Map Design for Mobile Display

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Abstract

How to effectively represent spatial information on handheld mobile devices is a key question given the increasing use of personal digital assistants (PDAs) and cellphones concurrent with the development of location-based services. The mobile use of digital maps on small displays presents new capabilities and challenges that differ from using paper maps in a mobile setting or viewing digital maps on a desktop computer. This research addresses these issues through a pilot study that evaluates maps on a mobile device used for a field-based task. Map representations at two levels of generalization were compared by analyzing subject performance in an on-foot route-following task with a handheld computer used as a navigation aid. In examining subject time and accuracy as well as interaction with the mobile device during the task, the results carry implications for map design for small, mobile displays and identify factors that affect the use of maps while moving. Maps are and will increasingly be used on small displays in mobile contexts for a variety of purposes and in many different environments. The requirements and preferences of mobile users, as well as how these maps are used in different contexts, must be understood in order to inform effective designs.

1. Introduction

Understanding what makes maps effective for small displays and how users interact with digital maps on handheld devices such as personal digital assistants (PDAs) and cell phones is critical to map design for mobile computing. Mobile GIS displays allow users to zoom in and out, to add or remove data layers, to change the appearance of the display, and even to modify the dataset itself. New capabilities resulting from mobility, ranging from the ability to interact with data to taking complex datasets into the field, give greater flexibility to maps and mapmakers. How people use these capabilities while actually engaged in mobile activities, whether as a sightseeing tourist or data-collecting researcher, needs to be understood in order to inform map design for these devices.

This research reports on a pilot study that examined subjects' performance during an on-foot navigation task with a handheld computer. Subjects followed routes marked on maps at two different levels of generalization, an aerial photograph and a classified, simplified version of the aerial photo. One focus of the experiment was to evaluate the level of map generalization with regard to three dependent variables: time to route completion, amount of map browsing, and accuracy in following the route. The statistical analysis indicates that the generalized map performed better than the aerial photograph, with significantly shorter time to route completion, and the use of fewer zoom levels and fewer zoom changes.

A second focus considered subjects' spatial abilities, familiarity with the study area, and experience with maps and mobile technology. Examining these factors with subjects' performance begins to address questions regarding user behavior with maps on handheld devices. What do patterns of map browsing reveal about how users behave when disoriented? Are there consistencies in the types and amounts of errors that people make, and how is error related to spatial ability? When characteristics of subjects, especially spatial ability, are included in the analysis, the conclusion that the generalized map was more effective is called into question. Overall, the results point to a variety of factors that affect the use of a mobile map, as well as a large variation in the way individuals interact with a digital map on a handheld device.

Representations starting at the least-generalized end of a representation spectrum were chosen for this study: a photorealistic image and a manually-created generalized map. A color aerial photograph at a scale of 1:12,000 was scanned to digital format and used as one display condition. Taken 14 months prior to the study, it portrays the actual environment in terms of detail and color, with no cartographic design applied. The generalized map is a classified and simplified version of the aerial photograph, created by manually tracing all readily-distinguishable landscape features in a GIS, then color-coding the polygons according to feature type: buildings, sidewalks, grass and other vegetation, trees, paved roads, sand and water. The objective was to evaluate two representations that were equivalent in feature information, with the only difference in the level of generalization being a reduction of detail and classification of features.

The use of the aerial photograph for this study represents a baseline, or even the “worst case” scenario in terms of map design, since there has been no design applied. Comparing the results with a generalized version of the same dataset, in which basic techniques of classification of feature types and simplification of detail have been used to create the map, the differences are attributable to the level of generalization, rather than other design factors, such as labels or symbology, that would be present in a map created by a cartographer. In addition, with aerial photography and high-resolution satellite imagery widely and increasingly available to the public, it is a convenient type of dataset to use as a map or backdrop image for a variety of purposes. In terms of its value as a realistic representation style, it has been argued (Bishop 1994) that the general public is more comfortable viewing realistic maps than generalized maps, since interpreting a realistic, hence familiar, scene is more intuitive than interpreting an abstract scene, especially to an inexperienced map user. The National Park Service has been moving towards more realistic maps since the 1980s, for example, incorporating texture and relief detail from aerial photography in order to make more user friendly maps for park visitors (Patterson 2002). However, depending on the purpose of the map, and in this case for use in a mobile, navigational context, the high level of detail in the aerial photograph carries the potential to overwhelm the user or make the map impossible to read on a small display. The shadows and small distortions inevitable in aerial photography may be confusing. The power of a generalized map, designed to a specific purpose and simplified in terms of any of a number of techniques, is that it can focus attention on information that is relevant to the map purpose (Visvalingam 1994). A generalized map may reduce cognitive load in terms of the user visually processing the image; however, reconciling the abstract representation to the real environment may introduce another burden (Bishop 1994).

