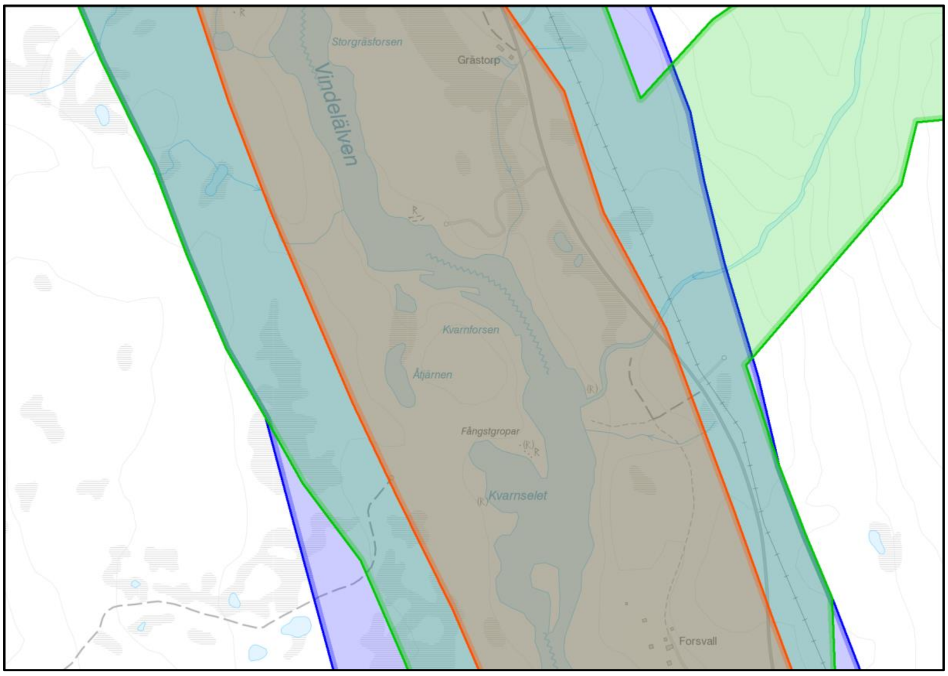


Figure 11. Thematic polygons are designed with transparent color fill.)*Source: Länsstyrelserna and Lantmäteriet, © Lantmäteriet, Dnr: I2014/00579)*

3. The polygons are represented with hatches (pattern), lines directed diagonally. Red area with -45 degree angle, green area with 45 degree angle and blue area with 90 degree angle, separation between lines is 12 pt. Patterns are drawn with solid color and the boundary with faded line style boundary towards inner region (Figure 12).

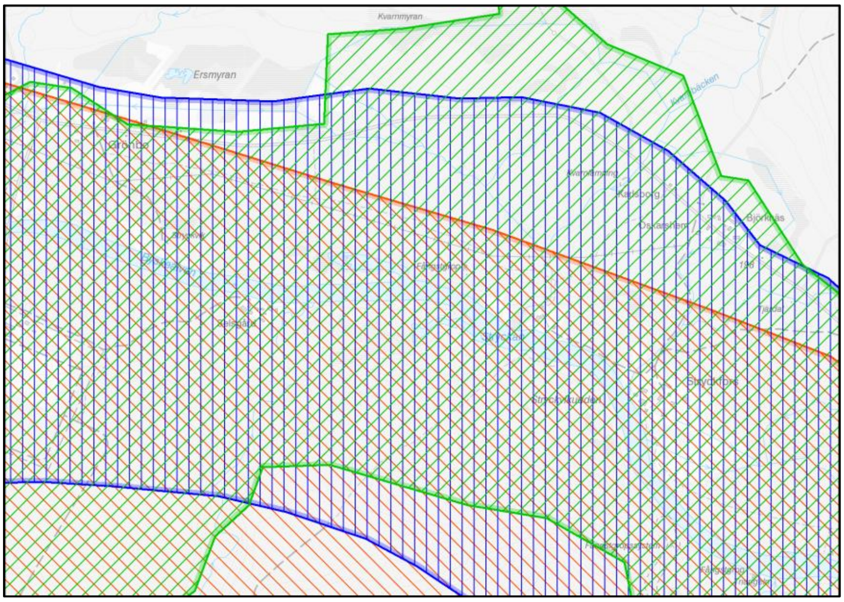


Figure 12. Thematic polygons are designed with hatches. (*Source: Länsstyrelserna and Lantmäteriet, © Lantmäteriet, Dnr: I2014/00579)*

4. The polygons are designed with icons that represent the inner region and with faded boundary lines towards inside (Figure 13; idea based on Toomanian et al., 2010).

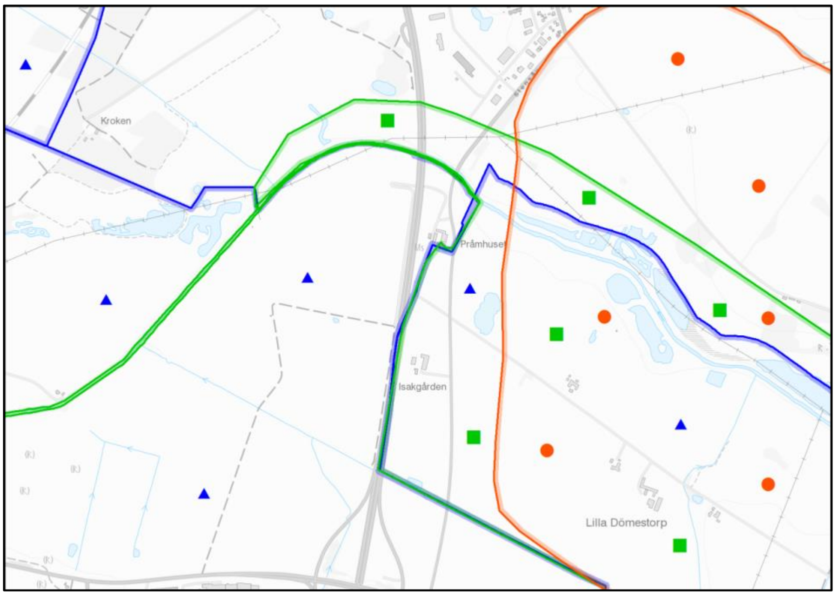


Figure 13. Thematic polygons designed with icons. (Source: Länsstyrelserna and Lantmäteriet, © Lantmäteriet, Dnr: I2014/00579)

3.3.3 Questionnaire design

Each test participant answered sixteen questions (Appendix 4), to make sure that they completed the task and to verify the quality of their inference making. The questions were task and map function related and simulated common map usage case scenario. The questions were presented on a separate view before the map stimuli. For the polygon identification task, multiple choice answers with tick boxes were presented on a separate view after the map stimuli. For the background search task, the answers were collected from the click events, as participants clicked on the target location on the map.

All the questions on the polygon identification task were the same. This was done to ensure minimal cognitive load for the participants. On the background search task, the structure of the question remained the same, but the object to be found from the map varied between a lake and a group of houses. Both of these objects can be discriminated from the map in simple manner, making them comparable (Figure 14).

Figure 14. Swedish topographic background map with faded colors; the map shows the objects which the participants had to discriminate from the background map: lakes and a group of houses. (Source: Länsstyrelserna and Lantmäteriet, © Lantmäteriet, Dnr: I2014/00579)

Presenting questions this way ensures the simplicity and straightforward answering procedure. Also, the questions were formulated in a short, clear and concentrated way to make them easily understandable and memorable, thus reducing the participant cognitive load. First question was, “A building is planned on the location marked with a house image (Image 1). Which restrictions (green, red, blue) apply on this location?”. The participants selected correct restriction areas by ticking boxes on the answering view. When the task was completed, users pressed space button to continue with the next question.

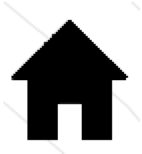


Image 1. House image.

After completing the polygon identification task, the background search task followed. The second and third question was to identify a feature (lake or group of houses) on the background map that is located in green and blue area, but not inside red area. All the questions had one certain answer and the object was clearly located inside the asked areas.

3.3.4 Pilot experiment

Before the actual experiment, multiple pilot experiments were designed and conducted, to get more experience about eye-tracking methodology and to enhance experiment structure. Also, for making sure all the equipment and software worked as expected. The pilot experiment was designed as a replica of the actual experiment. Time for completing the experiment was measured and also eye-movement data were collected to see initial recorded data and results from analysis.

3.3.5 Fixation ratio on AOI-s for borders

To find out if participants utilize the inside area or follow the borders to understand the location and extent of the thematic polygon area (irrespective if the transparency, hatches or icons are added to represent the inside of the polygon) the following method was used. Buffers were constructed by increasing the width of the border line (roughly 0.5 cm) to each side and AOI-s were created from that. Then, dwell time for all fixations and saccades were measured, to find net dwell time percentage for all border AOI-s. Border by itself contains meaningful information about the extent of the polygon, so does transparency and hatches. But icons without the borders are meaningless, so users have to understand both.

3.3.6 Eye-movement metrics analyses and performance measures

Based on the collected eye-movement data, four metrics were analyzed. These were fixation count, fixation duration, scan path length and net swell time in AOI. To fill requirements for statistical analysis, the raw data for fixation count, fixation duration and scan path length were log transformed, to ensure normal distribution. Other performance measures were the answers for questionnaires, the percentage of correct answers.

3.4 Procedure

Geoportals act as an interface to gain access to various spatial datasets. One of these datasets is restriction areas, which provide information for certain spots or property and the activities that are allowed in that location. Three main types of restriction areas are: nature conservation area, cultural heritage conservation area and outdoor activity conservation area. A commonly used case scenario is to find information for a location or a property, in order to build a structure or carry out some activity. If the selected spot or property intersects with any of the restricted areas, the interested person must contact government agencies maintaining this particular restriction type. Also, in many cases there are several or all three types of restrictions areas existing simultaneously on top of each other. To be able to verify all correct intersections and discriminate them separately, a person must understand the extent and location of the restriction area.

Another issue with this usage case is to find and relate the intended interest area, information from the background map and restriction areas. This issue comes from the fact that the thematic layers usually obscure information on the background map. The Swedish geoportal has two background maps, one with regular colors and one with faded colors. The intended purpose of this is to manipulate with visual hierarchy of foreground and background layers and to make either of those perceptually more salient. The interested person may use a background map design with faded colors to perceive restriction information more clearly, but due to faded colors, information on the background map may be hidden.

Tasks in this study are designed similarly, to simulate conditions to real usage of geoportals. The participants have a static background map zoomed into building level (scale of about 1:10,000) and several polygon restriction areas on top of it. First, the users have to verify correctly which restrictions apply to a certain location marked on the map. The location is marked with small pictorial symbol of a house. After this, the participants need to find an object from the background map that is located in certain restriction areas. All objects that were to be found were located inside green and blue areas, but not inside red areas. This made it easier for the participants to remember the task and the question.

During the trial tests, after each map, a map (Figure 8) with correct answers was presented to the participants to make sure, they understand the designs.

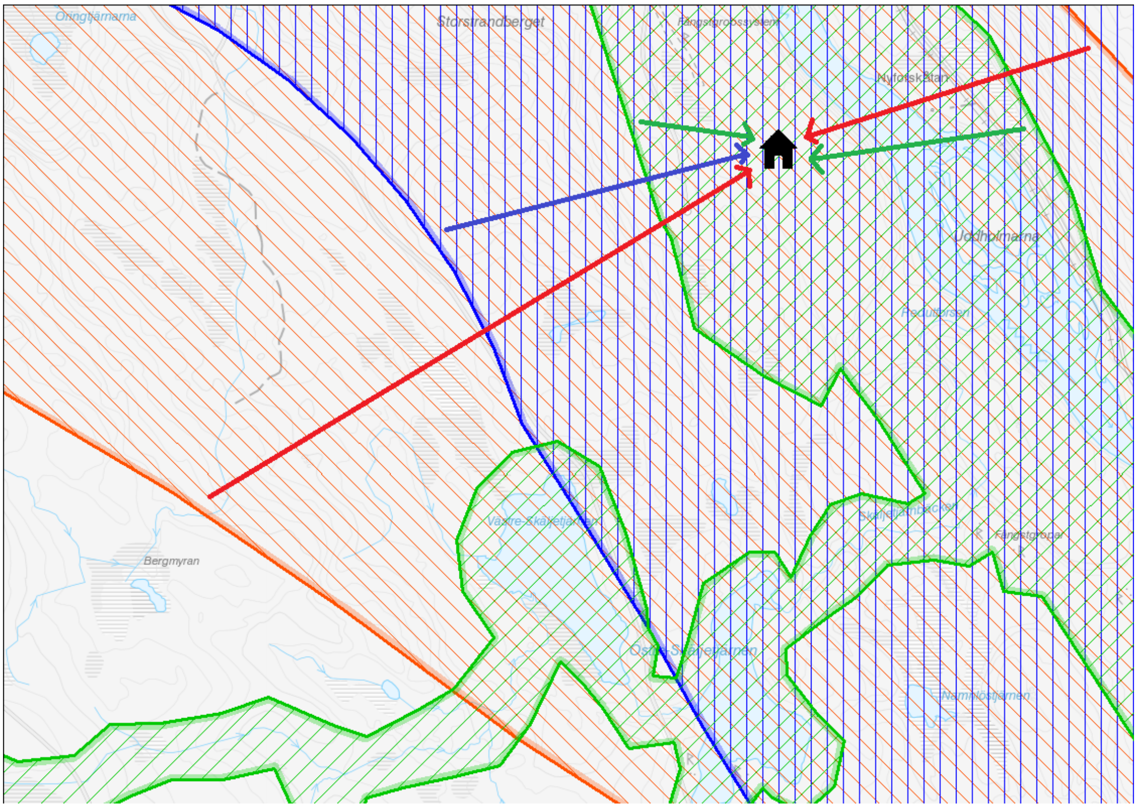


Figure 8. A map with correct answers. The arrows show which areas are overlaping with this particular house. On the target area, red, green and blue are overlapping as seen from the pointed arrows. (Source: Länsstyrelserna and Lantmäteriet, © Lantmäteriet, Dnr: I2014/00579).

The questions were designed to gain answers to the research questions presented in section 1.3. The task design, map design and question design are all linked together to do research for the visual properties of the four cartographic designs of thematic polygons. The polygon identification task was to find out, which areas apply or overlap on a certain location. To make this correct inference, participants have to understand the extent, boundaries, inner/outer regions and location of thematic layers. The second task, background search, was to discriminate a certain geographical object from the map that is located in specific restriction areas. To make this correct inference, the participants need to find this object in the background map and also understand the extent of restriction areas.

The eye-tracking experiment was carried out with each participant individually. At the beginning participants' signed a consent paper from the Humanities Lab (Appendix 2), to confirm their voluntary participation, anonymized data collection and that eye-movements were recorded. First, the participant received a brief introduction about the study. Then, map designs used in the study were described and explained to the participants, this included visual materials from the trial test. Descriptions were presented orally, but from the written materials (Appendix 3), to make sure all participants got exactly the same instructions, and thus knowledge and training about the maps. Also a caution notice, that the eye-tracking device is not harmful in any way during this experiment. If participant used glasses, he/she were asked to remove them, but only if the visual abilities would not suffer. This was done in order to improve recording quality. Then the participant was sited and the experiment instructor explained how to sit and maintain the body position during the experiment. Eye-tracking device was started and best seating position to record eye-movement taken.

Before starting the experiment, calibration was carried out. After each trial test, participants could ask questions about the experiment or any other details. When the experiment was finished, participant answered some preference questions about the designs. Also, participants were asked not to reveal any details about the experiment to other participants they may encounter.

