Effect of GPS on understanding relationship between mobile map and environment: A field experiment

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Objectives: GPS technology enables the visualisation of a map reader's location on a mobile map. Earlier research on the cognitive aspects of map reading identified that searching for map-environment points is an essential element for the process of determining one's location on a mobile map. Map-environment points refer to objects that are visualized on the map and are recognizable in the environment. However, because the GPS usually adds only one point to the map that has a relation to the environment, it does not provide a sufficient amount of information for self-location. The aim of the present thesis was to assess the effect of GPS on the cognitive processes involved in determining one's location on a map.

Methods: The effect of GPS on self-location was studied in a field experiment. The subjects were shown a target on a mobile map, and they were asked to point in the direction of the target. In order for the map reader to be able to deduce the direction of the target, he/she has to locate himself/herself on the map. During the pointing tasks, the subjects were asked to think aloud. The data from the experiment were used to analyze the effect of the GPS on the time needed to perform the task. The subjects' verbal data was used to assess the effect of the GPS on the number of landmark concepts mentioned during a task (landmark concepts are words referring to objects that can be recognized both on the map and in the environment).

Results and conclusions: The results from the experiment indicate that the GPS reduces the time needed to locate oneself on a map. The analysis of the verbal data revealed that the GPS reduces the number of landmark concepts in the protocols. The findings suggest that the GPS guides the subject's search for the map-environment points and narrows the area on the map that must be searched for self-location.

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Tiivistelmä - Referat – Abstract

Tavoitteet: GPS-teknologia mahdollistaa kartanlukijan sijainnin esittämisen mobiilikartan ruudulla. Kartanlukemista koskevien psykologisten teorioiden mukaan oman sijainnin määrittäminen kartalla edellyttää, että kartanlukija pystyy yhdistämään vähintään kaksi kartalla esitettyä kohdetta vastaaviin ympäristön objekteihin. Kuitenkin GPS-teknologian avulla esitetään yleensä vain yksi piste kartalla, joten GPS ei yksinään tarjoa kartan käyttäjällä riittävästi informaatiota oman sijainnin määrittämiseen. Tässä tutkimuksessa tarkasteltiin, miten kartanlukijat pystyvät hyödyntämään GPS:n tarjoamaa lisäinformaatioita ja miten GPS vaikuttaa oman sijainnin määrittämiseen kartalla.

Menetelmät: GPS-teknologian vaikutusta itsensä paikallistamiseen tutkittiin kenttäkokeessa. Koehenkilöille esitettiin mobiilikartan ruudulla kohde, ja heitä pyydettiin osoittamaan suunta kohteeseen. Suunnanosoitustehtävän suorittaminen edellyttää, että kartanlukija määrittää oman sijaintinsa kartalla. Vasta tämän jälkeen kartanlukija voi päätellä suunnan kohteeseen. Tehtävän suorittamisen aikana koehenkilöiden piti ajatella ääneen. Kokeessa kerätyn aineiston avulla selvitettiin, miten GPS vaikuttaa oman sijainnin määrittämiseen tarvittavaan aikaan. Koehenkilöiden tuottamien verbaalisten protokollien avulla tarkasteltiin GPS:n vaikutusta maamerkkisanojen esiintymiseen.

Tulokset ja johtopäätökset: Tulokset viittaavat siihen, että GPS-toiminto nopeuttaa oman sijainnin määrittämistä kartalla ja aiheuttaa laadullisia eroja kartanlukijan ongelmanratkaisuprosesseihin. Koehenkilöiden tuottamien verbaalisten protokollien analyysi osoitti, että GPS-toiminto vähentää maamerkkisanojen esiintymistä. Tulokset viittaavat siihen, että GPS vaikuttaa tapaan, jolla koehenkilöt etsivät kartalta ja ympäristöstä tunnistettavia objekteja, ja kaventaa kartan aluetta, jolta etsitään itsensä paikallistamisen kannalta oleellisia symboleja.

Avainsanat – Nyckelord - Keywords
Ihminen-konejärjestelmät, käytettävyys, kartografia, matkapuhelimet, sulautettu tietotekniikka.

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1. Introduction

Imagine yourself strolling in a forest with only a mobile map to guide your navigation. You notice a small pond and boulders on your right. You look at your mobile map and search for the symbols presenting the pond and the boulders. After finding the symbols, you may locate yourself on the map.

Recently, *topographic maps*, a map type typically used by hikers, have been integrated into mobile devices. Topographic maps are a special type of map that depicts landforms, and other physical objects that are on the ground. In addition to the map, mobile devices may include GPS (Global Positioning System) receivers that enable visualizing the map-reader's location on the map (Raper, Gartner, Karimi & Rizos, 2007).

Self-location on a mobile map is a process by which a map reader determines his or her own position in relation to the symbols on a map (Blades & Spencer, 1987). Determining one's location on a map requires the map reader to recognize *at least* two objects in the environment and their relations to symbols on the map (Aretz & Wickens, 1992; Levine, Jankovic & Palij, 1982; Levine, Marchon & Hanley, 1984; Liben & Downs, 1993; Oulasvirta, Estlander & Nurminen, 2009). However, because the GPS adds only one symbol to the map that has a relation to the environment, the GPS alone does not provide a sufficient amount of information for self-location.

The present thesis studied the effect of GPS on the process of self-location on a mobile map. The thesis presents an experiment employing a combination of the *pointing paradigm* (Oulasvirta et al., 2009; Thorndyke & Hayes-Roth, 1982) and *protocol analysis* (Ericsson & Simon, 1984; 1993). The study indicated that the GPS improved the subjects' performances in self-location and also showed that both the subjects' verbosity and use of GPS influenced the number of landmarks mentioned in the protocols. The results suggest that the GPS narrows the area on the map that needs to be searched to find relevant information for self-location.

2. Self-location on a mobile map

Several researchers have recognized that determining one’s own location on a map is a prerequisite for other map-based tasks (Bluestein & Acredolo, 1979; Ishikawa, Fujiwara, Imai & Okabe, 2008; Liben & Downs, 1993; Lobben, 2004). Because humans necessarily have an orientation (see Klatzky, 1998), self-location is closely connected to determining one’s heading on a map. Only after a map reader has a conception of his or her own location on the map, may he or she proceed to other tasks, such as planning a route to a destination, monitoring that he or she is not lost and deducing the directions to locations displayed on the map (Blades & Spencer, 1987; Board, 1978).

2.1 Map-environment points in self-location

In order to determine one’s location on a map, the map reader has to determine the relations between objects in the environment and the symbols on the map (Liben & Downs, 1993; Oulasvirta et al., 2009). According to Oulasvirta, Estlander and Nurminen (2009) solving the *mapping problem* is a prerequisite for determining one’s location on a map. The mapping problem refers to the process wherein the map reader has to recognize the correspondence between a symbol on the map (e.g. symbol X) and its referent in the environment (e.g. symbol X’). In the present thesis, the objects that are recognizable in the environment and visualized on the map are called *map-environment points.*

However, one map-environment point alone does not provide enough information for self-location. According to the *two-point theorem* (Levine et al., 1982; 1984) the map reader needs *at least* two map-environment points to determine his or her location on the map. Bluestein and Acredolo (1979) have pointed out that also mapping a direction along with one map-environment point may provide the *minimal amount of information* needed for self-location.