2. Related Research

This study complements continuing research on spatial information delivery for mobile devices, and is unique in considering controlled variations of map generalization in a field-based task. It is the first part of a series of studies to systematically test carefully controlled variations of representations to determine what makes effective mobile cartography, and why.

Dynamic, digital maps are key applications for mobile devices, especially for providing navigation assistance to non-expert users, or assisting scientists and others who work with spatial data in the field. A recent special issue of *Cartography and Geographic Information Science* dedicated to mobile mapping and GIS identified a research agenda for mobile GIS, encompassing the areas of infrastructure, data, and user issues (Clarke 2004). A major research area is navigation assistance and location-based services. Prototype navigation aids, both handheld and wearable varieties, continue to be developed and tested. Commercial products, such as in-car navigation systems, are already available to consumers. Research has not been able to keep pace with the technology, however, even for digital maps for standard-size computer monitors; there are no cartographic design guidelines yet for digital maps as there are for traditional paper ones (Meng 2003). There is a growing body of research investigating the variety of spatial information presentation available for handheld and wearable mobile devices: visual maps in 2D and 3D, text/audio descriptions, schematic diagrams, ground-view photography or video, or combinations of these. A review of these systems is beyond the scope of this paper (see Urquhart, Cartwright et al. 2003 for an overview of the more major projects), but many of these studies are concerned with how well a navigation system works as a whole, on a technological or usability level, such as which representation type or modality is more effective, rather than trying to determine *why* one representation method is better in light of how users interact with the information.

Map generalization research for small display is faced with the technological challenge associated with the limited screen space of mobile devices, and is driven by the need for automatic methods of creating representations that can adapt to the user's context (Edwardes, Burghardt et al. 2003), or can change scales and levels of detail in real-time (Hampe and Sester 2002). One of the primary problems of automatic generalization is devising a way to represent only the information that is relevant to the user at a particular time (Agrawala and Stolte 2001). The question of what that relevant information *is* remains to be determined.

A conceptual framework for approaching what information is important to represent on a mobile map has been developed by a number of researchers based on the context of the user and the mobile device. Since different types of information are necessary for different purposes and user activities, and given that the capabilities of GIS and digital images allow for dynamic maps that can potentially custom-tailor the amount and type of information displayed to individual users, the context of mobile map use is a starting point for designing effective spatial representations (Reichenbacher 2004). Nivala and Sarjakoski (2003) discuss mobile map context from the broad, mobile computing context categories of Computing, User, Physical, Time and History, defining more specific categories related to maps, encompassing hardware and infrastructure, and how, where and by whom the map on the device is used. They emphasize a need for research to determine which context factors are most important to incorporate for designing a map, and how exactly to do it (Nivala and Sarjakoski 2003).

Considering navigation systems specifically, Hampe and Elias (2004) focus the idea of context on the user, his navigation purpose, and his situation: individual characteristics of spatial skills, experience and familiarity with the area; whether he is moving by car, bicycle or foot; navigation style preferences; and characteristics of the situation, such as the time of travel, season, traffic conditions, etc. These factors are taken into consideration to determine the best way to present navigation information for a given context, such as which landmarks are going to be relevant, and which presentation modality fits with the attention and interaction limitations of the user (Hampe and Elias 2004). The information that this framework depends on, especially as regards how users' abilities and experience affect the way they use mobile maps, still needs to be determined.