On average, each participant used 20 minutes to complete the experiment, including introduction. The sharp recordings took eleven days to complete. All participants were interested about the experiment; three of them had been participating in eye-tracking experiments before.

The pilot experiment was conducted with six persons, four of them had very little knowledge about mapping systems. The procedure, maps, questions, eye-tracking device, eye-tracking software and instructions were similar as intended to be during the actual experiment. The experiment was composed of 8 trial maps and 16 experiment maps. All participants had the same experiment structure but different physical map areas. Each participant was assigned to a group from 1-4, and this determined, which design of the same physical area was presented to the participant. At the beginning, a trial test was carried out before each actual experiment.

In the pilot experiment it is necessary to simulate the actual conditions as much as possible. Eye-movements were also recorded, to know how and if participants are affected by the eye-movement recorder during the test. Time used for calibration and other procedures was also measured to know how much lab time is needed. Results from pilot experiment gave valuable information about the experiment, map designs and for questionnaire design and structure as well. After the pilot experiment, the experimental design was updated before the real experiment.

3.5 Analysis

To statistically analyze data from eye-movements, one-factor ANOVA with repeated measures, within subject design method was used. ANOVA was used because it shows if there is a significant difference between levels of independent variables, when comparing dependent variables between four groups (designs) and ANOVA is the most common method for experimental data (Holmqvist et al., 2011). As all participants saw all designs, different conditions (independent variables) are not independent from each other. For repeated measures experiment design, the ANOVA tests if there are any differences between related group (design) means (Laerd Statistics, 2015). ANOVA tests only the differences between designs, not if the designs are good or bad.

The main assumptions for ANOVA are normality, sphericity, continuous sample data, categorical independent variable and necessary removal of extreme outliers (ExcelMasterSeries, 2015). To ensure normality, natural logarithmic transformation was used to transform eye-movement data, except net dwell time on border AOI-s, this was originally normally distributed. All statistic measures computed in the results used logarithmically transformed data. Normality was tested with graphical interpretation from histograms and with Shapiro – Wilk test. Sphericity means that the overall group variances must be equal (observations for each conditions must be independent), as this was not the case, Huynd – Feldt correction was used, to correct the degrees of freedom of the F-distribution (Real-Statistics, 2014). Violation of sphericity assumption could produce Type 1 error with ANOVA, which means detecting a significant difference, when one does not exist (Laerd Statistics, 2015). The assumption of necessity to remove outliers was violated in this study because including outliers did not affect the results of statistical analysis. Also, the variation of individual performance was expected and to ensure similar repetition amount for each design, outliers were not removed.

Paired samples T-test with Bonferroni correction was used for post-hoc test to determine which designs differ significantly from each other, especially, which design differs from the first design. Bonferroni correction was used to balance multiple comparisons problem and to control the familywise error rate. T-test has similar assumptions as ANOVA and the assumptions were considered. In human-computer interaction tests and in psychology, t-test is used most widely (Sharp et al., 2007). An ANOVA shows only that the designs are significantly different, but not which ones.

4. Results

4.1 Questionnaires

Results of the preference study are presented on Figure 15. Results for the questionnaires are presented on Figure 16 for the polygon identification task and on Figure 17 for the background search task.

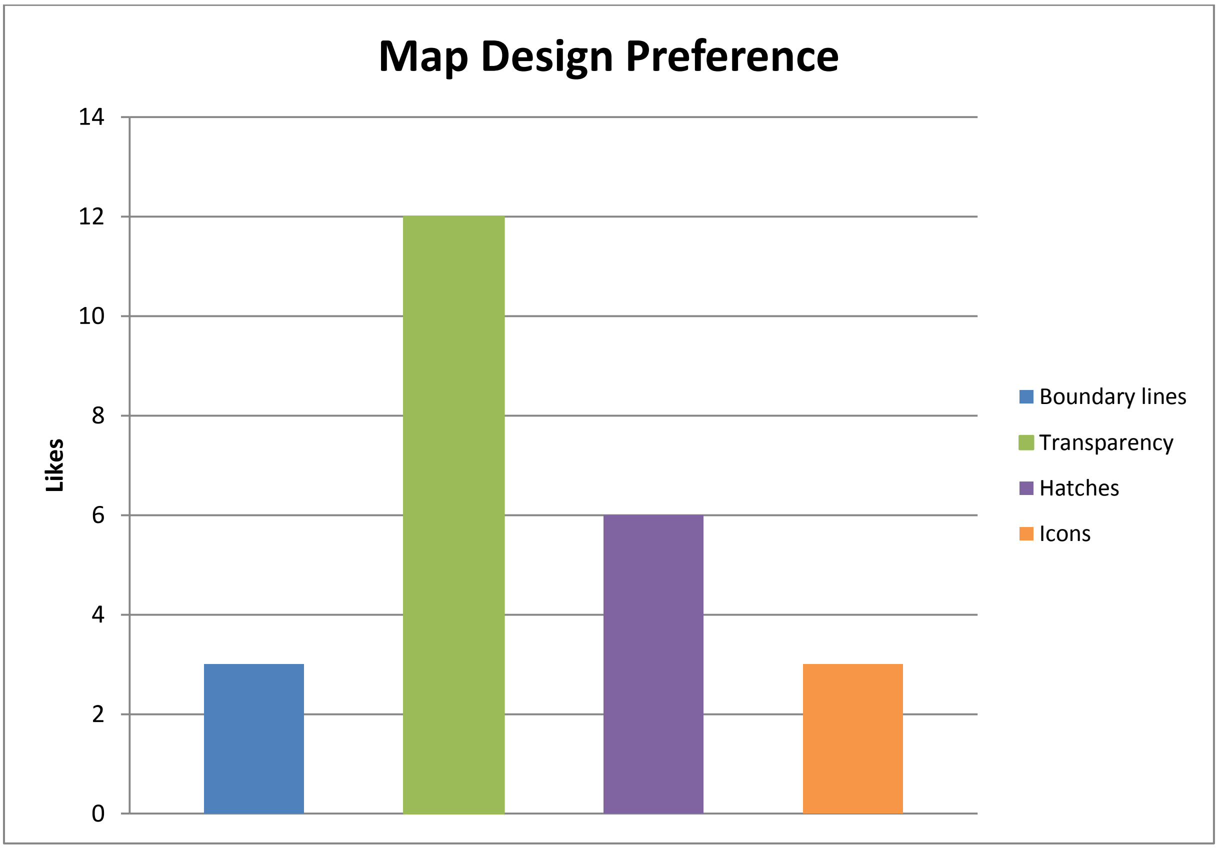


Figure 15. Results for the design preference study.

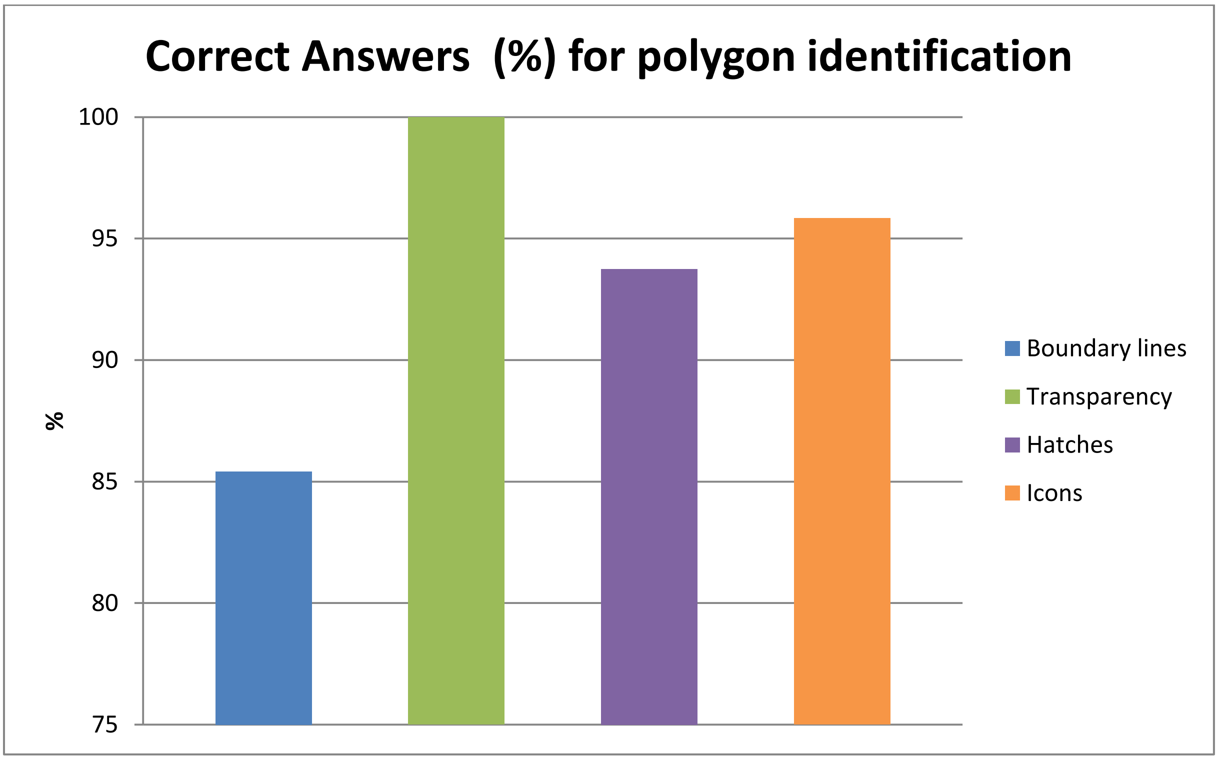


Figure 16. Results of the questionnaires for the polygon identification task.

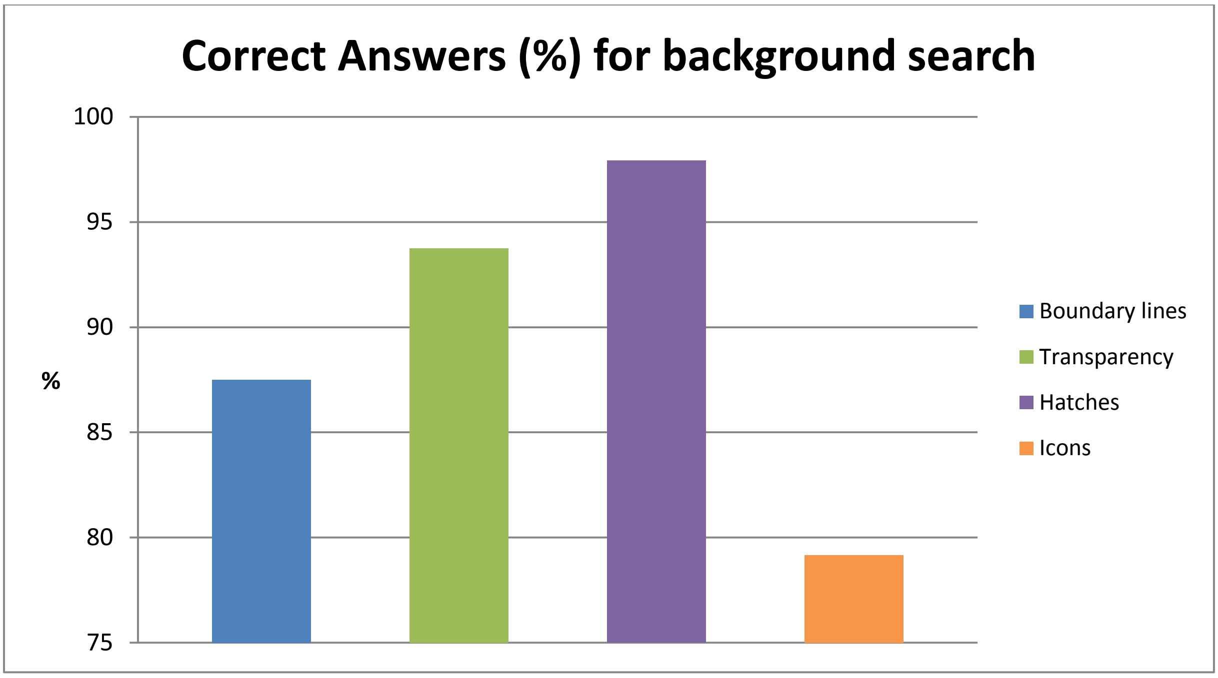


Figure 17. Results of the questionnaires for the background search task.

The most liked design was transparency, with twelve votes. On the second place were hatches, with six votes. On the third and fourth place were boundary lines and icons, both had 3 votes. The reason why participants liked transparency could be that they are used to it, transparency is used very commonly for presenting thematic polygons.

The percent of correct answers to polygon identification task was highest for the transparency, all the answers were correct. The least correct answers for this gave boundary lines, which had 85% correct answers. The percent of correct answers to background search task was highest for the hatches, which had 97% correct answers. The least correct gave icons, which had 79% correct answers.

4.2 Fixation duration

Eye-movement gaze plots for physical area F are displayed for the four designs (Figure 18 – 21). Results of the total eye-movement fixation duration for the polygon identification task are presented in Figure 22 and combined results for background search task on Figure 23, depending of the map physical area. Results of the average eye-movement fixation duration for the polygon identification task (Figure 24) and combined results for the background search task (Figure 25).

Figure 18. Eye-movement gaze plot for physical area F designed with only boundaries. (Source: Länsstyrelserna and Lantmäteriet, © Lantmäteriet, Dnr: I2014/00579).

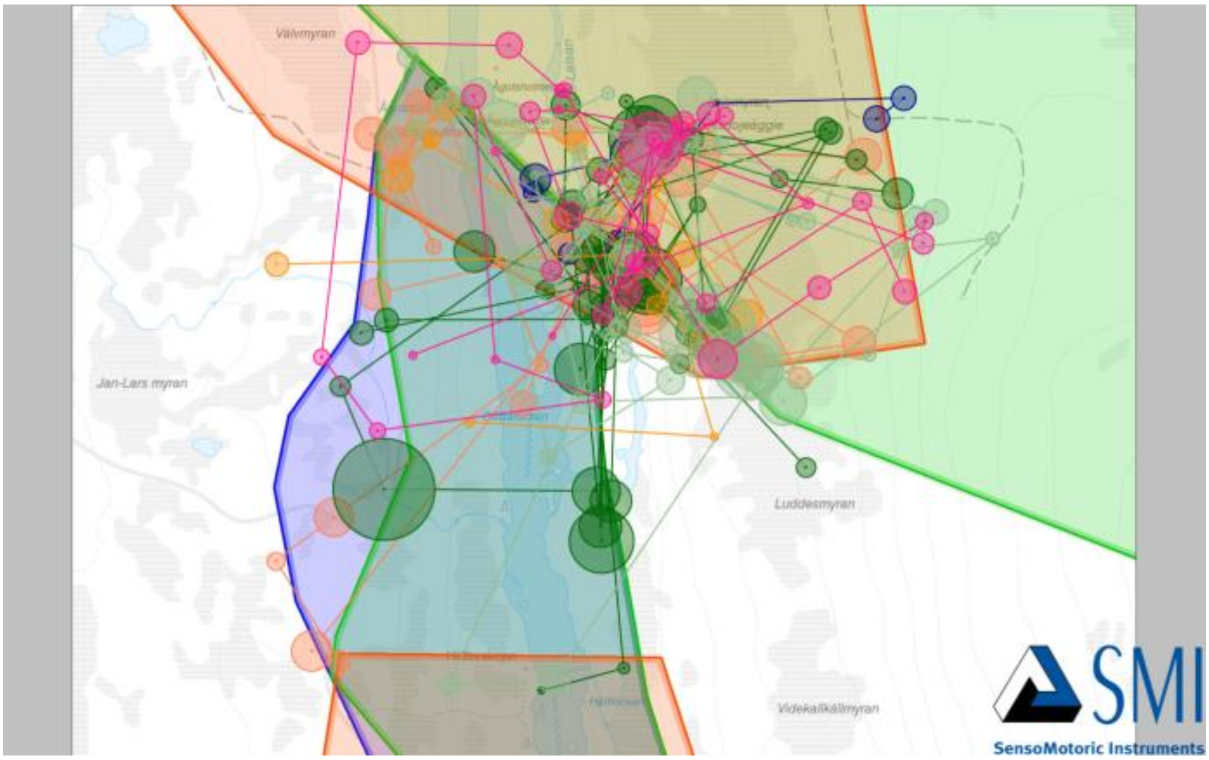


Figure 19. Eye-movement gaze plot for physical area F designed with transparency. (Source: Länsstyrelserna and Lantmäteriet, © Lantmäteriet, Dnr: I2014/00579).