The process of recognizing map-environment points consists of two elements: *the visual search* (Wolfe, 1994) for symbols on the map and the evaluation of their *relevance* for the self-location process. In map reading, the visual search on the map refers to the ability to identify the relevant symbols on the map. The *relevance of a symbol* is defined either by the map reader's ability to recognize the symbol's referent objects in the environment from a certain position or by the map reader's memory of landmarks that he or she has recognized earlier. Because the map reader's position and memory of the environment influence how the *symbol's relevance* for map reading is determined, the map reader's location in the space affects the *problem input* (Newell & Simon, 1972) for the self-location task. Figure 1 represents an abstraction of the process of searching relevant map-environment points for the purpose of self-location.

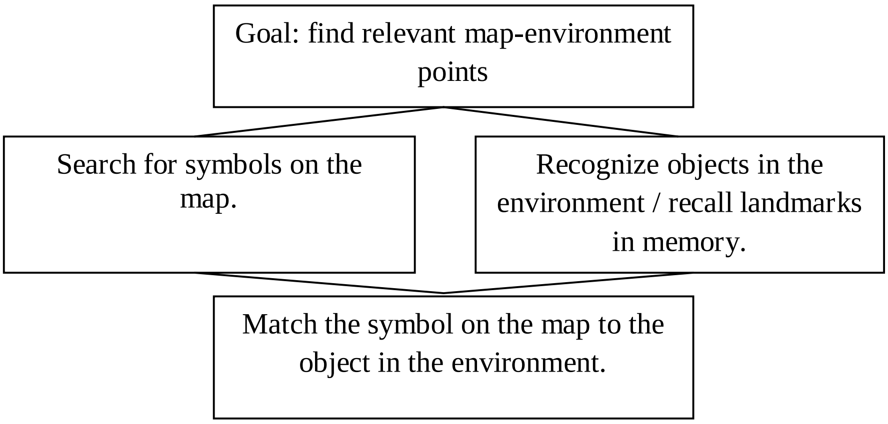

Figure 1. The figure represents an abstraction of the processes involved in finding the relevant map-environment points for self-location. The map reader's goal is to find relevant map-environment points for self-location. This process involves searching symbols on the map and recognizing landmarks in the environment. The relevance of the symbols on the map is determined by map reader's ability to match them to the environment.

Schofield and Kirby (1994) showed that narrowing the search area on the map reduces the time needed to locate oneself on a map. In their study, participants were shown a miniature model of an environment and were asked to locate on a map a target shown in the miniature environment. The study implies that the self-location process is influenced by the visual search for relevant symbols on the map.

Aretz and Wickens (1992) showed that matching an environment and a map requires more cognitive processing in complex environments than in elementary environments. In their study, subjects were shown a pseudo-map displaying arbitrary symbols instead of landmarks and a view of an environment. Subjects were asked to indicate whether the pseudo-map and the environment can be matched together. The tasks were completed the fastest when only three symbols were displayed on the map; the greater the number of symbols shown, the more the reaction time increased. These findings by Aretz and Wickens (1992) may be explained by the number of landmarks presented on the map influencing the difficulty of finding relevant map-environment points for self-location.

The nature of landmarks used in map reading and navigation has been studied mainly in city environments (Denis, Pazzaglia, Cornoldi & Bertolo, 1999; May, Ross, Bayer & Tarkiainen, 2003). The study by Brosset, Claramunt and Saux (2008) showed that the ability to read topographic maps and city maps are based on the recognition of different kinds of objects in the environment. According to Lynch (1960), the consistency of city environments affects the *legibility* and ease of navigation. Conversely, in nature environments, map readers have to rely on recognizing ambiguous landmarks. Since topographic maps do not have a structure defined by humans (as city maps do), the search for map-environment points on topographic maps may be especially demanding.

The formulation of the mapping problem by Oulasvirta et al. (2009) emphasizes that self-location is based on understanding the references between symbols on a map and the objects in the environment. Although the GPS allows for visualizing the map reader's location on the map, it does not provide enough information for self-location. Even if the map reader is able to treat the GPS as one map-environment point, additional information is needed for self-location.

2.2 Effects of GPS on self-location

Liben and Downs (1993) have recognized that self-location on a map requires understanding three kinds of relations between the *self*, the *environment* and the *map*. First, the map reader has to understand his or her own location in the environment and in relation to objects in the environment. This element of self-location is called the *person-space relation*. Second, the map reader has to be able to interpret the correspondences between the map and the environment represented on it. The map reader may establish a *map-space relation* by interpreting the semantic content of the cartographic symbols on the map and their relation to the environment (Bluestein & Acredolo, 1979).

The third component for determining one's location on a map is the *person-map relation*. In order for the map reader to be able to locate himself or herself on the map, he or she has to understand his or her location in the environment (the person-space relation) and the referential relation between the map and the environment (the map-space relation). After understanding these relations, the map reader may proceed with processes called *projection* (Bluestein & Acredolo, 1979) and *structure matching* (Levine et al., 1982). In the process of projection, the map reader has to be able to transform the vertical view of the map into the horizontal view from which the environment is usually viewed. While doing this, the map reader has to preserve the integrity of the features on the map and the spatial relations among them. Because the map and the environment might not be viewed simultaneously, memory factors have a role in projecting the map and the environment presented on it. The process of structure matching is similar to the process of projection. In structure matching, the map reader has to connect specific symbols on the map to the corresponding objects in the environment (Levine et al., 1982; Oulasvirta et al., 2009). As a result of structure matching, the map reader has recognized a set of map-environment points (objects recognizable in the map and in the environment).

The three relations (person-space, map-space and person-map relations) proposed by Liben and Downs (1993) allow for analyzing the possible effects of the GPS on the map reading process (see table 1 for a summary of the possible effects). The first component of the self-location process, the person-space relation, covers only the cognitive processes involved in searching and recognizing the objects and landmarks in the environment. Because the GPS only adds information to the map (and no information to the environment), the person-space component of the self-location process remains uninfluenced by the GPS. Furthermore, the second component in the self-location process, the map-space relation, refers only to the semantic content of the cartographic and pictorial symbols on the map and their relation to the objects and landmarks in the environment. By adding the GPS-based information of the map reader's location to the mobile map, the map reader receives only one additional symbol that has a relation to the environment. The most significant effect of the GPS may be on the third component of the map reading process, the person-map relation. Because the GPS adds information to the mobile map, it may influence the search for map-environment points. More specifically, the GPS may either improve or impair two of the elements involved in searching map-environment points: *the visual search* for symbols on the map and determining their *relevance* for self-location.