An extensive framework of context for mobile cartography has been developed by Reichenbacher (2004), and is largely concerned with the adaptive nature of maps on mobile devices. This approach emphasizes that the information content for the map (such as areal extent and level of detail) and the information visualization (scale, generalization, symbolization, etc.) are categories in which elements can be presented in a specific and optimal way for the user and his situation (Reichenbacher 2003). Reichenbacher (2004) reviews current approaches and outlines several specific research directions for mobile cartography.

The methodology and results from this pilot study inform these contextual frameworks by assessing patterns of behavior with subjects of different spatial abilities and experience using maps of varying representation in a controlled experiment. These results are specific to the type of environment of the study area and the activity of route-following, and would likely be different if the experiment were replicated in a different type of area, such as a downtown city center or a forest, with a different sized study area, and if subjects were finding their way to a destination point rather than following a given route. Systematically considering maps in all contexts is a necessary step towards a more complete understanding of how people interact with maps while mobile. This knowledge will inform generalization techniques, such as in determining just what level of detail is necessary, or to what extent features can be aggregated or simplified to fit on the display and still be useful.

3. Methods

In order to evaluate map generalization for handheld computer displays in a mobile context, an experiment was designed to have subjects use digital maps to complete a navigation task. Research subjects were 16 graduate students from different departments at the University of California, Santa Barbara (UCSB), 10 males and 6 females, ages ranging from 20 to 37. Their task entailed walking along a route displayed on a map on a tablet PC, using the map as a navigation aid. Subjects were instructed to complete the route as accurately as possible and as quickly as possible, but walking at their normal pace. Subjects did the task with both display conditions, following a different route each time. The two display conditions are shown in Figure 1. Each route was the same length, 0.74 km, contained the same number of turns (19), and covered similar-sized, non-overlapping areas of the UCSB campus (Figure 1). Routes and map order were systematically varied among participants to avoid confounds from any differences in the two routes or from practice effects. Prior to starting the task, subjects received training with the tablet PC and completed short practice routes with each map type, to get

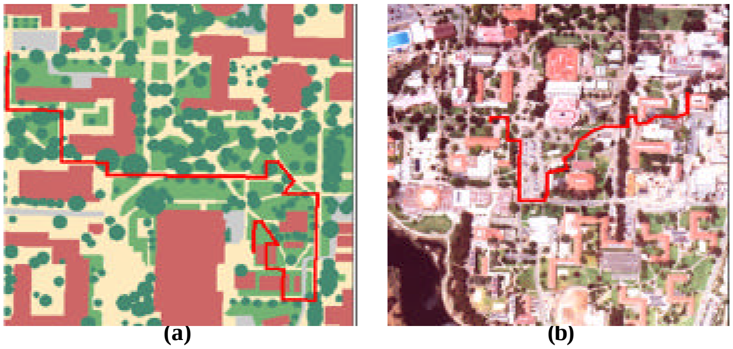

(a) (b)

Figure 1. (a) generalized map display with route 1, (b) aerial photograph display with route 2

familiar with the interface, display and task instructions. The navigation task was designed so that subjects would need to interact with the device continually, referring to the map in determining where to walk.

(a) (b)

Figure 2. (a) tablet PC, (b) PDA handheld device

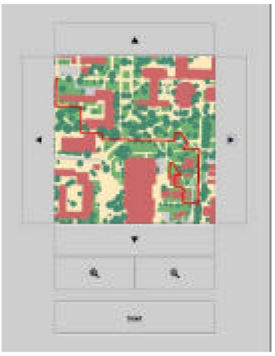
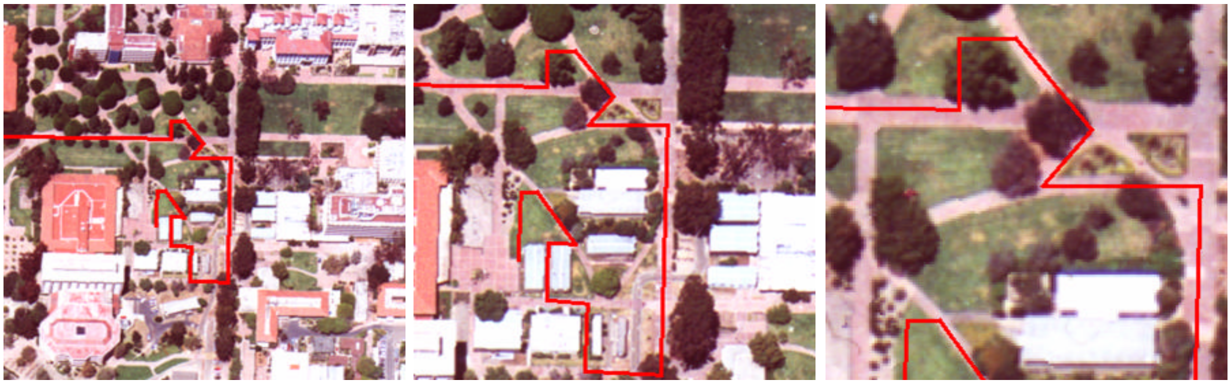