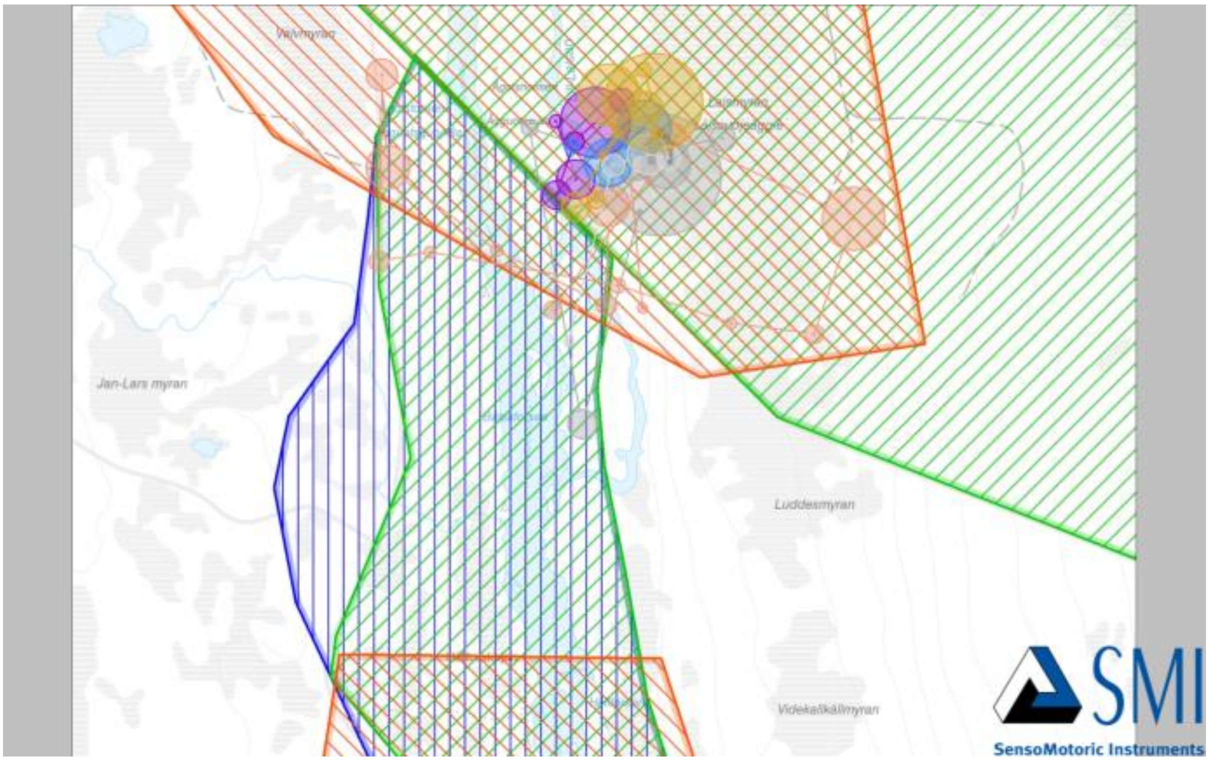


Figure 20. Eye-movement gaze plot for physical area F designed with hatches. (Source: Länsstyrelserna and Lantmäteriet, © Lantmäteriet, Dnr: I2014/00579).

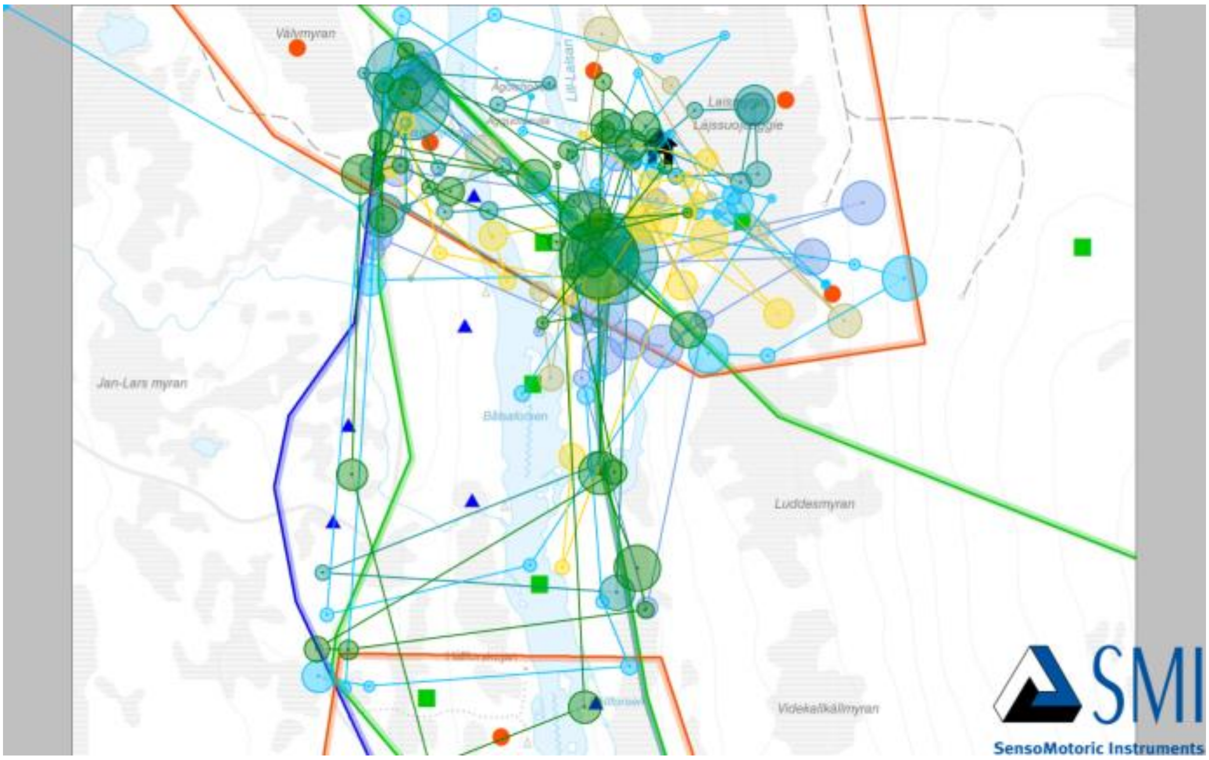


Figure 21. Eye-movement gaze plot for physical area F designed with icons. (Source: Länsstyrelserna and Lantmäteriet, © Lantmäteriet, Dnr: I2014/00579).

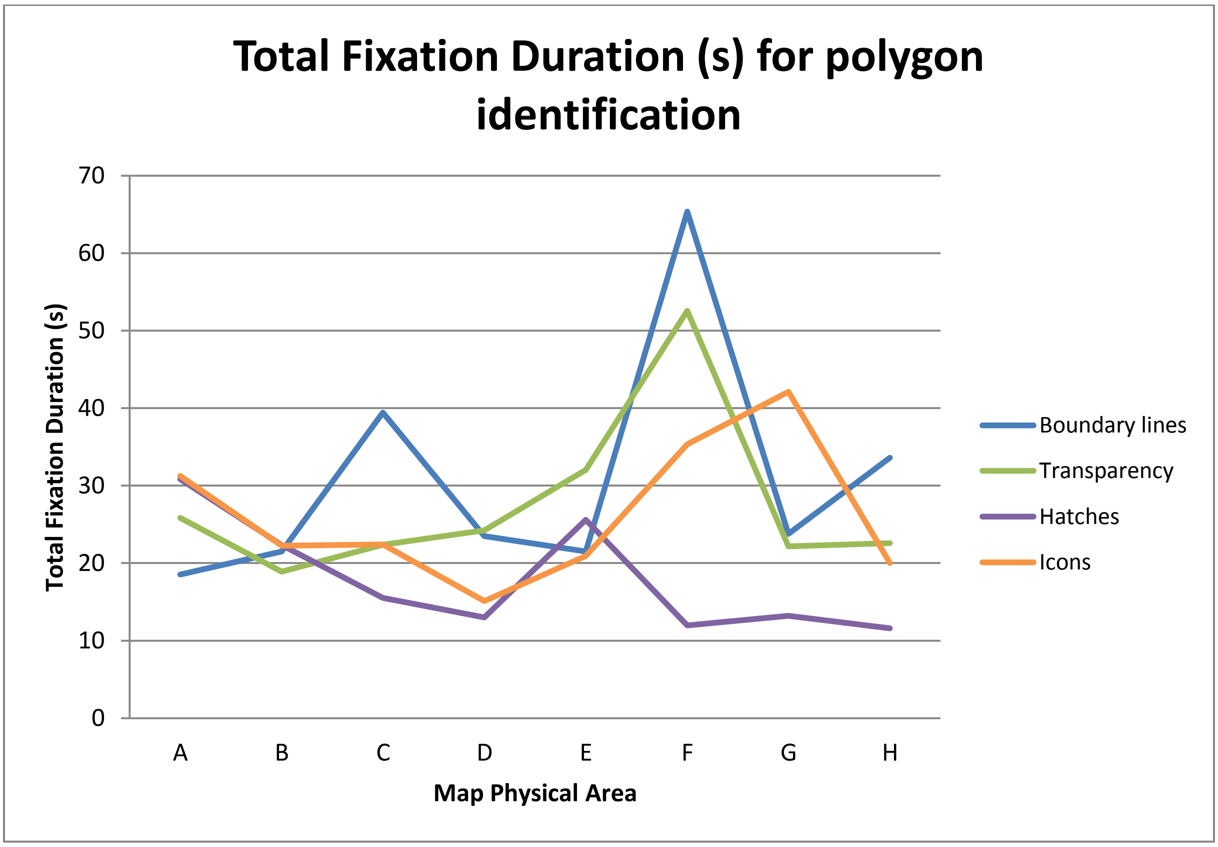


Figure 22. Results of the total fixation duration, measured in seconds for the polygon identification task.

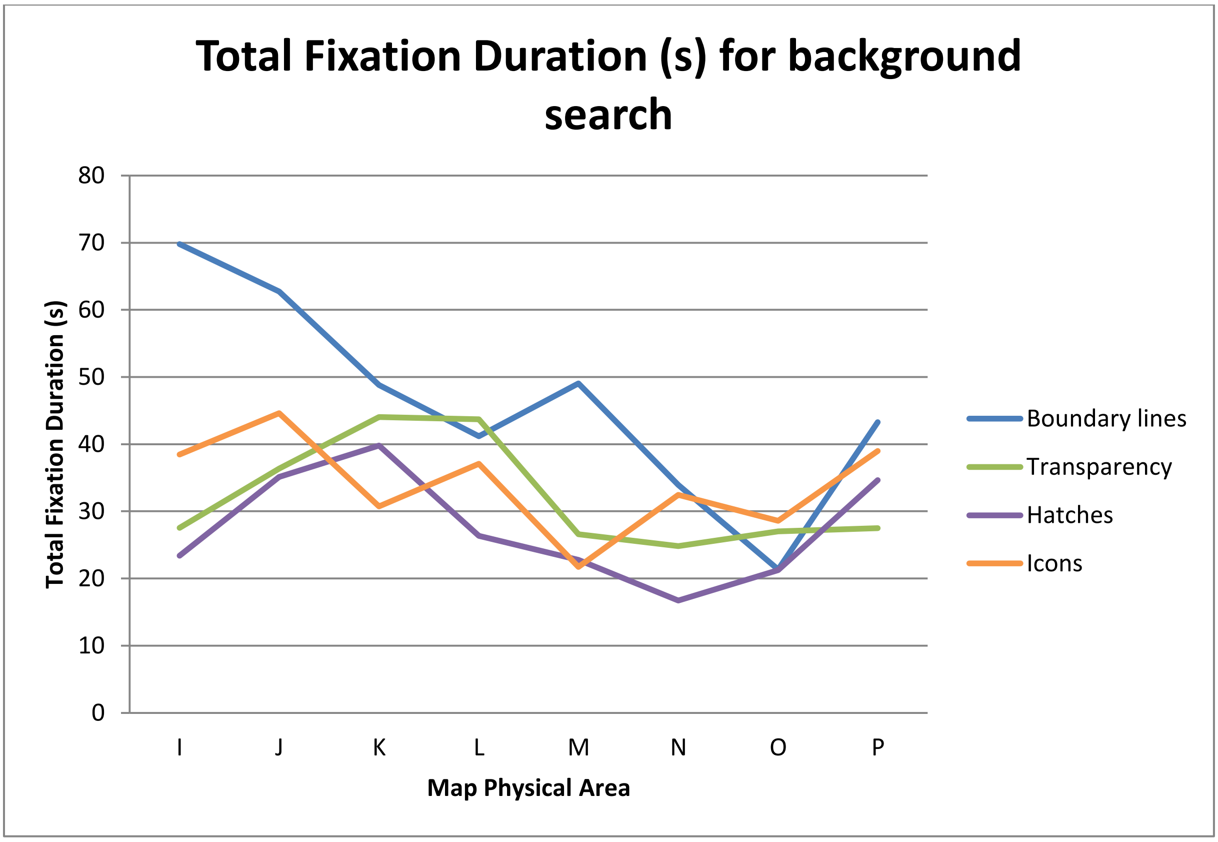


Figure 23. Results of the total fixation duration, measured in seconds for the background search task combined.