Component of the self-location process	**Person-space relation**	**Map-space relation**	**Person-map relation**
Essential features of the component	Map reader's location in relation to the objects in the environment.	Semantic interpretation: understanding the referential relation of the map and environment.	Mapping problem: understanding the relation between a point in the environment (point X) and a point on the map (point X').
Effect of GPS on the component	No effect.	GPS adds one symbol to the mobile map that has a relation to the environment.	GPS may improve or impair the *search* for symbols on the map and the evaluation of their *relevance* for self-location.

Table 1. The three-component model of self-location on a map (Liben & Downs, 1993) and the possible effects of a GPS on the different components.

2.3 Methods of studying real-world map reading

Although there is a large body of literature on wayfinding with maps, only a few studies have addressed the online nature of map reading in real environments (Liben, Kastens & Stevenson, 2002). The existing literature conveys topics such as spatial-knowledge acquisition from mobile maps (Willis, Hölscher, Wilbertz & Li, 2009), the nature of landmarks in urban navigation (May et al., 2003), the schematization of map information (Casakin, Barkowski, Klippel & Freksa, 2000) and visualizing the decision points on a map (Klippel, Tappe & Habel, 2003; Klippel, Tappe, Kulik & Lee, 2005; Klippel, Richter & Hanser, 2006). In general, two kinds of experimental paradigms exist for studying map use in real environments: the *navigation paradigm* and the *pointing paradigm*.

The navigation paradigm has been employed to study the differences between the use of paper maps and GPS-based mobile maps (Ishikawa et al., 2008). In a study by Ishikawa et al. (2008), the participants either learnt the route to a target through experience or they were shown the target on a mobile map or on a traditional paper map. The study showed that the groups with either a traditional map or direct experience outperformed the group with GPS-based mobile maps. The researchers suggest that the impaired performance may result from the GPS continuously updating information on the screen of the mobile device and causing a greater cognitive load for the map reader. This view suggests that the map readers were unable to benefit from the GPS. However, the study by Ishikawa et al. (2008) may be criticized for comparing GPS-based mobile map reading to reading a traditional paper map and thus failing to assess the effect of GPS.

The pointing and navigation paradigms have been combined with *protocol analysis* to study map reading of 2D and 3D mobile maps (Oulasvirta et al., 2009). In the pointing tasks, the subjects were shown a target on either a 2D or a 3D map, and they were asked to indicate the direction to the target. In order to deduce the direction to the target, the map reader has to first determine his or her own location on the map (Thorndyke & Hayes-Roth, 1982). The protocols transcribed from the think-aloud data were used to assess the problem-solving strategies involved in self-location and to analyze the nature of the landmarks used to deduce direction.

Blades and Spencer (1987) have expressed hope that analyzing think-aloud data could be used to study the cognitive aspects of map reading. The protocols transcribed from the think-aloud data can be analyzed in multiple ways. When the structure of the problem solving activity is examined, excerpts from the protocols are compared to an abstract model of the problem-solving activity (see Ericsson & Simon, 1984, 1993; Newell & Simon, 1972). When the data is used to assess the content of the mental representations, the excerpts are categorized and the number of excerpts in the categories is quantified (*the quantifying qualitative data approach* proposed by Chi 1997). The quantifying qualitative data approach resembles the *content analysis* method that is used in the social sciences to study the content of communication (Krippendorf, 1980; 2003). Content analysis may be used to quantify the appearance of certain utterances (words, phrases, etc.) in texts. Chi (1997) has pointed out that since subjects vary regarding how verbose they are, verbal analysis should concentrate more on *what* the subjects say than on *how much* they say in general. This may be done, for example, by controlling for the general level of verbosity in the analyses.

3. Aims of the study

The aim of the present study was to assess the effect of GPS on the cognitive processes involved in determining one's location on a map. The earlier research identified that searching for map-environment points is an essential element of the process of determining one's location on a mobile map. Because the GPS adds a symbol to the map that has a semantic relation to the environment, the GPS may influence the search for map-environment points. To investigate whether the GPS impairs or improves the search for map-environment points, three research questions are formulated:

> *Q1. Does GPS influence the time needed to locate oneself on a map?*

If the GPS impairs the search for map-environment points, the time needed to determine one's location on a map will be increased. However, if the GPS improves the search for map-environment points, the GPS will reduce the time needed to locate oneself on a map.

> *Q2. Does the GPS influence the number of map-environment points needed for self-location?*

If the map readers are unable to exploit the information provided by the GPS, the number of map-environment points needed in self-location will be unaffected by the GPS. On the contrary, if map readers benefit from the GPS, it will reduce the number of map-environment points needed in self-location.

> *Q3. Does the use of GPS change the way map-environment points are searched?*

The search process involved in finding the relevant map-environment points for self-location may be either improved or impaired by the GPS. If the time needed to perform self-location and if the number of map-environment points needed in the process either decreases or is unaffected by the GPS, the GPS does not influence the search for map-environment points. However, if the GPS decreases the time needed for self-location and the number of map-environment points, it may be concluded that the GPS guides the search for map-environment points.

4. Methods

The previously introduced pointing paradigm was modified to meet the purposes of the present study. The present experiment was organized in a nature environment, and the map application used in the study displayed topographic maps of the experimental area. Half of the tasks were performed with the GPS on, and in the other half of the tasks the GPS was switched off.

4.1 Map application and navigational aids used in the study

A prototype version of the iUbiMapper map application software was used as a research platform in the study. The application was developed at the Finnish Geodetic Institute (FGI) as part of the UbiMap -research project. The iUbiMapper application works on Apple iPhone mobile devices.

The map views are manipulated using the touch-screen function of the Apple iPhone 3GS. The map views can be scrolled by moving a finger on the screen. The application can display maps on six different scales (1:2362, in which one centimetre on the map corresponds to approximately 23.62 meters in the environment, as well as 1:4724, 1:9449, 1:18898, 1:37795, and 1:75591). The map can be zoomed in by double clicking the screen with a finger and can be zoomed out by touching the screen with two fingers at the same time.

The iUbiMapper application includes a GPS function, which enables visualizing the map reader’s location with a red symbol. Around the symbol, a circle is displayed. The diameter of the circle around the GPS -symbol displays how accurately the application can determine the map reader’s location.

The subjects were also provided with a Suunto A30 Scout compass. This was done to make the experiment resemble traditional map reading in nature environments.

4.2 Site of the experiment

The experiment was conducted near Lake Halkolampi in Nuuksio National Park. Nuuksio National Park is located in the capital region of Finland, and the distance from Helsinki to Halkolampi is approximately 30 kilometres.

4.3 Participants

Twelve subjects participated in the study. The subjects were recruited from the emailing list of a university student scouting organization. Since the map software used in the study lacked a legend that would explain the meaning of the symbols and characters on the map, only subjects who had experience in reading topographic maps were recruited.

The subjects were on average 24 years old, and eight of them were female. The subjects' self-reported map reading skill was on average good (on scale 1-5 where 4 indicated good map reading skills). Three subjects reported that they use a smart phone daily, eight subjects reported that they never use a smart phone, and one subject reported that she uses a smart phone yearly (see appendix 1 for more details about the subjects). All subjects spoke Finnish as their mother tongue, and the verbal data recorded in the experiment was in Finnish.