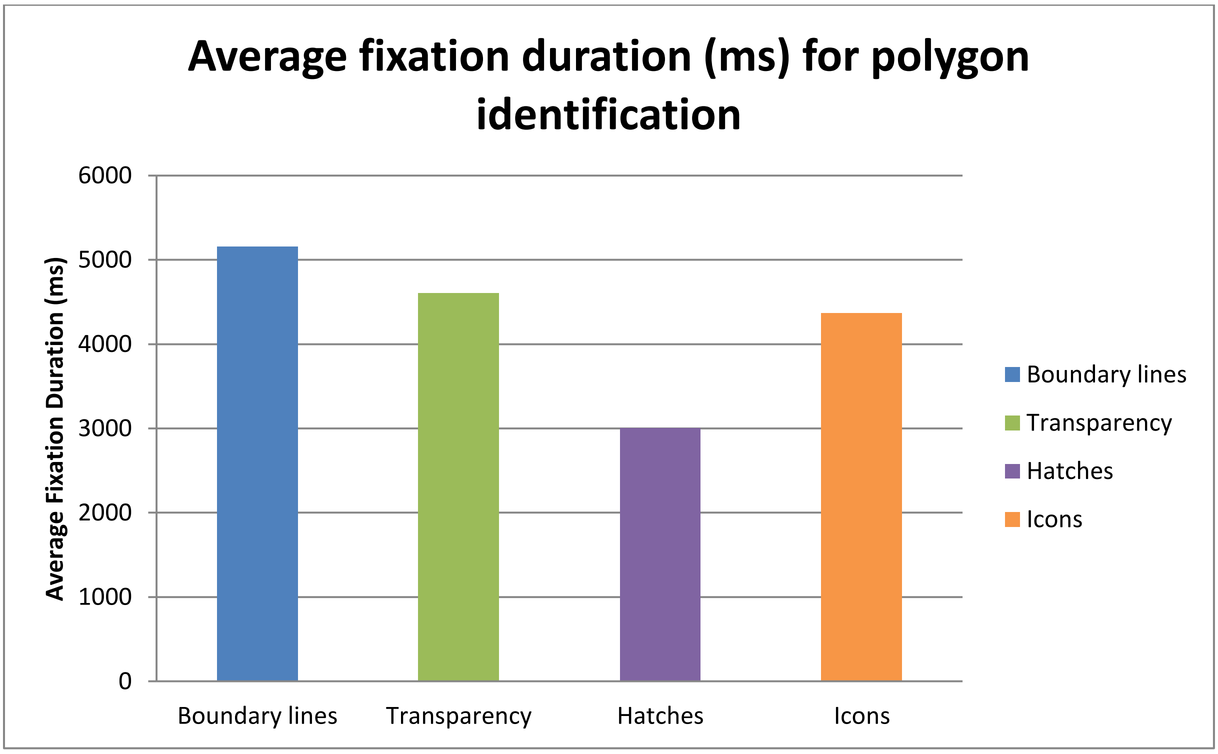


Figure 24. Average fixation duration for the polygon identification task.

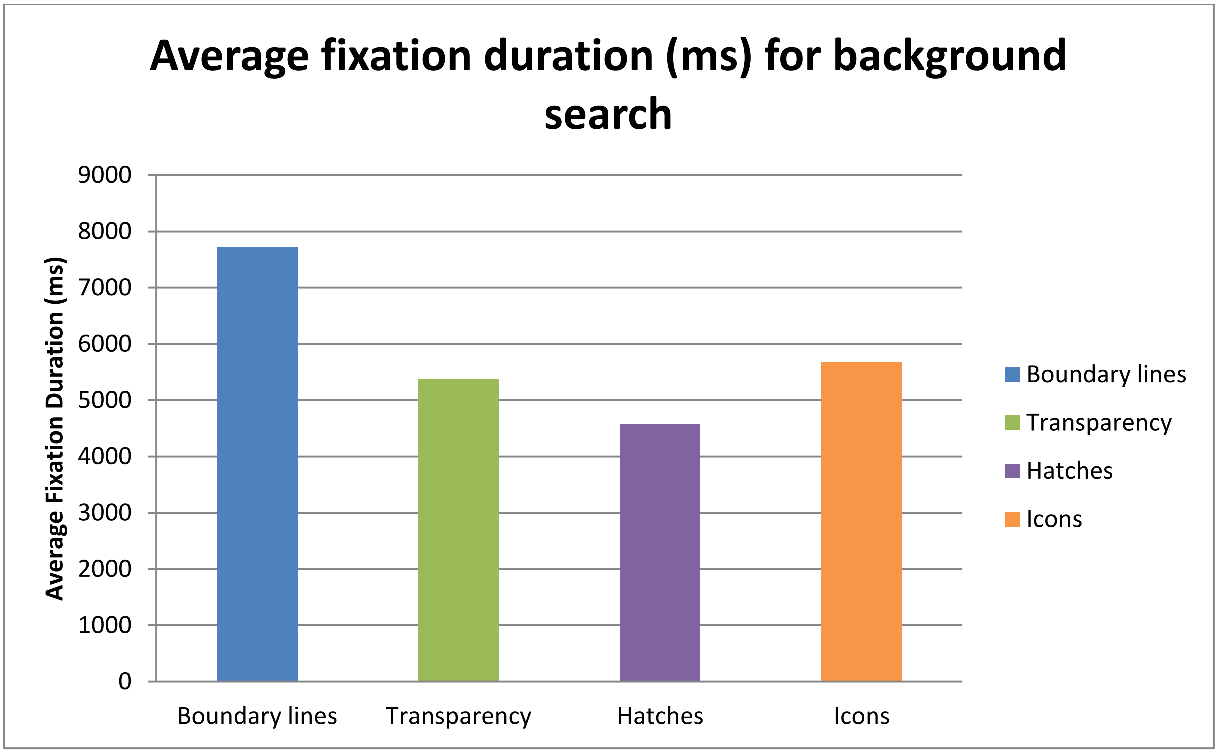


Figure 25. Average fixation durations for the background search task combined.

A one-way within subjects ANOVA with a Huynd – Feldt correction was conducted to compare the effect of cartographic design on fixation duration for only boundary lines, transparency, hatches and icons conditions. There was a significant effect of design type on fixation duration ($F (2.96, 281.43) = 16.83$, $p < 0.0005$).

Post hoc tests using paired samples t-test with the Bonferroni correction comparing four conditions were conducted. A first paired samples t-test indicated that there was a significant difference in the fixation duration for only boundaries (Mean (M) = 3.73, Standard Deviation (SD) = 0.25) and transparency (M= 3.63, SD 0.22) conditions; $t (95) = 3.05$, $p= 0.002$. Second paired samples t-test indicated that there was a significant difference in the fixation duration for only boundaries (M= 3.73, SD= 0.25) and hatches (M= 3.50, SD= 0.25) conditions; $t (95) = 6.75$, $p < 0.0005$. Third paired samples t-test indicated that there was a significant difference in the fixation duration for only boundaries (M= 3.73, SD= 0.25) and icons (M= 3.64, SD= 0.22 conditions; $t (95) = 2.70$, $p = 0.008$.

4.3 Scan paths

Results of the total eye-movement scan path lengths for the polygon identification task (Figure 26) and combined results for the background search task (Figure 27).

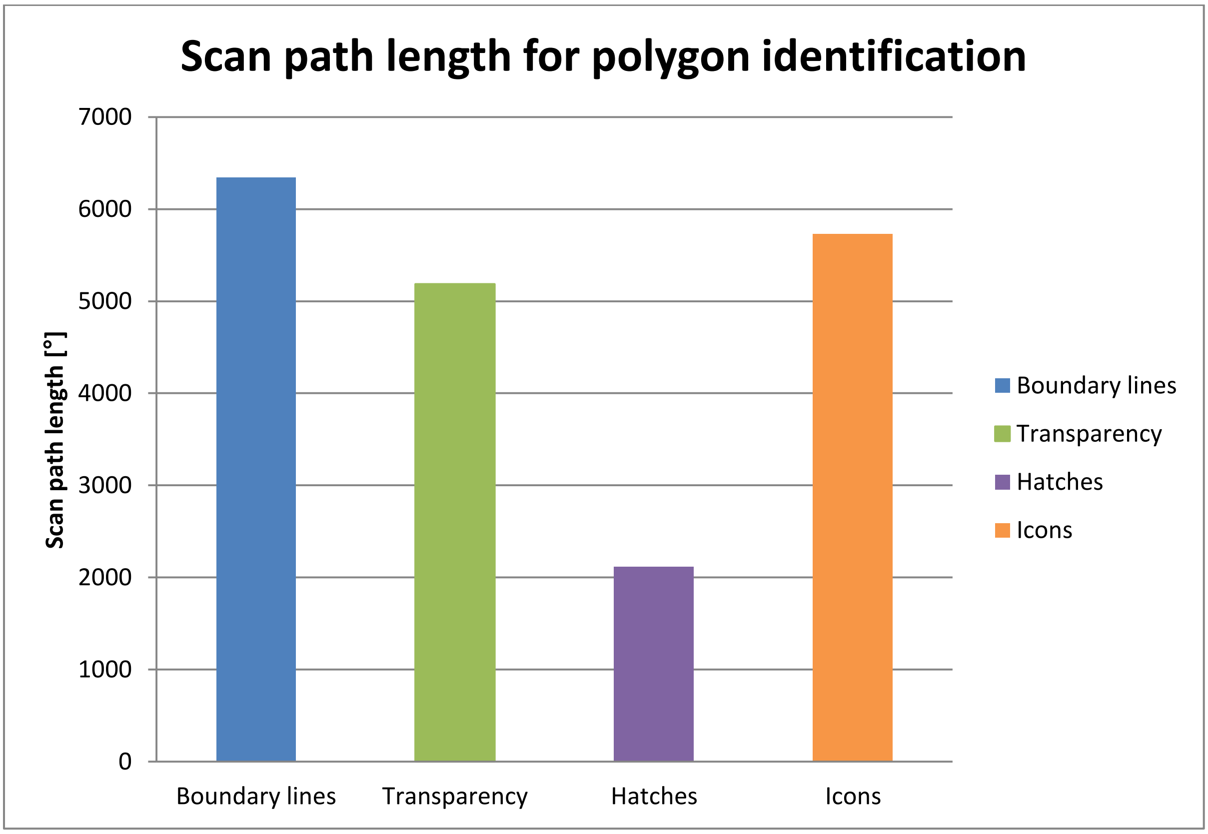


Figure 26. Results of the total scan path length, measured in amplitudes for the polygon identification task.

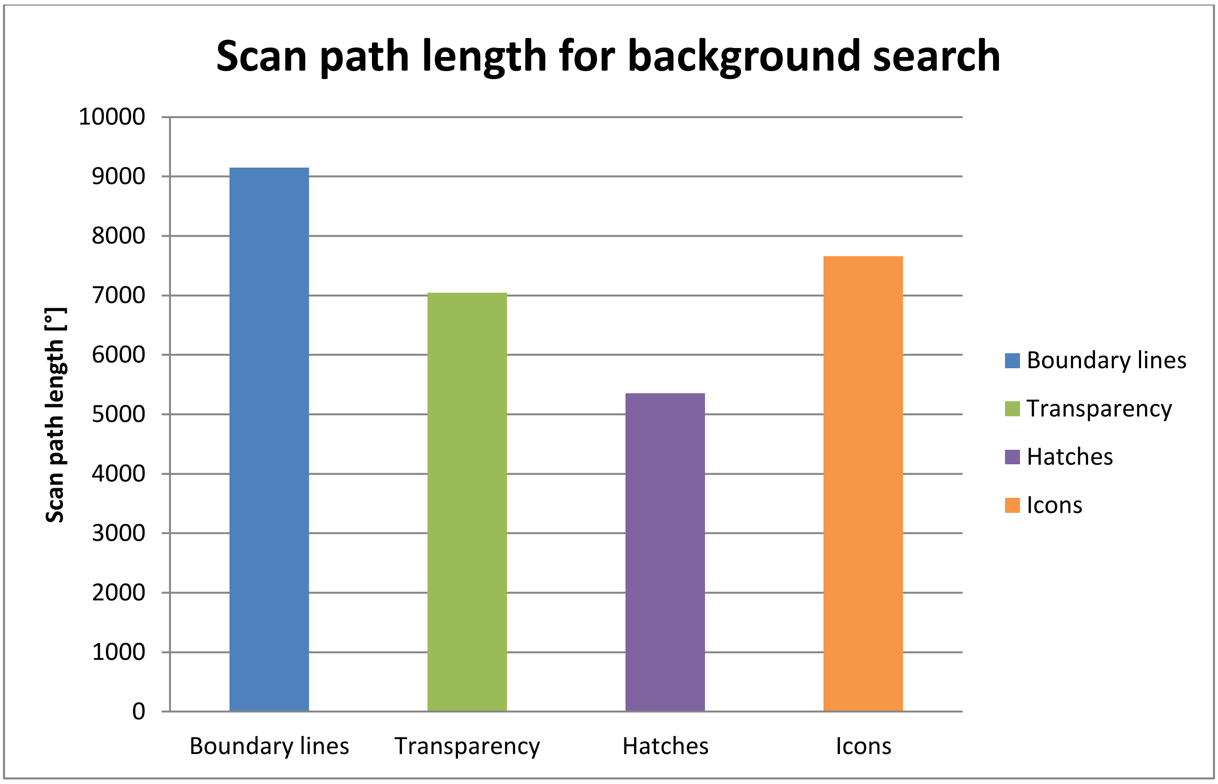


Figure 27. Results of the total scan path length, measured in amplitudes for the background search task combined.

A one-way within subjects ANOVA with a Huynd – Feldt correction was conducted to compare the effect of cartographic design on scan path length for only boundary lines, transparency, hatches and icons conditions. There was a significant effect of design type on scan path length ($F(2.50, 237.91) = 41.16$, $p < 0.0005$).

Post hoc tests using paired samples t-test with the Bonferroni correction comparing four conditions were conducted. A first paired samples t-test indicated that there was a significant difference in the scan path lengths for only boundaries ($M= 3.60$, $SD= 0.31$) and transparency ($M= 3.49$, $SD= 0.28$) conditions; $t(95) = 2.79$, $p= 0.006349$. Second paired samples t-test indicated that there was a significant difference in the scan path lengths for only boundaries ($M= 3.60$, $SD= 0.31$) and design 3 ($M= 3.14$, $SD= 0.45$) conditions; $t(95) = 8.81$, $p < 0.0005$. Third paired samples t-test indicated that there was not a significant difference in the scan path lengths for only boundaries ($M= 3.60$, $SD= 0.31$) and icons ($M= 3.56$, $SD= 0.23$) conditions; $t(95) = 1.01$, $p = 0.31$.

4.4 Dwell time

Results of the eye-movement net dwell time percent on borders AOI-s for the polygon identification task (Figure 28) and for the background search task combined (Figure 29).

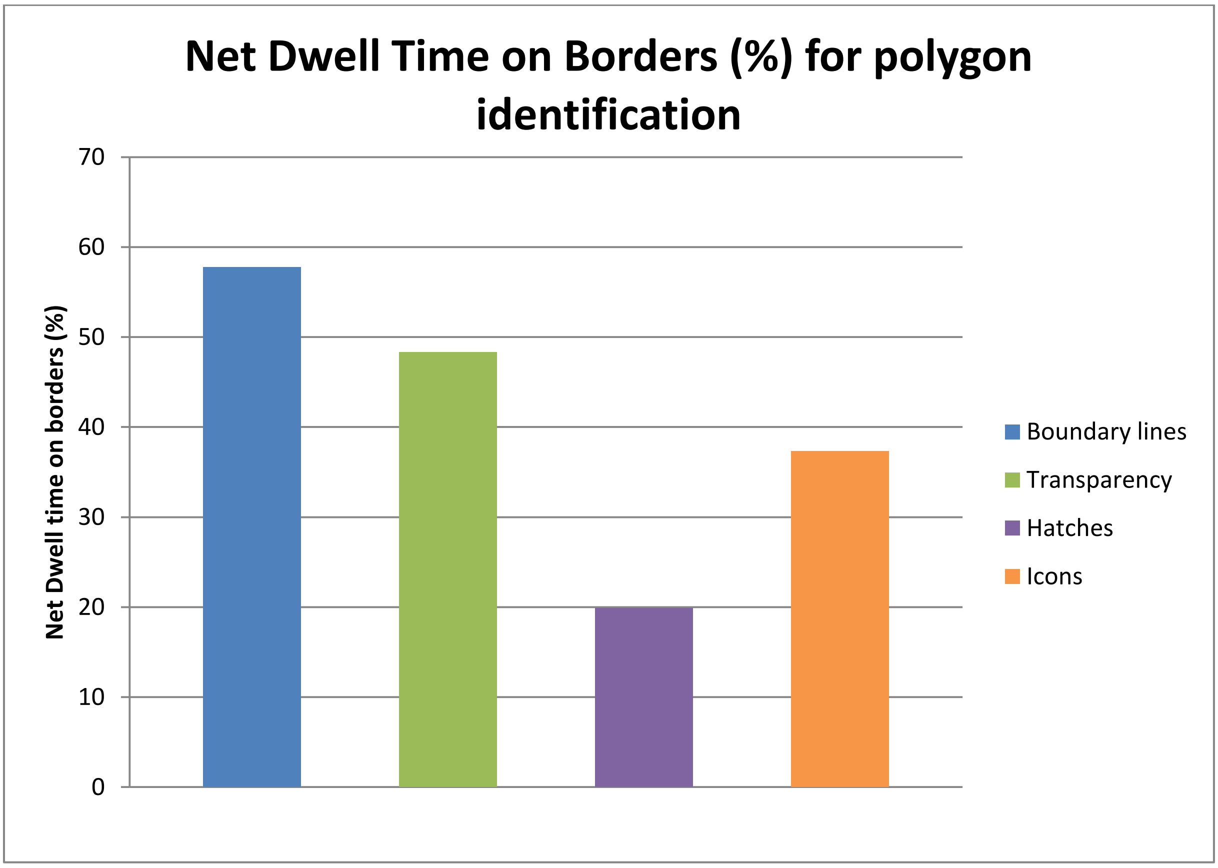


Figure 28. Results of the net dwell time percent on borders for the polygon identification task.

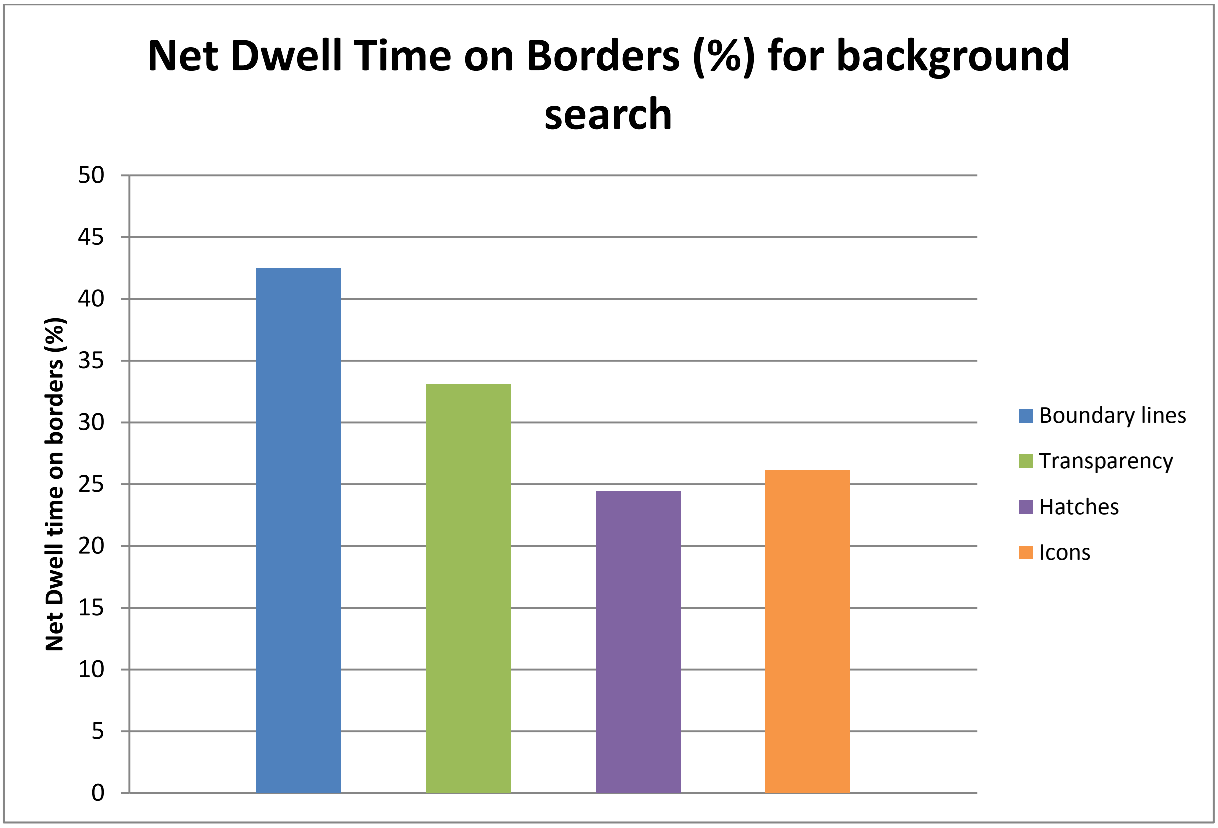


Figure 29. Results of the net dwell time percent on borders for the background search task combined.

The values for Net Dwell Time on AOI-s were normally distributed, so ANOVA was calculated with raw data. A one-way within subjects ANOVA with a Huynd – Feldt correction was conducted to compare the effect of cartographic design on net dwell time for only boundary lines, transparency, hatches and icons conditions. There was a significant effect of design type on net dwell time (F (2.79, 265.59 = 49.23, $p < 0.0005$).

Post hoc tests using paired samples t-test with the Bonferroni correction comparing four conditions were conducted. A first paired samples t-test indicated that there was a significant difference in the net dwell time for only boundaries (M= 50.12, SD= 17.43) and transparency (M= 40.70, SD= 18.27) conditions; t (95) = 4.43, $p < 0.0005$. Second paired samples t-test indicated that there was a significant difference in the net dwell time for only boundaries (M= 50.12, SD= 17.43) and hatches (M= 22.15, SD= 15.69) conditions; t (95) = 10.21, $p < 0.0005$. Third paired samples t-test indicated that there was a significant difference in the net dwell time for only boundaries (M= 50.12, SD= 17.43) and icons (M= 31.71, SD = 17.39) conditions; t (95) = 8.07, $p < 0.0005$.

4.5 Fixation count

Results of the average eye-movement fixation count for the polygon identification task (Figure 30) and for the background search task combined (Figure 31).

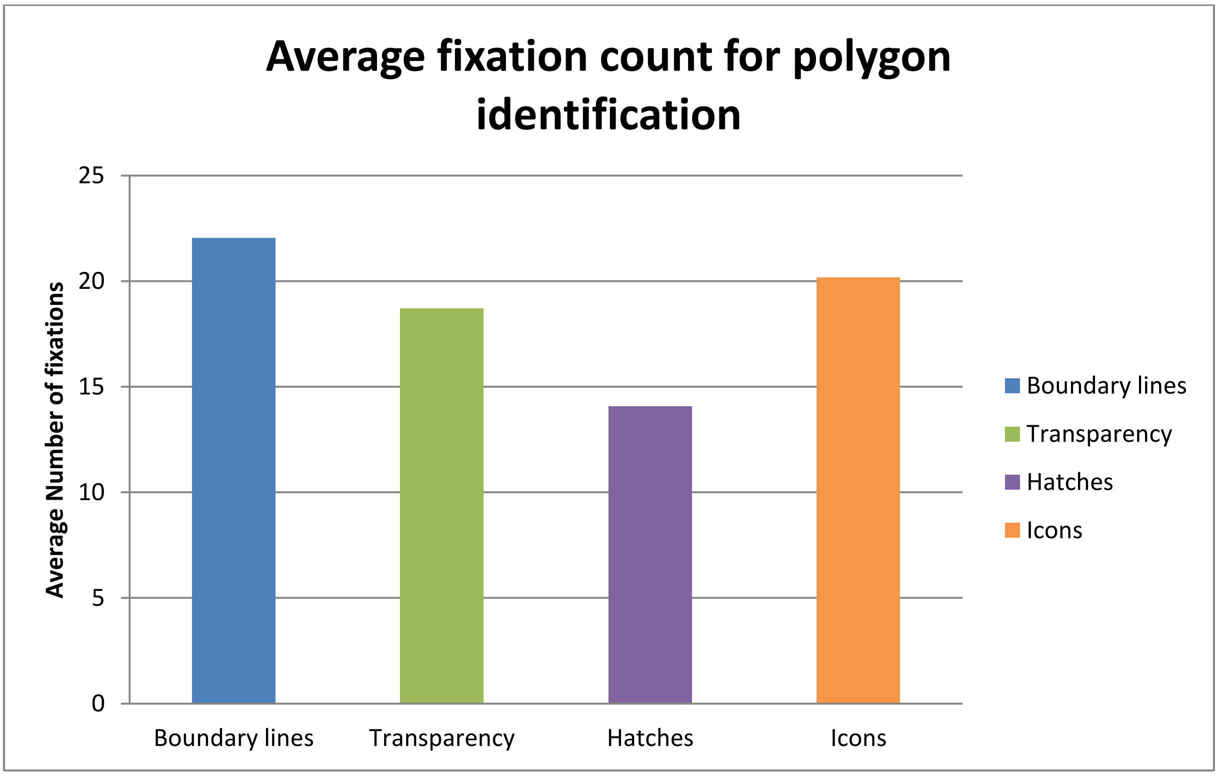


Figure 30. Results of the fixation count for the polygon identification task.

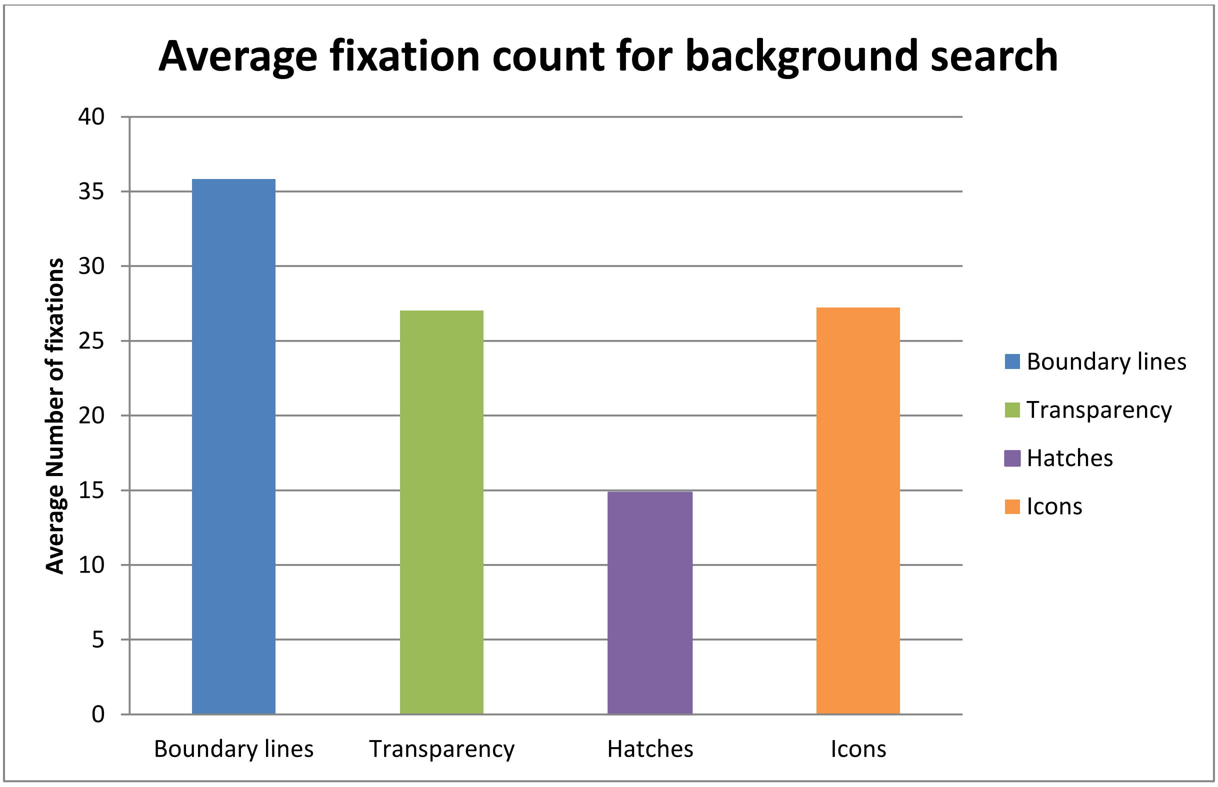


Figure 31. Results of the average fixation count for the background search task combined.

A one-way within subjects ANOVA with a Huynd – Feldt correction was conducted to compare the effect of cartographic design on fixation count for only boundary lines, transparency, hatches and icons conditions. There was a significant effect of design type on fixation count ($F (2.82, 268.53) = 55.39$, $p < 0.0005$).

Post hoc tests using paired samples t-test with the Bonferroni correction comparing four conditions were conducted. A first paired samples t-test indicated that there was a significant difference in the fixation count for only boundaries ($M = 1.38$, $SD = 0.25$) and transparency ($M = 1.29$, $SD = 0.22$) conditions; $t (95) = 3.53$, $p = 0.000638$. Second paired samples t-test indicated that there was a significant difference in the fixation count for only boundaries ($M = 1.38$, $SD = 0.25$) and hatches ($M = 1.05$, $SD = 0.31$) conditions; $t (95) = 10.74$, $p < 0.0005$. Third paired samples t-test indicated that there was not a significant difference in the fixation count for only boundaries ($M = 1.38$, $SD = 0.25$) and icons ($M = 1.32$, SD 0.21) conditions; $t (95) = 2.30$, $p = 0.023$.

5. Discussion

5.1 Summary of main results

Two main properties for good map designs were investigated in this study – effectiveness (correctness of answers) and efficiency (response time). The results for effectiveness were best with transparency, on the polygon identification task and with hatches, on the background search task. Efficiency was measured by total fixation duration (corresponds to reaction time), which was the shortest with the hatches design, on all tasks. Other measures that are strongly related to fixation duration (and thus efficiency) are scan path length and fixation count, which were the shortest and the least with the hatches design, on all tasks. To understand if the users utilize the additional information offered by inside fill, the measure of net dwell time on borders was applied. The percentage of net dwell time on borders was the smallest with the hatches design, on all tasks. From these empirical results, it is clear that to interpret the extent of the polygon and discriminating the polygon were easier with the hatches design.

When comparing the results between tasks, it is evident that during the polygon identification task the hatches work way better than other designs. But during the background search task, the difference between designs is smaller, except for fixation count. Thus, from the results of the background search task, it is evident that the hatches are obscuring the background map, hiding important information.

When comparing the results between eye-movement metrics, Holmqvist et al. (2011) explained how the results affect design quality. Longer scan paths mean non-meaningful representations (users are confused) and poor design. As the hatches had the shortest scan path, one could interpret that this design was good for this particular map task solving experiment. Fixation duration show also one general pattern, when the fixations are longer, deeper processing and increased cognitive effort is apparent (Holmqvist et al., 2011). As the hatches had the shortest fixation duration, one could interpret that perceiving information was cognitively simpler, thus meaning the design was good for this particular task. Fixation count gives also insights to how difficult it is to interpret information presented on the map (Holmqvist et al., 2011). As the fixation count was smallest with the hatches design, on could assume that this map stimuli or layout was easily interpreted.