4.4 Pointing tasks

In the present study, subjects were shown a target on a map and asked to indicate the direction to the target. The subjects were instructed to think aloud while performing the task. In all pointing tasks, the target was marked on the map with a green symbol (⌘). To be sure that the subjects had recognized the target and located themselves on the map correctly, subjects were asked to report the cardinal direction (north, east, south, west) or intercardinal direction (north-east, south-east, south-west, north-west) to the target.

The experiment was a 2×2 within-subject design. The conditions in the experiment were the following:

- *Distance to the target*: Half of the pointing tasks were *proximate pointing tasks,* and half of them were *remote pointing tasks*. In the proximate pointing tasks, the target was visible from the actual site where the task was performed. In the remote pointing tasks, the target was not visible from the actual task site.
- *GPS condition*: Half of the pointing tasks were performed with the GPS switched on (*GPS*), and half of the pointing tasks were completed with the GPS switched off (*no GPS*).

4.5 Sites, targets and pairs

In figure 2, the circles represent the *actual sites* where the pointing tasks were performed in the experimental area. The arrow heads indicate the locations of the targets that were shown to the subjects on the mobile map.

To control the order of the tasks, the pointing tasks were divided into four pairs (pairs A, B, C and D in figure 2). Each pair contained one proximate pointing task and one remote pointing task. In pairs A and C, the subjects performed the proximate pointing tasks before the remote pointing tasks, and in pairs B and D, subjects performed the remote pointing tasks before the proximate pointing tasks.

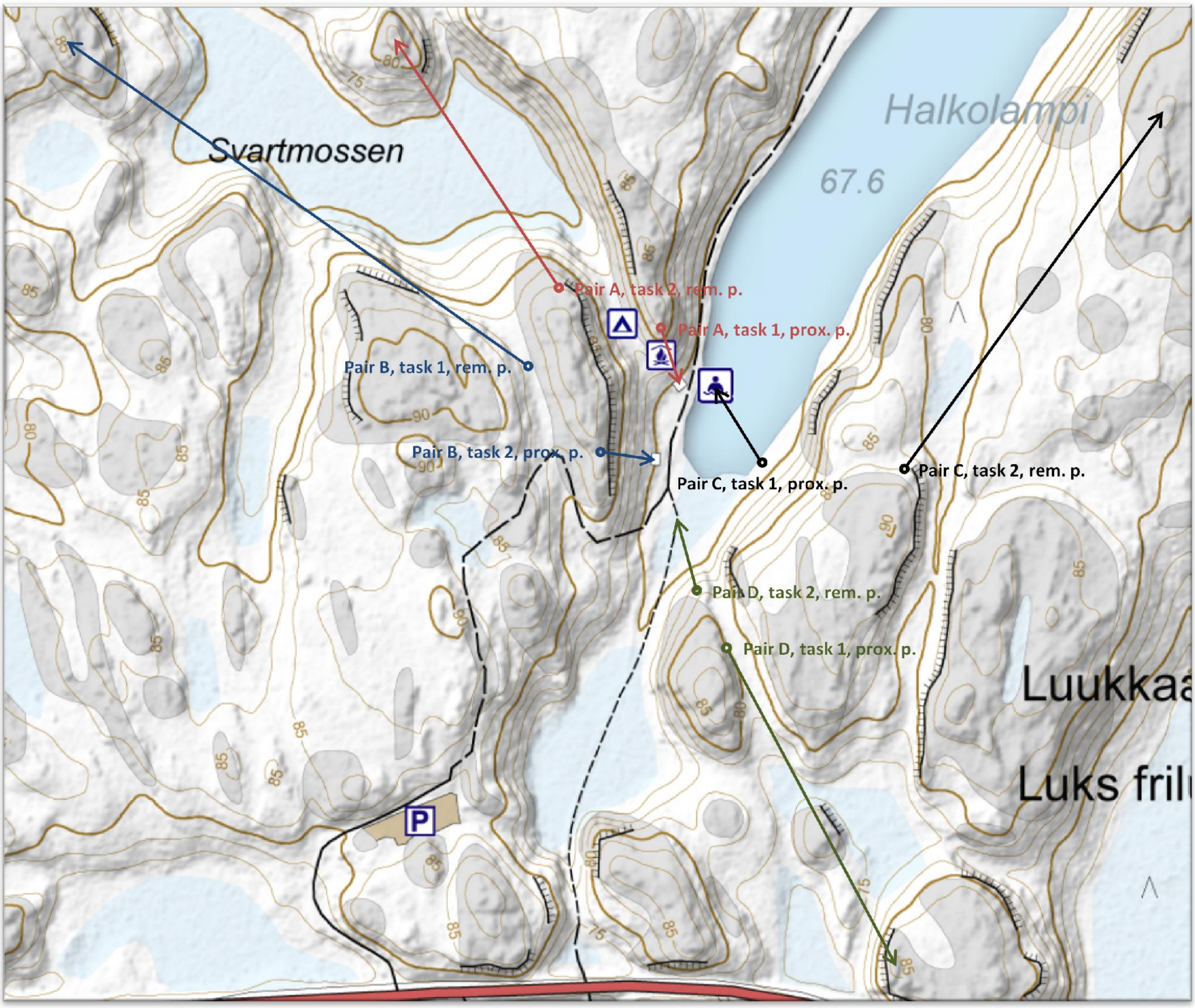

Figure 2. The *actual sites* where the pointing tasks were performed are marked with circles. The arrows point to the targets' locations. The pointing tasks were divided into four pairs. The red sites and arrows refer to pair A, the blue circles and arrows refer to pair B, black ones to pair C and green ones to pair D.

The order of the pairs was balanced using the following manipulations (see appendix 1 for a summary):

- Five subjects performed pairs A and B with the GPS, seven subjects performed pairs A and B without the GPS.
- Six subjects performed the pointing tasks in pair A before those in pair B, and six subjects performed the pointing tasks in pair B before those in pair A.
- Six subjects performed the pointing tasks in pair C before those in pair D, and six subjects performed the pointing tasks in pair D before those in pair C.

These manipulations of the execution order and of the experimental conditions resulted in eight different configurations. With only twelve subjects, balancing the number of subjects in each configuration was impossible.

4.6 Procedure

Before the actual pointing tasks, subjects performed two practice tasks: one proximate pointing task with the GPS switched on and one remote pointing task without the GPS. The aim of these tasks was to familiarize the subjects with the iUbiMapper application and to have them practice thinking aloud.

After completing the practice tasks, the subjects were escorted to a site where a pointing task was then performed. The pointing task started when the mobile device was handed to the subject and was stopped when the subject gave the mobile device back. After each pointing task, the subjects were escorted to the next site.

During the pointing tasks, subjects were allowed to manipulate the map view by zooming in and out and by moving the map on the mobile device's screen. Before a new pointing task was started, the mobile application was reset: the scale of the map was set to 1:37795, and the map was centred (Lake Halkolampi was at the centre of the map).