5.2 The study

There were two main aims in this study. The first was to improve the efficiency and effectiveness of cartographic map design, particularly when adding thematic polygons on top of a background map. The second was to utilize the methodology of eye movement metrics analysis for studying the usability and readability of cartographic map design. To improve map design, four different cartographic design techniques for thematic polygons were compared. Eye-tracking experiment was conducted, to analyze these techniques. Participants solved map reading tasks while their eye-movement data were collected. Results were analyzed to find out if there are statistically significant differences between designs. The results and analysis focus on the difference of performance when adding additional information to only boundary lines design technique. Each addition, transparency, hatches and icons help the user to perceive more information from the map but still carry the same information. This way it is possible to see if and how the users utilize the additional information and which type of design is helping the user more, thus being efficient and effective. Outcome of the analysis was used to compare designs efficiency and effectiveness and to give guidelines for optimal design in geoportals. These guidelines generally apply, when the target user group, tasks and map data are similar to these used in this study. Eye-tracking methodology was utilized in order to see if it is suitable for solving particular map reading problems. Eye-movement analysis could reveal further insights why a certain design gives better results.

The concept of informational and computational equivalency described by Simon (1978) applies also for design used in this study. All designs carry exactly the same information and are informationally equal but as visible from the results, are very different from the computational equivalence point of view. From this it is clear that computational efficiency is determined by map design and can be improved by enhancing map design.

Ooms et al. (2012) found that effective maps can represent complex data and still be easily legible by the user, which is visible from the results as well. Combination of several polygons on top of each other, represent complex data, but maps were still readable by the participants.

5.3 Feedback from the participants

Overall, participants mentioned that the most useful design for those tasks was the hatches, but they did not like them. They said that hatches show the overall size, extent and proportions of the area very well, but from only boundaries it is difficult to see that. Also, they said that these designs have different advantages for various tasks.

5.4 Critics

There are a number of critics (Petchenik, 1983, described by Montello, 2002) that have pointed out issues considering map design research overall and using eye-tracking to investigate visual search problems. Some critics state that map design research overall is problematic and is not helpful for designing better maps. Concerns are that map users use maps differently than participants' during experiments. Map users do not have one specific clear task or question when they use maps and also, the results are context dependent. This evident issue can be balanced with good experimental design by creating multiple tasks for the same independent variables and focusing the problem in a clear way to solve a very specific problem. This way the results are context dependent, but still can be generalized. Other critics state that user's individual differences and having low-level map reading task, decrease the value of the study. Here as well, good experiment design excludes these issues, by selecting target intended users for the map aim and function. Also, making map solving tasks as similar as possible to the actual map usage can improve the results.

Critics (Irwin, 2004) for using eye-tracking methodology point out several issues for using this method in cartographic design research, but when keeping these in mind during the experiment design process, it is possible to get accurate results. One concern is that the cognitive process can happen on wider area than only the fixation location. This can be balanced by separating target objects from each other and increasing distance between objects. Another issue is that, cognitive processing can happen without certain fixation, but this can be balanced by analyzing scan path data, to get information about the attended areas between fixations.

5.5 Further studies

This research could be extended with further studies:

- Special design for hatches – gap distance, color and line width
- Different pattern symbology – lines vs points
- More maps and complicated tasks
- Gradually add more map elements and increase the task difficulty
- Other eye-movement measures
- Task and map purpose related design for geoportals
- Get more general results - less controlled study

6. Conclusions

6.1 Cartographic recommendations

Based on the analysis of the four designs one can state that to improve design techniques for polygons that are on top of each other and on top of the background map would be a design that includes elements from various designs. For example, when including likeability of the transparency (to make readers like the map more), overall usage of borders and overall best performance from eye-movement measures for the hatches design, optimal design combination for geoportals can be recommended. To make it easier to see the background map, the distance between lines could be bigger. From the results it is evident that for different tasks different design techniques work better and also participants like different designs. It is important that geoportals enable various design properties to be manipulated by the users and more than one default design option. In this way, the user could choose an appropriate design for the intended map usage. Combined and improved design techniques are proposed from the study results (Figure 32, Figure 33, Figure 34).

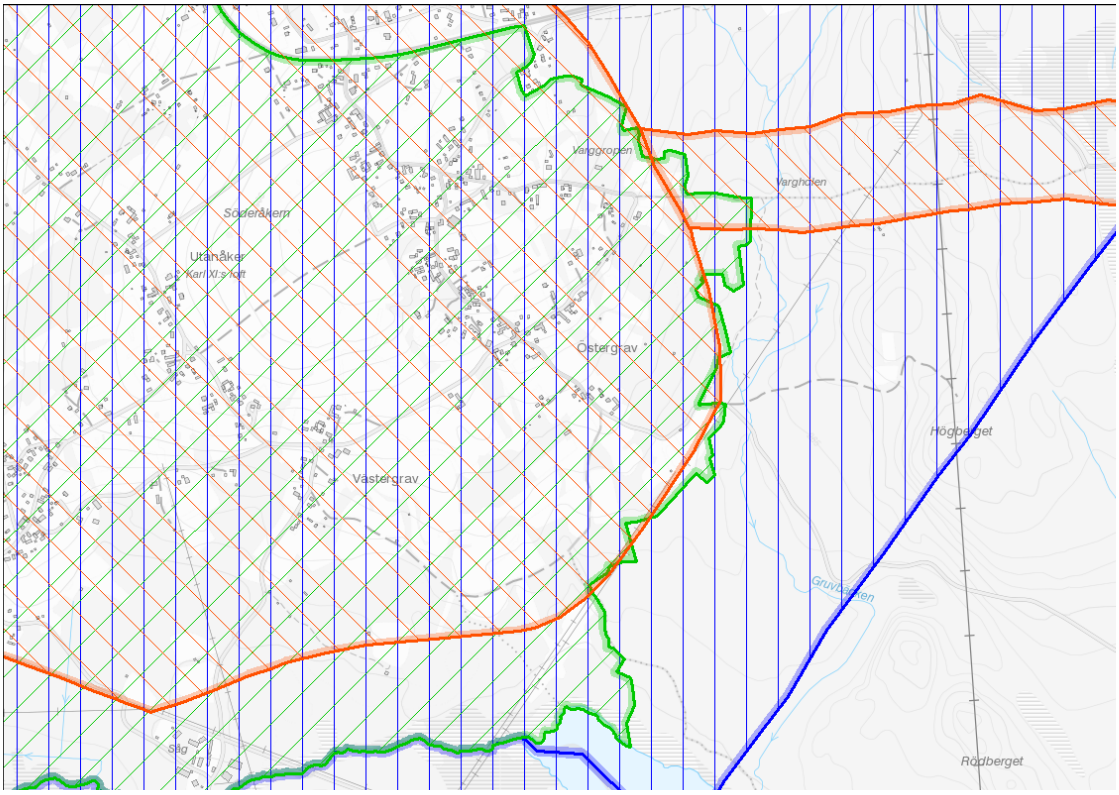


Figure 32. Hatches design, separation between lines has been increased to 24 pt. (Source: Länsstyrelserna and Lantmäteriet, © Lantmäteriet, Dnr: I2014/00579).

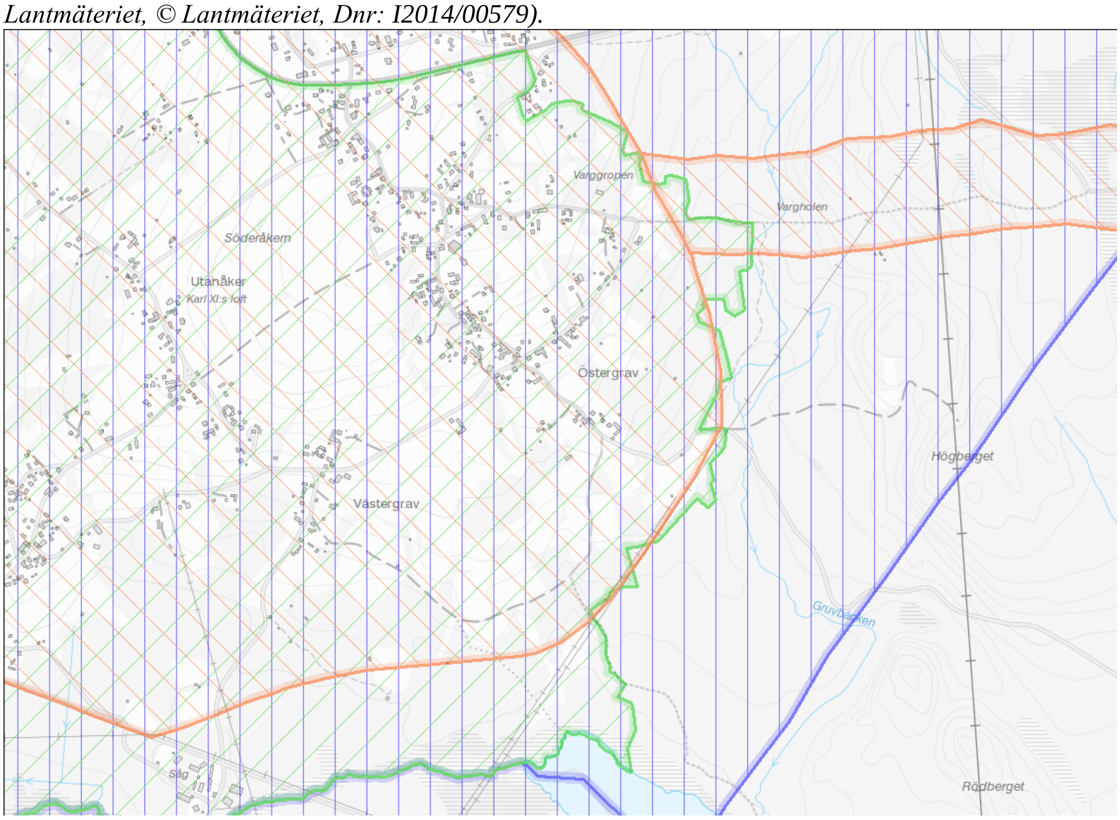


Figure 33. Hatches design, separation between the lines has been increased to 24 pt, transparency set to 50% for the whole design, line width set to 1 pt. (Source: Länsstyrelserna and Lantmäteriet, © Lantmäteriet, Dnr: I2014/00579)

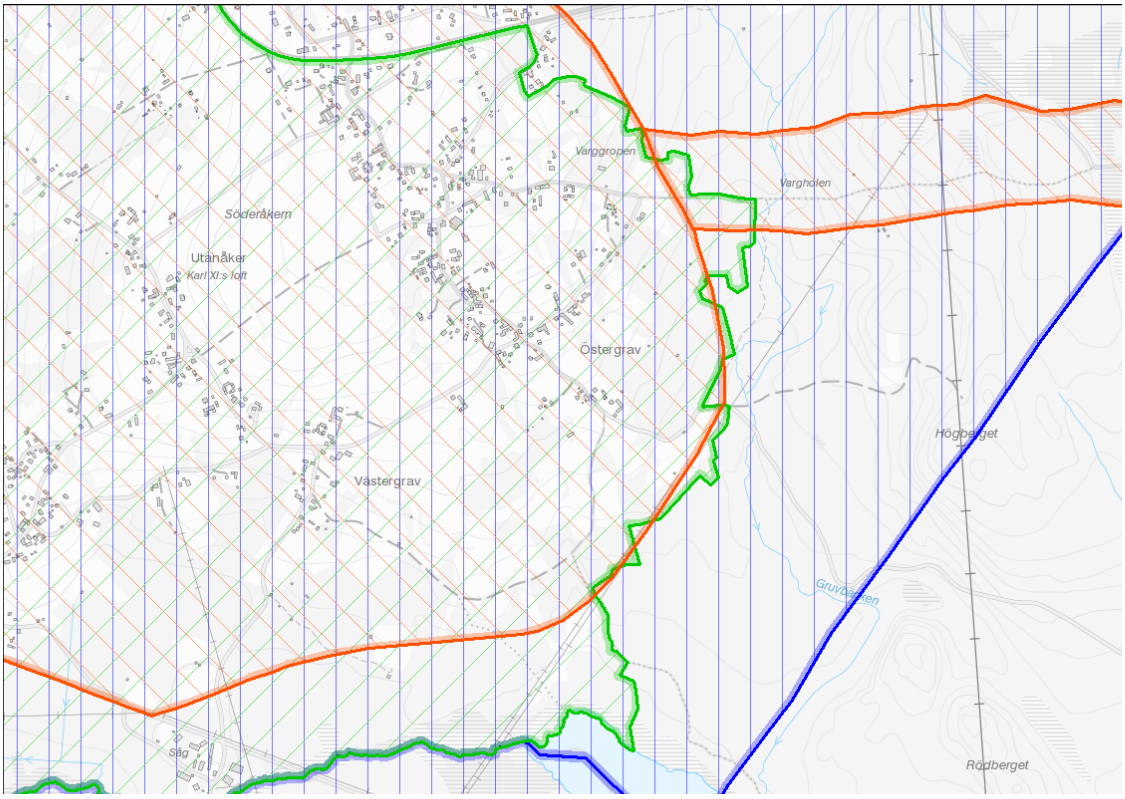


Figure 34. Hatches design, separation between lines increased to 24 pt, transparency for the diagonal pattern set to 50%, line width for the patter set to 1 pt, borders are fully visible. (Source: Länsstyrelserna and Lantmäteriet, © Lantmäteriet, Dnr: I2014/00579).

6.2 Utilization of eye-tracking methodology

Visual search problems are commonly studied with eye-tracking methodology. With this method, user's eye-movements on the map stimuli are recorded. These eye-movements give insights to how users perceive information and to the cognitive process behind that. It is known that map user's look at the places on the maps from where they wish to acquire information. The amount of studies that are using this method has increased, specifically studies that seek empirical evidence for better design techniques.

Eye-tracking can be applied to map design research when more thorough understanding about map reading cognitive processes is needed. For example, reaction time only gives the efficiency for a particular map design, thus information about why this particular design works better remains unknown. However, information from eye-movements can in many cases explain why certain design is better. Also, this methodology gives empirical evidence. Eye-movement data shows which map elements are attended by the map users and which elements are mostly used to solve tasks.

The main issues for using eye-tracking methodology are related to experiment design, it must be focused to give answers for very specific questions. Other drawbacks can be the amount of time necessary to spend for the data collection and finding participants. Also, to study eye-tracking methodology, measures, techniques and statistical analysis for the results, can be time consuming and difficult.

Eye-tracking offers additional information, more than just reaction time and correctness of answers. From the eye-movement data it is possible to conclude why the reaction time and quality of inference are different between designs. Disadvantages are that the experiment design and artificial task design are far from the real task solving situation and the results are only effective in laboratory circumstances. In order to make statistically significant conclusions, the whole experiment must be controlled and all real life uncertainty removed. Some previous disadvantages described by Montello (2002) are no longer existing, for example the expensive and complicated learning curve of the eye-tracking software; the current software is simple and intuitive.