If subjects were silent for longer than twenty seconds, the experimenter reminded them to start thinking aloud again. No feedback on how well the subjects performed was given during the experiment.[1]

4.7 Recording apparatus

Data were recorded using a digital voice recorder and a video camera. A microphone connected to the recorder was placed close to the subject's mouth to

[1] During the trials, the supervisor only answered questions concerning the pointing task instructions and how the map view could be manipulated.

store the think-aloud data. The experimenter videotaped the subject's movement while he or she was performing the pointing tasks.

4.8 Preprocessing of the data

The subjects' verbal data were transcribed word-for-word from the audiotapes. The information from the videotapes was used to exclude the pointing tasks in which the subjects moved from the actual site (eleven tasks, seven in no-GPS conditions and four in GPS conditions) because in these tasks the experimental conditions would have varied between the subjects.

As is often the case in field experiments, loss of data occurred. Specifically, the voice recording system turned out to be unreliable, and some tasks from the first three subjects were not recorded due to technical problems. However, in these cases, the think-aloud protocols were transcribed from the videos.

The direction from the actual site to the target and the directions reported by the subjects were compared[2]. The tasks in which the reported direction was incorrect were excluded from the analysis (three tasks, all in no-GPS conditions). With these losses, 82 tasks (38 in no-GPS conditions, 44 in GPS conditions) were analyzed.

[2] Sometimes subjects reported the direction ambiguously (e.g. a subject might report that the target is "somewhere south-east or south"). In this kind of situation, the reported direction was defined as correct if the subjects mentioned the right direction.

5. Data analysis

Data from the pointing tasks consisted of two measures: *the time needed to perform the task* and *the number of landmark concepts in the protocols*. The time needed to perform each task was used to assess performances in the pointing tasks. The qualitative data from the think-aloud protocols was used to analyze *how* the GPS changed the strategies used to solve the pointing tasks.

The time needed to perform the pointing tasks was assessed from the audiotapes. This was done by calculating the time from the subject's first word (after the experimenter gave the mobile device to the subject) until the subject's last word (before he or she handed the mobile device back to the experimenter).

The number of landmark concepts in the protocols mentioned while performing the pointing task was measured. These concepts are words referring to objects that can be recognized both on the map and in the environment. The landmark concepts were divided into seven categories (roads and paths; buildings; water and lakes; hills and elevation; vegetation; compass; GPS). Concepts referring to the use of the compass and to the GPS were treated as landmark concepts because they can be used as one point connecting the map to the environment represented on it (this can be done, for example, by using the compass to align the map to the direction the subject is facing). The landmark concepts were first identified in Finnish language (see appendix 2 for a full list of the landmark concepts), and later translated to English (see table 2 for a summary).

Category	Landmark concepts in English
Roads and paths	Roadway, big road, car park, path, road, path, crossing, road branch, trail.
Buildings	Cooking shelter, dry toilet, shelter, shed, hut, table, building, woodhouse, tent site, fireplace, toilet.
Water and lakes	Lake, pier, pond, shore, shoreline, (the bay) Halkolahti, (the lake) Halkolampi, beach, opposite shore, water.
Hills and elevation	Ridge, crag, rock, cliff top, cliff, hill, mound, valley, slope, hillside, wall, mountain.
Vegetation	Rock, forest, (a swamp) mossen, (the swamp) Stormossen, swamp, (the swamp) Svartmossen.
GPS	GPS.
Compass	Compass.

Table 2. The table summarizes the landmark concepts that were identified from the think-aloud protocols. A full list of the landmark concepts, in Finnish, identified in the protocols is in appendix 2.

5.1 Statistical analyses

The effect of two factors and one covariate on *the time needed to perform the pointing task* and on *the number of landmark concepts in the protocols* were analyzed:

- *GPS condition* refers to the experimental conditions in which the mobile device's GPS function was either switched on (GPS) or off (no GPS).
- *Distance to the target* refers to the experimental conditions in which the target was either visible (proximate pointing task) or out of sight (remote pointing task) from the actual site where the pointing task was performed.
- *Verbosity* refers to the total number of words in the protocols. Since the subjects might vary regarding how much they tend to speak during the tasks, the verbosity was used as a covariate in the analyses.

The data from the experiment included several observations from each subject, and thus the observations cannot be considered to be independent from each other. To treat the correlation between the observations, the statistical analyses were performed using a *linear mixed model* (LMM), which includes a *fixed effect part* and *random effects part*. The fixed effect part of the LMM accounts for the influence of the independent variable data (GPS condition, distance to target, verbosity), whereas the random effects part of the LMM accounts for subject-to-subject variation. The LMM permits the inclusion of multiple measurements from one subject and for missing data, thereby increasing statistical power while controlling for within-individual variation.

The dependent variable data, *the time needed to perform the task* and *the number of landmark concepts*, were entered into an LMM. In these analyses, the factors *GPS condition* (two levels: GPS, no GPS) and *distance to the target* (two levels: proximate pointing and remote pointing) and the covariate *verbosity* were assessed.

To analyze how the GPS influenced *the time needed to perform the pointing tasks*, the following LMM analysis was computed:

- What is the effect of *GPS condition* (two levels), *distance to the target* (two levels) and *verbosity*, and the interactions between these variables, on *the time needed to perform the pointing tasks*?

To assess the qualitative effect of the GPS on the way the pointing tasks were performed, the following statistical analysis was computed:

- What is the effect of *GPS condition* (two levels), *distance to the target* (two levels) and *verbosity*, and the interactions between these variables, on *the number of landmark concepts in the protocols*?

6. Results

The analysis of the time needed to perform the tasks indicated that subjects needed more time to perform the pointing task when the GPS was off. The analysis of the number of landmark concepts in the protocols showed that there were qualitative differences in the protocols between the GPS conditions.

6.1 Time needed to perform the pointing tasks

In the LMM, the main effect for the covariate verbosity on *the time needed to perform the pointing task* reached the level of statistical significance ($F(1, 39)=11.377$, $p=0.002$). Figure 3 depicts the linear dependency between verbosity and *the time needed to perform the task*. The cross symbols represent *the mean time needed to perform the pointing task* at four points of the verbosity data (62, 81, 102, 404). These data points correspond to 25, 50, 75 and 100 percentiles of the verbosity values.