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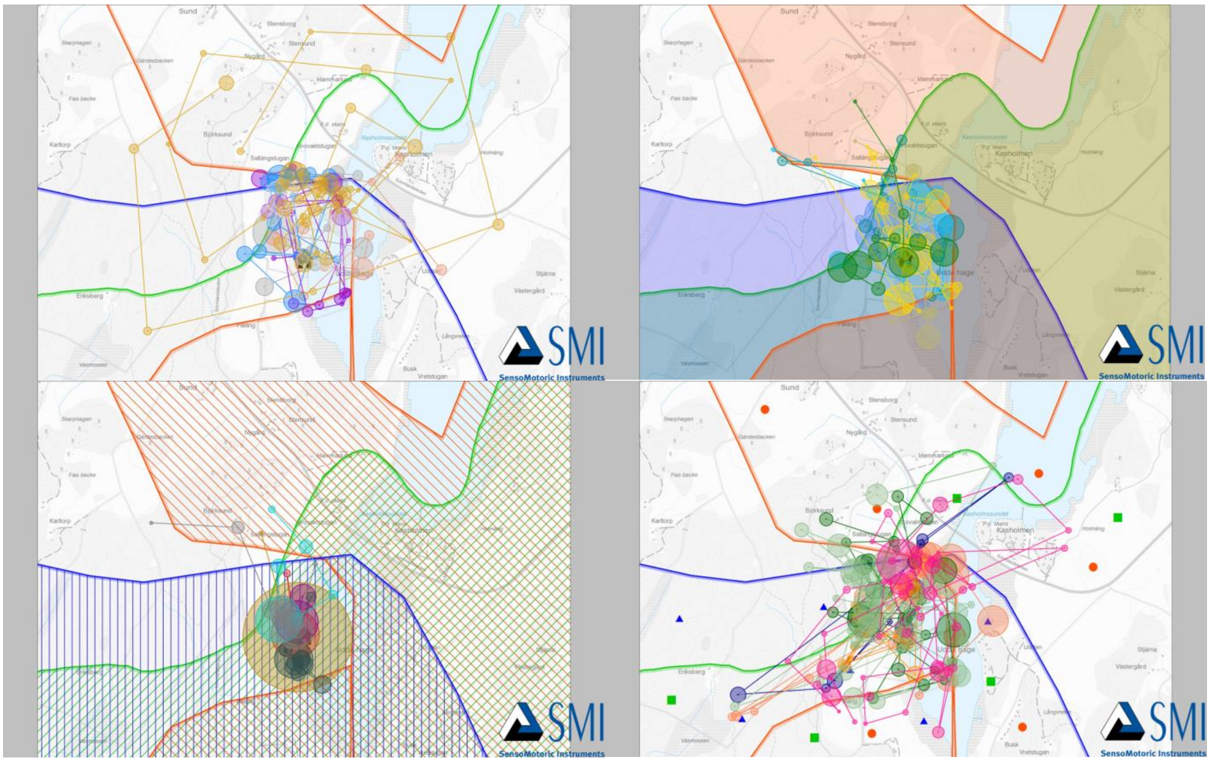
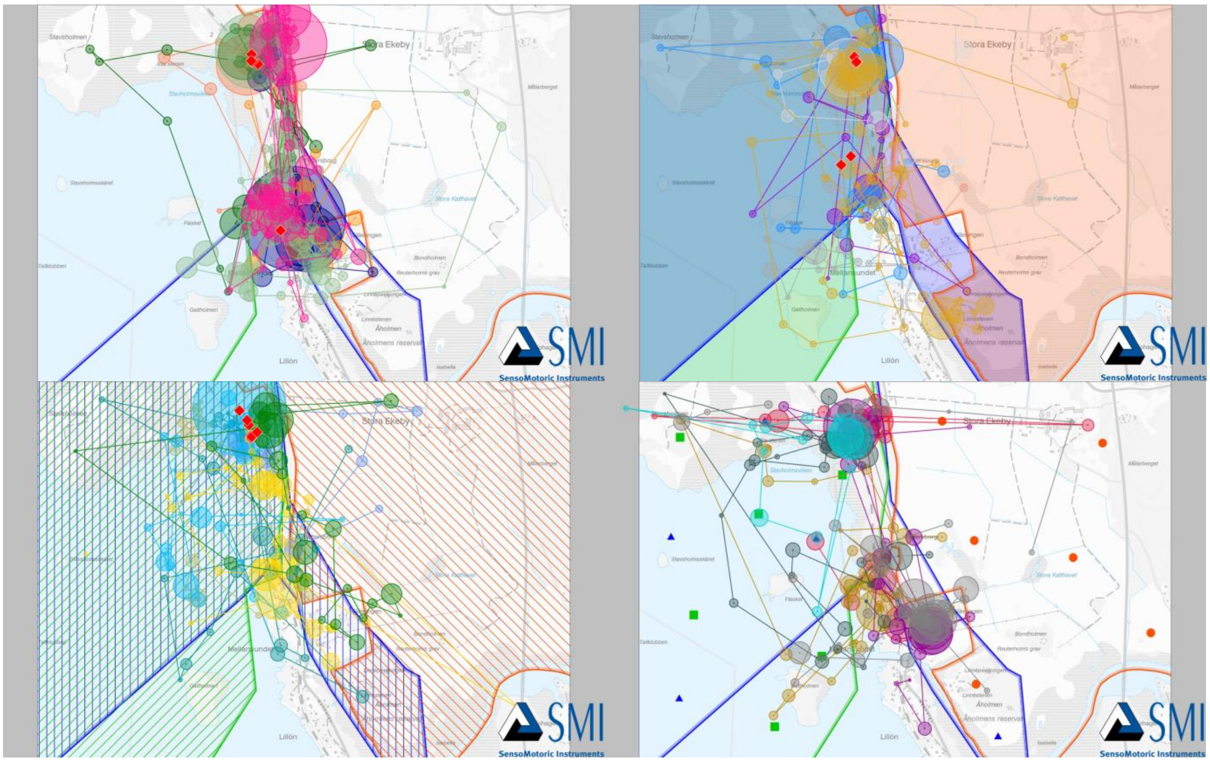
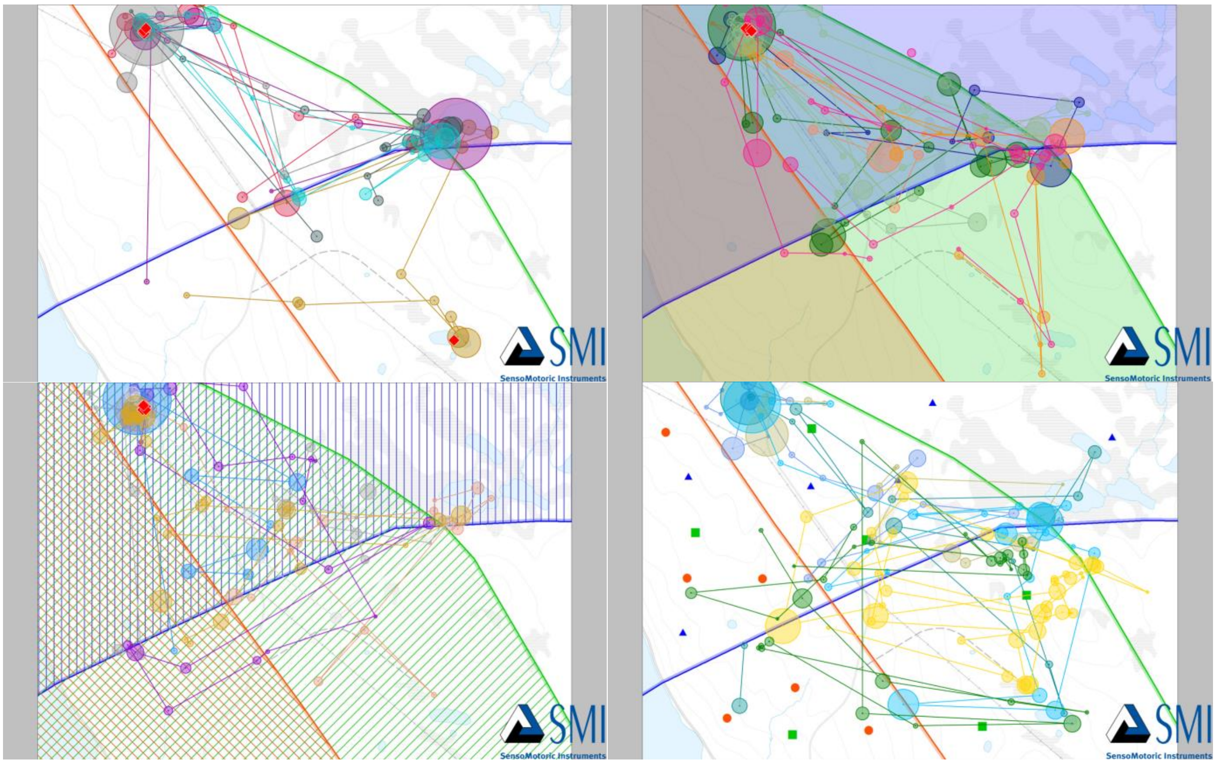
Appendix 1 - Physical Map Areas



Physical map area G. (Source: Länsstyrelserna and Lantmäteriet, © Lantmäteriet, Dnr: I2014/00579)



Physical map area J. *(Source: Länsstyrelserna and Lantmäteriet, © Lantmäteriet, Dnr: I2014/00579)*



Physical map area O. (Source: Länsstyrelserna and Lantmäteriet, © Lantmäteriet, Dnr: I2014/00579)

Appendix 2 - Consent Paper

Lund University Humanities Lab

Lund University Humanities Laboratory
Centre for Languages and Literature
Helgonabacken 12
22362 Lund
Sweden
humlab@humlab.lu.se

Experiment: Map design research experiment
Experiment leader:
Andreas Kiik, andreas.kiik.380@student.lu.se
Lars Harrie, Department of Physical Geography and Ecosystem Science, LU
Marcus Nyström, Humanities Laboratory, LU

Pre-experiment information
This is an experiment about map design research. You will solve map reading tasks to find certain areas from the maps. Full disclosure of the details of the experiment will be provided after the experiment and you will then have the right to have your data destroyed if you are not satisfied with the purpose. Your participation should be entirely voluntary. You may choose to discontinue the experiment at any time during the experiment if you wish.

Post-experiment information
Thank you for your participation. By signing this document, you consent that:

- You have been given full disclosure of the aim of the experiment and you have decided to not have your data detroyed. This right remains up to the day the data has been used in an academic publication or presentation.
- You understand that the data is reported in anonymized form and that the experimenter may be forced by Swedish law, under rare circumstances, to present the data to external researchers wanting to examine any anomalies in the data.
- You understand that we have recorded your eye-movements, and the privacy risks each data type poses to you.
- You have received and understood the information in the section "Pre-experiment information" before the experiment.

Date & City Name Signature

Consent paper from Lund University Humanities Lab

Appendix 3 – Instructions for participants

Description of the experiment, explanation of the map designs and instruction for calibration:

The task in this experiment is to find which areas are overlaping on a certain location. There are three types of areas: green, red and blue. These areas are designed with four different ways. This experiment will take about twenty minutes.

Now I will start with describing the maps and designs:

1. Areas are represented only with boundary lines, the fading of the line is towards inside (and this is for all designs).

For example, this green area on the left, this is the inside, you can see it from the faded boundary lines. And this is the outside. Inside is within this area and every object overlaps with this area.

These are green areas, overlaped by blue areas and red areas.

This is the boundary of blue areas.

These are blue areas, overlaped by green areas and red areas.

This is the boundary of red areas.

These are red areas, overlaped by green and blue areas.

2. Areas are represented with boundary lines and transparent fill.

For example, this green area, this is inside, you can see it from the faded boundary lines and from the transparent filling that represents the inside. Often these areas overlap, and colors change. Here you can see green and blue overlapping, here you can see only blue. And here in the middle red, green and blue are overlapping.

3. Areas are represented with hatches on the inside and boundary lines.

For example, this green area, this is inside, you can see this from the faded boundary lines and from diagonal pattern that represent the inside area. Each area has different pattern, green and red are diagonal and blue is vertical. You can see the overlapping areas from the colors of the diagonal patterns. For example, here red, green and blue are overlapping. And here red and blue are overlapping.

4. Areas are represented with icons on the inside and with boundary lines.

For example, this red area on the right, this is inside, and you can see it from the faded boundary lines and red icons that represent the inside area. You can see the overlaping areas from the colors of the icons. For example, here, green and red are overlaping and here green, red and blue are overlaping.

Please ask any questions you have.

These arrows show how to sit. Ideally no arrows are visible.

Now we are going to start with the experiment.

Please try to sit in the similar position.

First the experiment starts with calibration and then after that, you will move on at your own pace.

1. Please follow the red dot with your eyes

2. Do not try to predict the movement, just follow

3. Try not to move your head, only your eyes.

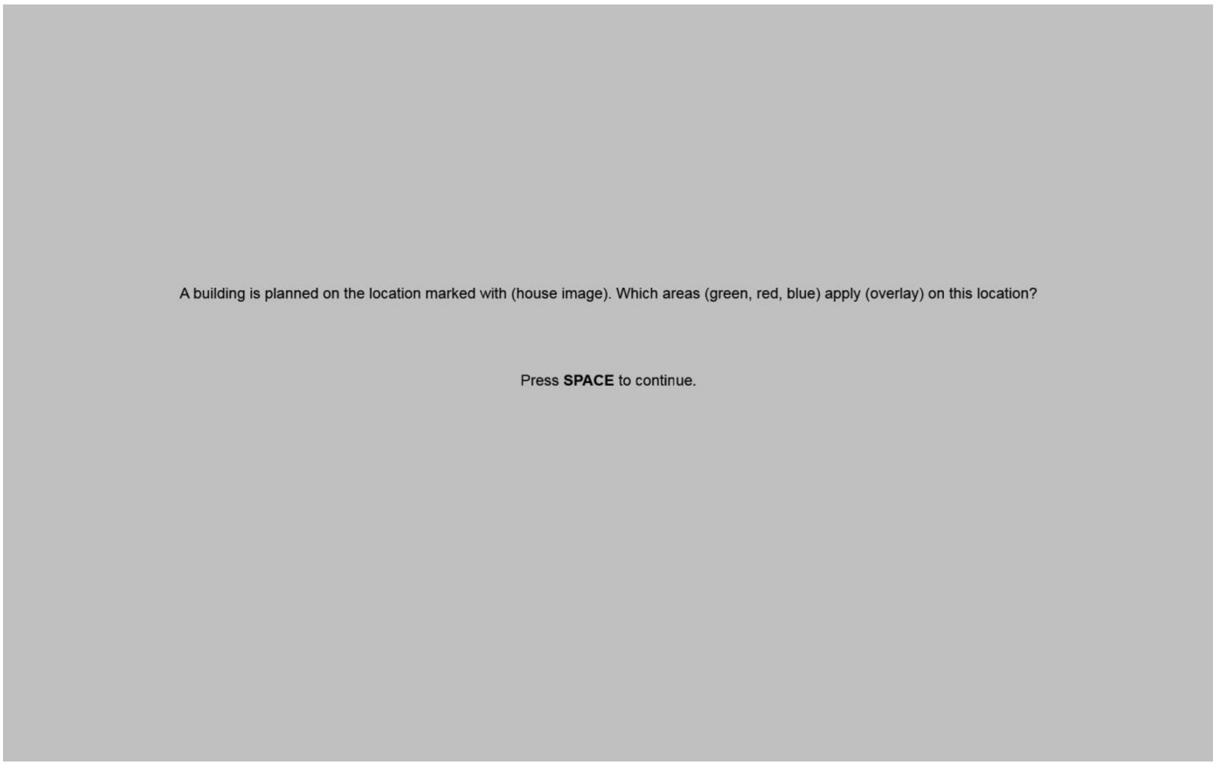
At the end of experiment:

Thank you for participating in this experiment, the results are used to improve web maps. Are you interested in the findings? If yes, I will email you.

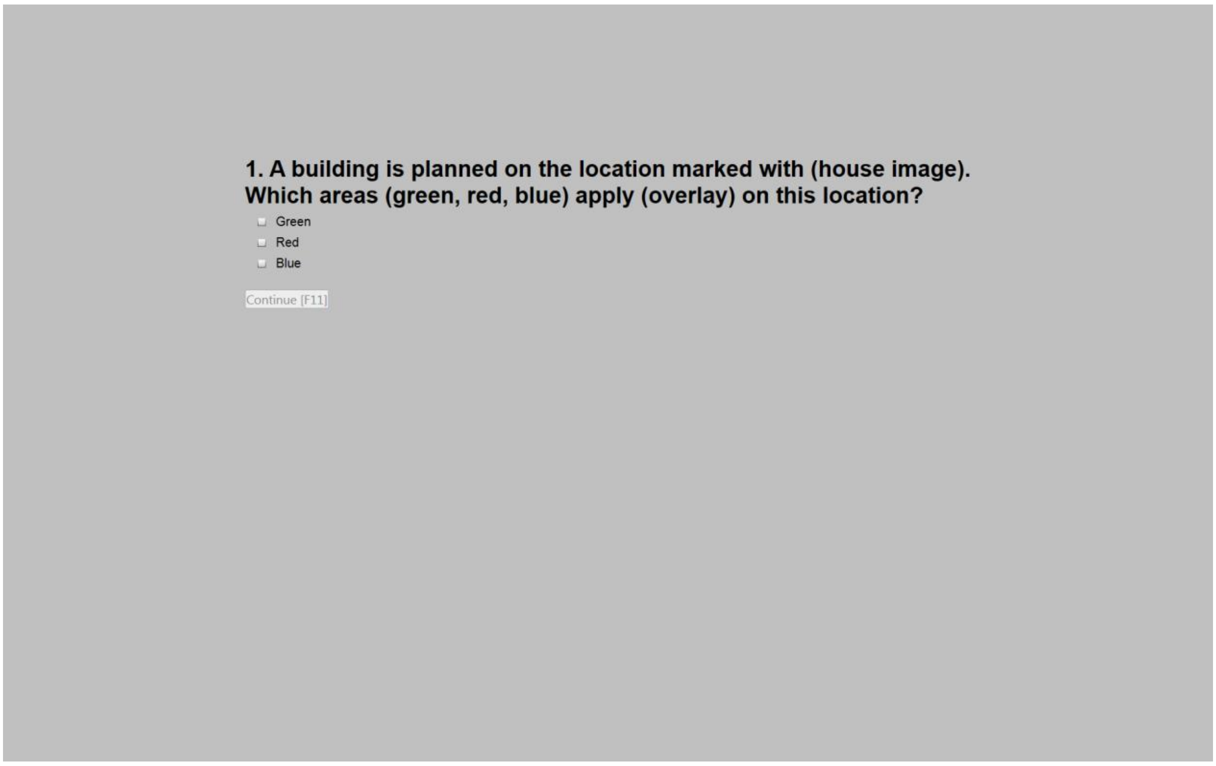
Appendix 4 – Questionnaires

Questionnaires as presented to participants on screen:

Instructions for question 1.



Question1.



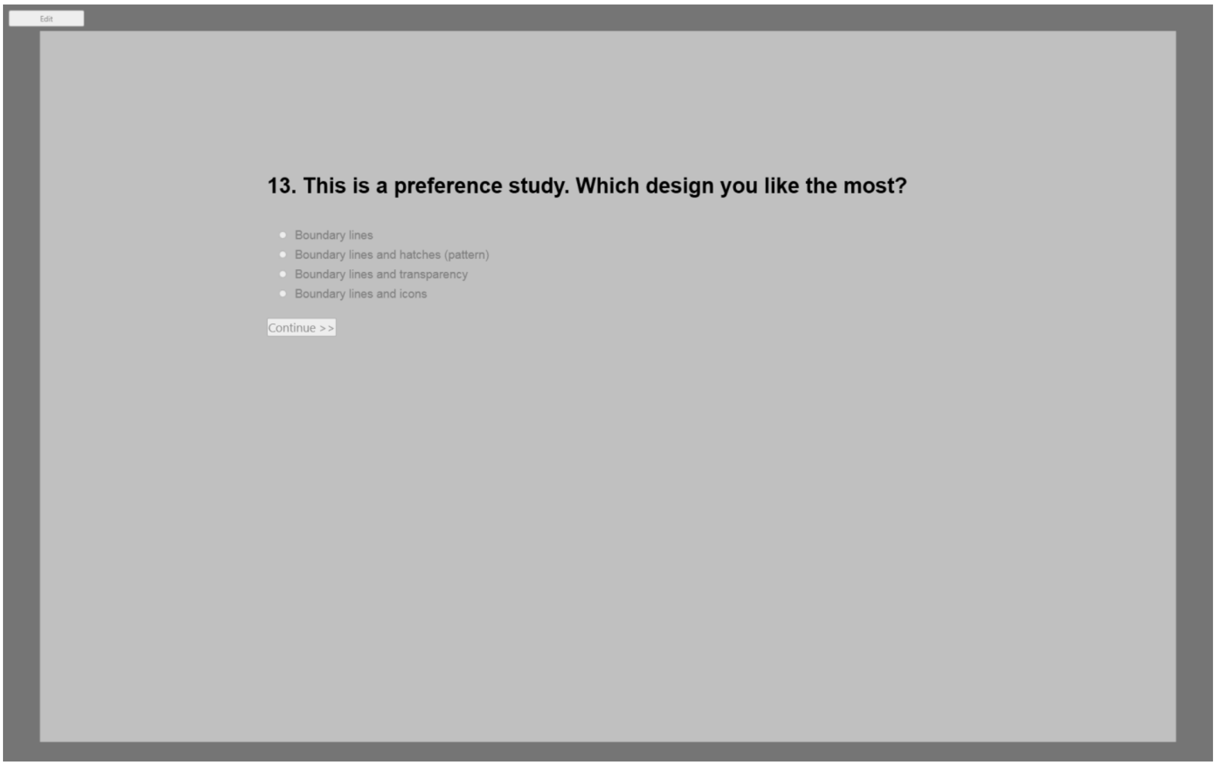
Answer dialog for question1.

Instructions for question2.

Question 2.

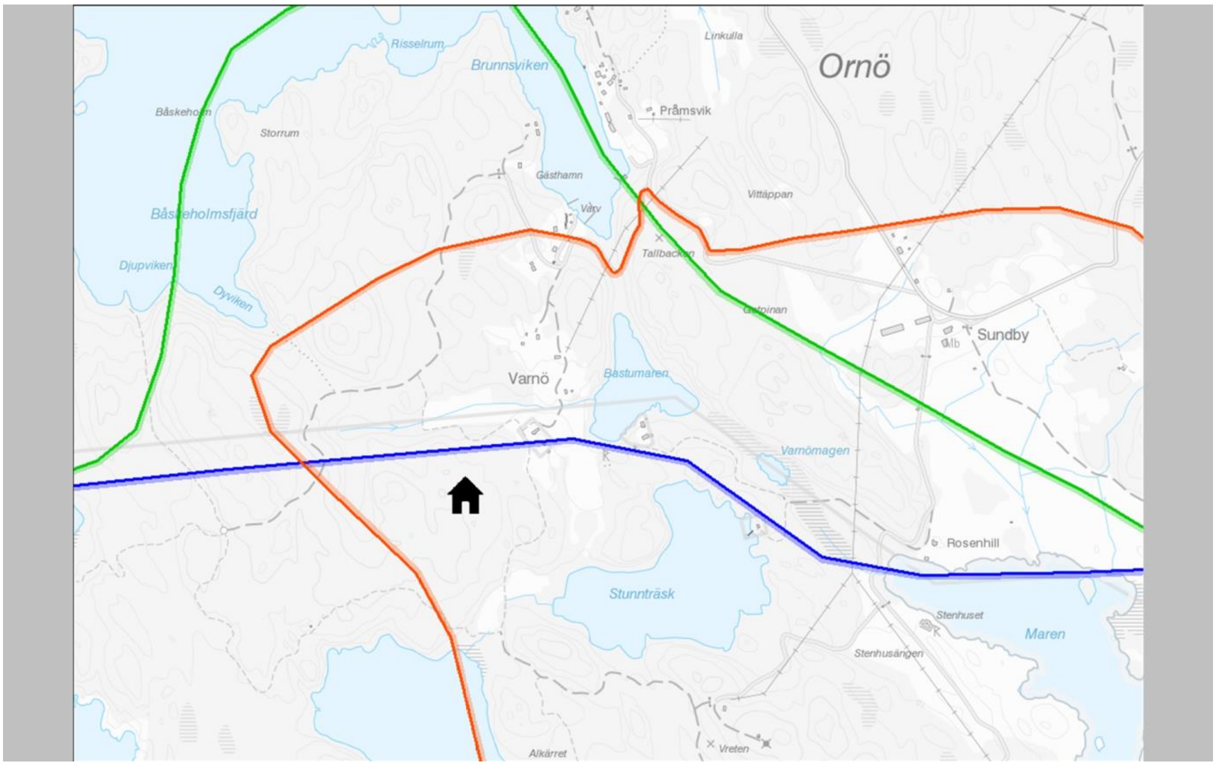
Instructions for question 3.

Question3.

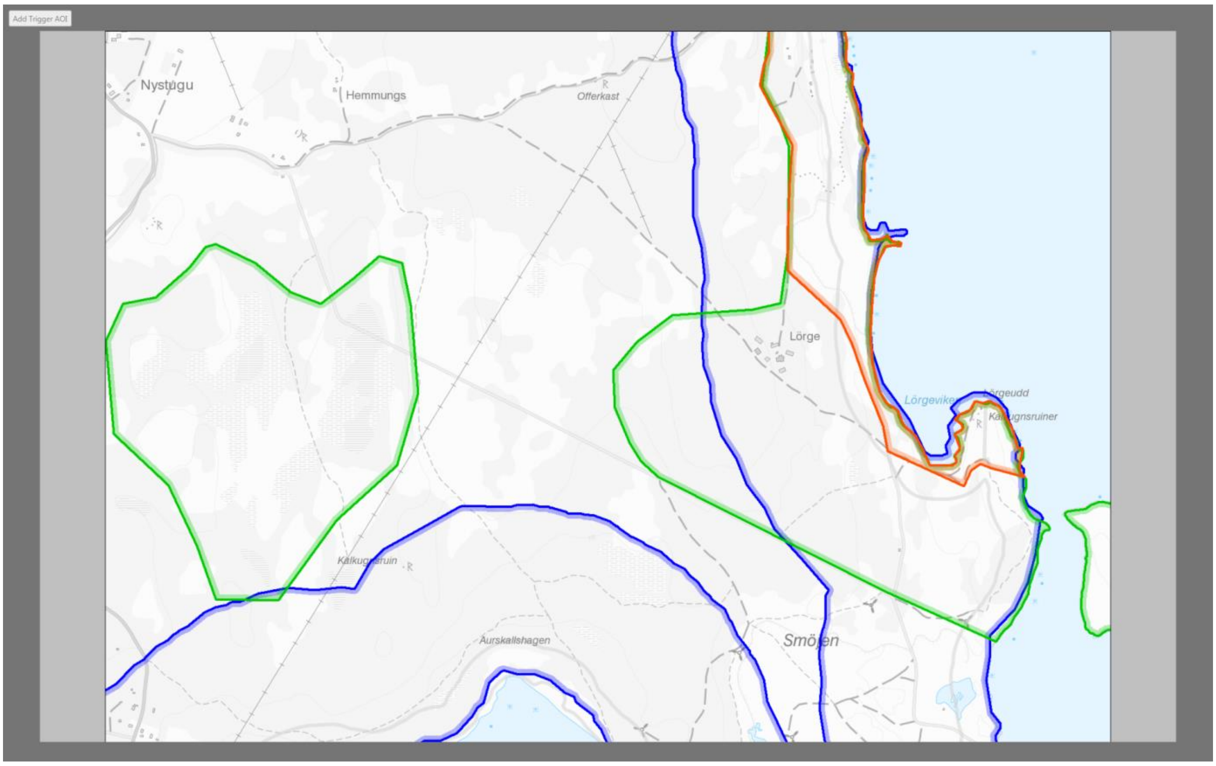


Question for preference study.

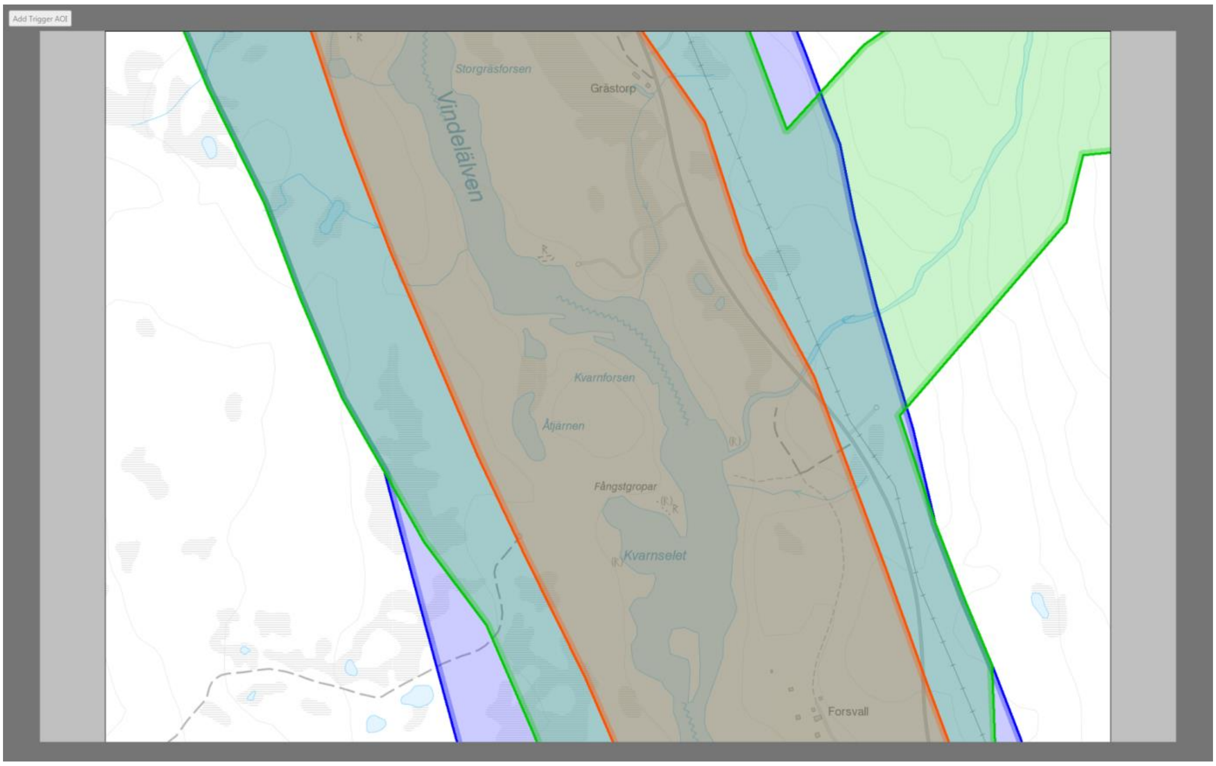
Appendix 5 – Map examples for all tasks



Map for polygon identification task.



Map for background search (villages) task.



Map for background search (lakes) task.

Gulaserien

Institutionen för naturgeografi och ekosystemvetenskap, Lunds Universitet.

Student examensarbete (Seminarieuppsatser). Uppsatserna finns tillgängliga på institutionens geobibliotek, Sölvegatan 12, 223 62 LUND. Serien startade 1985. Hela listan och själva uppsatserna är även tillgängliga på LUP student papers (www.nateko.lu.se/masterthesis) och via Geobiblioteket (www.geobib.lu.se)

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301 Sean Demet (2014) Modeling the evolution of wildfire: an analysis of short term wildfire events and their relationship to meteorological variables

302 Madelene Holmblad (2014). How does urban discharge affect a lake in a recreational area in central Sweden? – A comparison of metals in the sediments of three similar lakes

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Modelling. A Case Study of the Common Toad in Lomma Municipality
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