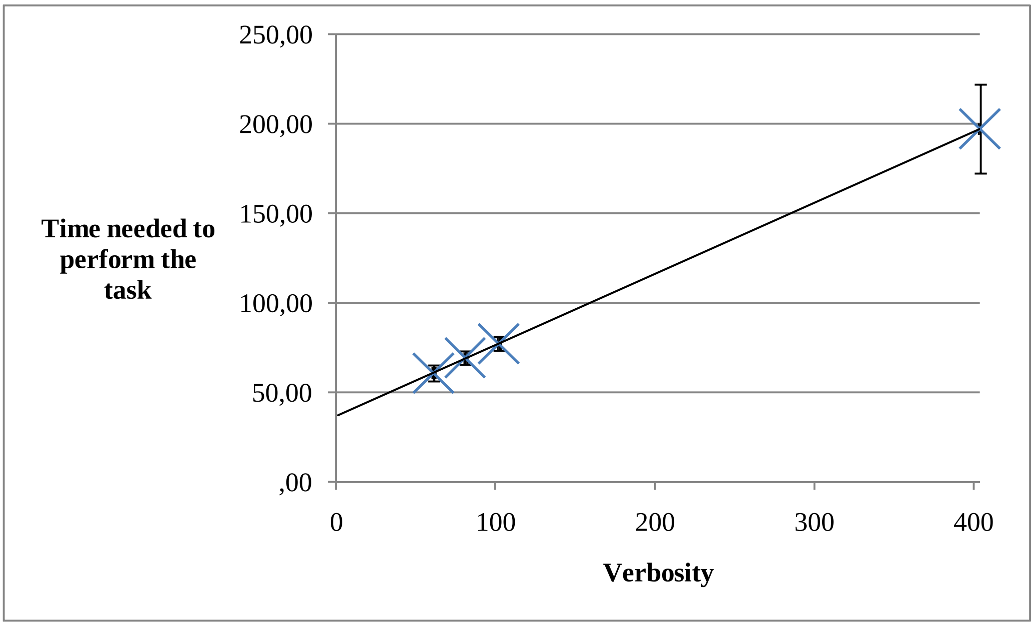

Figure 3. A linear model of *the time needed to perform the pointing task* in seconds (y-axis = 0-250) as a function of the verbosity data. The error bars display the standard error of the mean in the data points. The regression line is based on the LMM. The standard errors of the means are computed by comparing the estimations derived from the LMM to the data from the experiment.

Furthermore, the main effect for the factor GPS condition on *the time needed to perform the task* almost reached the level of statistical significance ($F(1,65)=3.470$, $p=0.067$). The mean time needed to perform the pointing task was shorter in GPS condition (mean=69.7 s) than in no-GPS condition (mean=80.5 s).

No other main effects or interactions reached the level of statistical significance on the time needed to perform the task.

6.2 The number of landmark concepts in the protocols

In the LMM, the main effect for the factor verbosity reached the level of statistical significance on *the number of landmark concepts in the protocols* ($F(1,75)=55.484$, $p<0.001$). Figure 4 displays the linear dependency between verbosity and *the number of landmark concepts in the protocols*. The cross symbols in figure 4 represent *the number of landmark concepts* at four points of the verbosity data (62, 81, 102, 404). These data points correspond to 25, 50, 75 and 100 percentiles of the verbosity values.

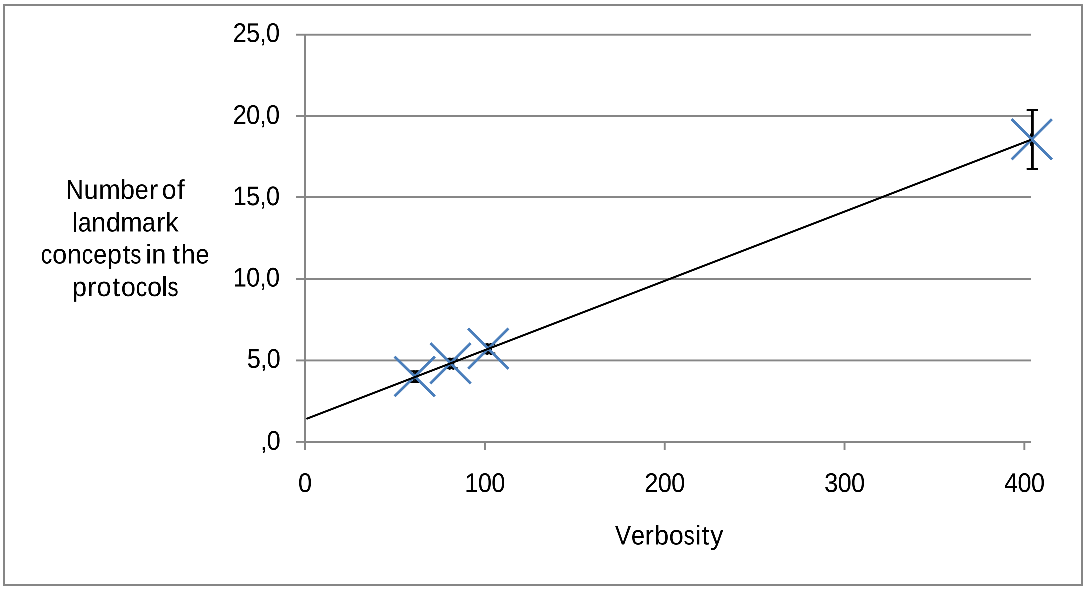

Figure 4. A linear model of *the number of landmark concepts* (y-axis 0-25) as a function of the verbosity data. The error bars display the standard error of the mean in the data points. The regression line is based on the LMM. The standard errors of the means are computed by comparing the estimations derived from the LMM to the data from the experiment.

The factor distance to the target had a statistically significant effect on *the number of landmark concepts in the protocols* (F(1,75)=4,845, p=0.031). The subjects mentioned, on average, fewer landmark concepts in the remote pointing tasks (mean=4.8) than in the proximate pointing tasks (mean=5.9).

The interaction between the factor GPS condition and the covariate verbosity reached the level of statistical significance on *the number of landmark concepts in the protocols* (F(1,75)=5.806, p=0.018). Figure 5 displays the linear dependency between *the number of landmark concepts in the protocols* and the verbosity in the no-GPS and GPS conditions. In addition to the linear model, figure 5 depicts *the mean number of landmark concepts in the protocols* in the no-GPS and GPS conditions at four points of the verbosity data (61, 81, 102, 404). These data points correspond to the 25, 50, 75 and 100 percentiles of the verbosity values.

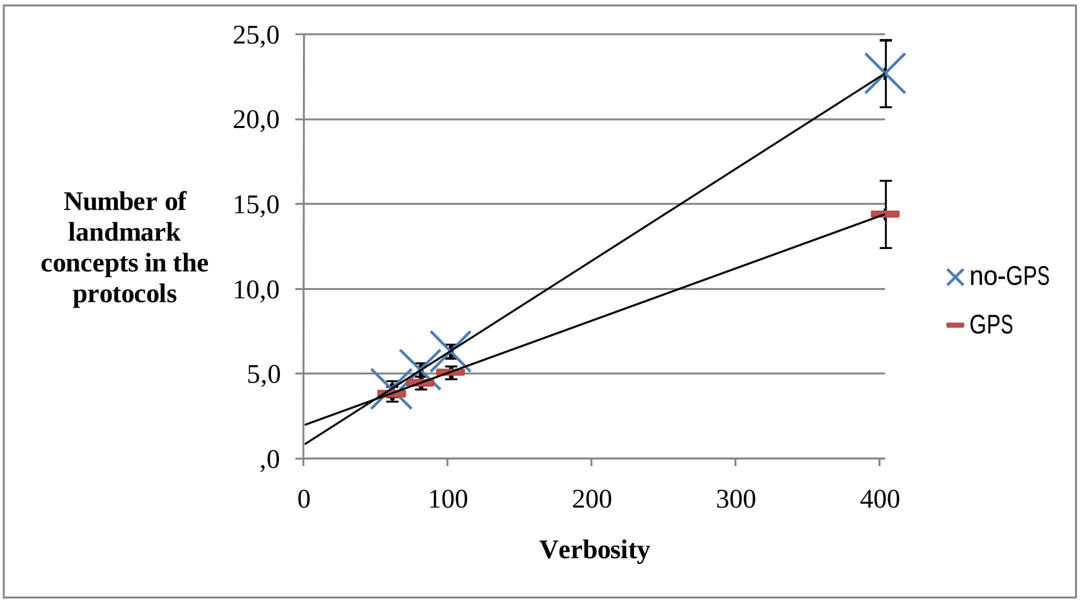

Figure 5. A linear model of *the number of landmark concepts in the protocols* (y-axis 0-25) as a function of the verbosity data and GPS conditions. The error bars display the standard error of the mean in the data points. The regression line is based on the LMM. The standard errors of the means are computed by comparing the estimations derived from the LMM to the data from the experiment.

No other main effects or interactions reached the level of statistical significance on the number of landmark concepts mentioned in the protocols.

7. Discussion

The present study was conducted to assess the effect of GPS on self-location on a mobile map. The study is based on the view that determining one's location on a map requires the map reader to recognize points in the environment that can be connected to the map.

The results showed that the subjects' verbosity had the strongest effect on two of the measures recorded in the experiment: *the time needed to perform the pointing task* and *the number of landmark concepts in the protocols*. After controlling the effect of subjects' verbosity, the statistical analyses indicated that the GPS also reduced the time needed to perform a pointing task. Moreover, the statistical analyses revealed that in addition to verbosity, the GPS influenced the number of landmark concepts in the protocols.

7.1 Research questions

The results from the present experiment allow answering the research question posed in chapter 3.

> *Q1. Does GPS influence the time needed to locate oneself on a map?*

Yes. The results indicated that the GPS may decrease the time needed to perform the pointing tasks. If the pointing task is considered to consist of two phases (*locating oneself on the map* and *deducing the direction*) the GPS can be seen to affect only *the self-locating phase* of the task.

> *Q2. Does the GPS influence the number of map-environment points needed for self-location?*

Yes. The interaction between verbosity and the GPS condition had a significant effect on the number of landmark concepts in the protocols. In most cases (more than 75% of the data), the number of landmark concepts in the protocols was lower in the GPS conditions than in the no-GPS conditions. This difference suggests that the GPS reduces the number of map-environment points needed to locate oneself on a map.

> *Q3. Does the use of GPS change the way map-environment points are searched?*

Yes. The results from the present study indicated that *the time needed to perform the pointing tasks* is reduced by the GPS. Furthermore, the results showed that *the number of landmark concepts* increases as a function of the *verbosity* more steeply in no-GPS conditions than in GPS conditions. Even though, verbosity has a significant effect on the number of landmark concepts in the protocols; their number is also dependent on the GPS condition. In general, the number of landmark concepts is lower in the GPS conditions than in the no-GPS conditions. These findings suggest that map readers are able to more efficiently find the map-environment points needed in self-location when the GPS is used.

7.2 GPS guiding the search for map-environment points

The present study indicated that adding a symbol that shows the map reader's location on a map improves the performances in the self-location tasks and reduces the number of landmark concepts in the protocols. These findings imply that the GPS helps the map readers in solving the mapping problem (Oulasvirta et al., 2009) and understanding the person-map relation (Liben & Downs, 1993). The effects may be mediated by the GPS improving the search for map-environment points and evaluation of their relevance.

More specifically, the results from the present study suggest that the GPS guides the search for map-environment points and narrows the search area on the map. This theory is in line with the study by Schofield and Kirby (1994). In their study, subjects were shown a location on a miniature model of a landscape, and they were asked to show the location of a target on a topographic map. The reaction time was reduced when the area on the map where the target may have been located was reduced.

According to a study by Willis et al. (2009), mobile map reading leads to a more fragmented and regionalized knowledge representation of the space than reading a traditional paper map. Willis et al. (2009) suggest that the small screens of mobile devices might be one of the factors causing the “local” focus of attention during mobile map reading. The present study also suggests that the use of a GPS might strengthen the local focus of attention in mobile map reading.

Furthermore, in the present study subjects mentioned on average more than two landmark concepts while performing a pointing task. This finding together with the findings by Aretz and Wickens (1992) imply that the two-point theorem (Levine et al., 1982; 1984) should be considered as expressing the minimal computational principles that govern the process of self-location on a map rather than be a psychologically realistic description of how self-location is carried out. In their study, subjects were shown pseudo maps displaying arbitrary symbols instead of landmarks and a view of an artificial environment. Subjects were able to connect the view to the pseudo-map the fastest when only a few symbols were displayed on the map. The more symbols were displayed, the more the reaction time increased.

7.3 Implications for the design of mobile map applications

The idea that a GPS narrows the search area on a map has implications for the design of mobile map applications. According to the present study, self-location on a map requires the map reader to search the symbols that are located near the subject’s positions on the GPS and connect them to the corresponding objects in the environment. However, in real-world map-reading tasks, the map reader may have to switch quickly between multiple tasks (e.g. self-location and route planning). When the information requirements for the different tasks change, the map reader has to zoom and scroll the map to find the relevant information for each task. The manipulation of the map may cause an increased cognitive load to the user, especially when the maps are displayed on the small screen of a mobile device.

The present study suggests that combining *large-scale* and *small-scale maps* may help to reduce the cognitive load caused by the different map-based tasks. These kinds of approaches for mobile map applications have been implemented, for example, in the *wired fisheye lens* map interface (Carswell, Fotheringham, McArdle, Yamamoto, Ozeki & Takahashi, 2009) and in the *variable-scale* approach for small-display cartography (Harrie, Sarjakoski & Lehto, 2002).

7.4 Limitations and further research

Even though the present study allows for drawing conclusions about the effects of a GPS on the cognitive processes involved in self-location on a mobile map, future research should take certain considerations into account. First, the results of the present study showed that the GPS had *an almost significant effect* ($p<0.10$) on the time needed to perform self-location. Recruiting more subjects and gathering more data might increase the power of the statistical analyses. Second, the present study did not employ methods to record how the subjects manipulated the map view. Because the GPS might influence how map readers zoom and scroll the map, methods for recording these interactions with the mobile device are needed. Third, in the present study, the subjects' orientation in the environment was not controlled. Because organisms necessarily have a location and an orientation in space (see Klatzky, 1998), orientation is also an important factor affecting self-location on a map. Controlling the effects of orientation would ensure that a misalignment of maps with the environment does not influence the experimental data (Levine et al., 1982; Levine et al., 1984; Shepard & Hurwitz, 1984). Fourth, the present study showed that subjects' verbosity influenced the time needed to perform the pointing tasks. In future studies, it may be beneficial to control the effect of thinking aloud on subjects' performance. This may be done, for example, by using the *retrospective* think-aloud method instead of the *concurrent* think-aloud method. In retrospective think-aloud, the subjects are asked to verbalize their thoughts after they have performed the task. Using this kind of method would ensure that the time needed to perform the task is not dependent on the subject's verbosity.

8. Conclusions

The present thesis showed that even with the additional information provided by the GPS, the self-location process is governed by the search for map-environment points. The present study falsified the assumptions that the GPS either would not affect or would impair the map-reading process. Furthermore, the study suggested that the GPS might guide the search for map-environment points and help map readers to determine their relevance for self-location.

The narrowed-search theory can be seen to have implications for the design of mobile map applications. For instance, since map readers concentrate more on the area displayed around the GPS, this area should be visualized in more detail than the remaining map area. However, because the field of HCI research on mobile map reading is still emerging, the present study and the implications drawn from it may serve merely as a first step towards integrating cognitive research concerning map reading and the design of mobile map applications.

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Appendices

Appendix 1:. A list of the subjects in the present study.

Subject's age	Sex	Self-reported skill in map reading	Smart-phone usage	Subject's route
29	Female	Average	Never.	AB(GPS)-CD
27	Male	Good	Daily	AB-DC(GPS)
26	Male	Average	Never	AB(GPS)-DC
26	Male	Good	Daily	BA(GPS)-CD
26	Male	Good	Daily	BA-CD(GPS)
28	Female	Very good	Never	BA-DC(GPS)
21	Female	Average	Never	BA-DC(GPS)
21	Female	Good	Never	AB(GPS)-CD
20	Female	Good	Never	AB-CD(GPS)
21	Female	Weak	Never	AB-DC(GPS)
22	Female	Average	Never	BA(GPS)-CD
26	Female	Average	Yearly	BA-DC(GPS)
mean = 24.4				

Appendix 2: A full list of the landmark concepts in the protocols in Finnish.

Category	Landmark concepts in English	Landmark concepts in Finnish
Roads and paths	Roadway, big road, car park, path, road, path, crossing, road branch, trail	AUTOTIEN, ISOTIE, PARKKIPAIKKA, POLKU, POLKUA, POLKUJEN, POLKUKIN, POLKUU, POLULLA, POLULLE, POLULTA, POLUN, POLUNHAARA, POLUSTA, TEITTEN, TIE, TIEN, TIETÄ, POLKU, POLKUA, POLKUJEN, POLKUKIN, POLKUU, POLULLA, POLULLE, POLULTA, POLUN, RISTEYS, RISTEYKSEN, RISTEYKSESSÄ, RISTEYKSESSÄKÄÄN, RISTEYKSESTÄ, RISTEYSKIN, RISTEYSTÄ
Buildings	Cooking shelter, dry toilet, shelter, shed, hut, table, building, wood house, tent site, fireplace, toilet	GRILLIKATOKSELT, GRILLIKATOKSELTA, GRILLIKATOKSEN, GRILLIKATOKSET, GRILLIKATOS, GRILLIKATOSRAKENNUS, HUUSI, HUUSIN, HUUSIST, HUUSI, HUUSIN, HUUSIST, KATOKSEN, KATOKSESSA, KEITTOKATOKSEEN, KEITTOKATOS, NUOTIOKATOKSEN, NUOTIOKATOS, NUOTIOPAIKALLA, NUOTIOPAIKAN, NUOTIOPAIKKA, NUOTIOPAIKKAKIN, NUOTIOPISTE, MÖKISTÄ, MÖKKERÖST, MÖKKI, MÖKKII, PÖYTÄ, RAKENNUKSEN, RAKENNUKSIA, RAKENNUS, HALKOMAJA, TELTTAKOHTA, TELTTAPAIKALTA, TELTTAPAIKAN, TELTTAPAIKKA, TULIPAIKKA, TULISIJA, VESSA
Water and lakes	Lake, pier, pond, shore, shoreline, (the bay) Halkolahti, (the lake), Halkolampi, beach, opposite shore, water	JÄRVEKSI, JÄRVEN, JÄRVENRANNAN, JÄRVESTÄ, JÄRVI, LAITURI, LAITURIA, LAITURILLA, LAITURIN, LAMMELLE, LAMMEN, LAMMENKAISTALEEN, LAMMENRANNAN, LAMMESTA, LAMPEA, LAMPI, LAMPIKIN, LÄNSIRANNALLA, NIEMENNOKAN, RANNALLA, RANNAN, RANNAS, RANNASSA, RANTA, RANTAVIIVA, HALKOLAHTI, HALKOLAMMEN, HALKOLAMPI, UIMALAITURI, UIMAPAIKAN. UIMAPAIKKA, UIMAPAIKKAA, UIMARANNALLE, UIMARANNAN, UIMARANTA, UIMARANTAA, UIMARANTOJA, VASTARANNALLA, VEDESSÄ, VETTÄ, VESI
Hills and elevation	Ridge, crag, rock, cliff top, cliff, hill, mound, valley, slope, hillside, wall, mountain	HARJANTEELLA, HARJANTEEN, JYRKÄNNE, JYRKÄNNETTÄ, JYRKÄNTEELLÄ, JYRKÄNTEEN, JYRKÄNTEESTÄ, JYRKÄNTEIDEN, KALLIOIDEN, KALLIOILLA, KALLIOITA, KALLIOKIELEKE. KALLIOKIELEKKEEN, KALLIOKIN, KALLIOLLA, KALLION, KALLIOSTA. KALLIOT, KUKKULA. KUKKULAA. KUKKULALLA, KUKKULAN, KUKKULAT, KUKKULOITTEN, KUMPAREEN, KUMPAREET, KUMPARETTA, KURU, KURUA. KURUN, LAAKSO, LAAKSOSSA, MÄEN, MÄENRINNETTÄ. MÄKI, NYPPYLÄLLÄ, NYPPYLÄN, NYPPYLÄÄ, RINTEELLÄ. RINTEEN. RINTEESSÄ, SEINÄMÄÄN, VAKO,. VAOLLA, VUOREN
Vegetation	Rock, forest, (a swamp) mossen, (the swamp) Stormossen, swamp, (the swamp) Svartmossen	AVOKALLION, METSÄPOHJAN, METSÄÄN, MOSSEN, STORMOSSEN, SUO, SUOALUA, SUOKSI, SUON, SVARTMOSSEN, SVARTMOSSENIN, SVARTSMOSSEN
GPS	GPS	PAIKANNIN, PAIKANNINTA, PAIKANNUS, PAIKANNUSPISTE, PAIKANNUSTA, PAIKANNÄYTTÄJÄ, PAIKANOSOTTIMEEN
Compass	compass	KOMPASSI, KOMPASSIA, KOMPASSIMERKIN, KOMPASSIN, KOMPASSISTA