Figure 3. Map display interface

The hardware platform was a ruggedized tablet PC (Figure 2a), and a Java application displayed the map image in a 6 x 6 cm window, the size of the display dimensions of a typical PDA-sized handheld computer (Figure 2b). While this research is concerned with the limitations of small displays, using a tablet PC, which runs a Windows XP operating system, allowed more flexibility and control over the experimental design and data collection than a PDA would have. A pan frame surrounded the four sides of the image, with incremental zoom in and zoom out buttons below the image window (Figure 3). All buttons were selected by touching the screen with a finger. Figure 4 shows zoom levels 3, 4 and 5 for the aerial photograph, with spatial resolutions of (a) 1 meter, (b) 0.5 meter, and (c) 0.25 meter, respectively.

The study area was the UCSB main campus, although the area extent that the subjects walked during the task was only a small portion of the entire area, approximately 0.07 square kilometers. A view of the full extent of campus was available to subjects for purposes of orientation, and subjects began the task with the image at its full extent. Maps were oriented on the device the conventional north-up, but subjects were free to physically rotate the device to rotate the map. Indeed, all subjects rotated the map during the navigation task according to the direction in which they were heading, consistent with findings in other research that users prefer to use a map oriented to their direction of travel (Warren and Scott 1993; Bornträger, Cheverst et al. 2003). Such physical rotation of the map, or of one's body, in order to line up the orientation of the map to the real world reduces the amount of mental rotation required of the subject to reconcile the map with the real environment (Aretz and Wickens 1992). To begin the task,



(a) (b) (c)

Figure 4. (a) zoom level 3, (b) zoom level 4, (c) zoom level 5

subjects were taken to the start point of the route, given the tablet computer with the map zoomed all the way out, oriented towards north to match the map orientation, and shown the start point of the route on the map. Before beginning to walk the route, subjects zoomed and panned to orient themselves according to their preference, pushed the button labeled "start", and began walking. Upon reaching the end of the route, subjects pushed the "stop" button.

It should be noted that although there is a GPS integrated into the tablet PC, no location information appeared on the map. This first study was concerned with how subjects performed with just the map and the route, requiring subjects to maintain their location themselves. An important follow-up study will be to replicate the experiment with location information from the GPS, to understand the effects of such assistance.

One goal of the study was to evaluate the maps with regard to time efficiency, amount of map browsing in the form of zooming, and accuracy.

- Time efficiency considered the total amount of time it took each subject to complete the route for each display condition. Faster completion of the navigation task would indicate a more effective map. It was hypothesized that the generalized condition would result in faster time to route completion.
- The amount of map browsing was defined as the amount of zooming done by a subject in completing the task. Pushing buttons takes time and requires user attention, and keeping track of the changing display during zooming requires the subject to remember previous views, as opposed to viewing a static display. Also, the action of zooming suggests that the subject needs additional information; therefore, less zooming interactions would suggest a more effective map, one with enough information in the current display. It was thought that the generalized map would require less zooming than the aerial photograph map, given the comparatively lesser amount of detail and higher contrast among feature types.
- The ability to complete the task accurately was seen as an important factor to consider. A map type that contributes to user error is not an effective map. For the task, subjects were instructed to follow the route marked on the map as closely as possible, and were told that the route would not necessarily follow sidewalks or paths. Accuracy was measured by the number of errors subjects made along the route with respect to features. Walking around the wrong side of a tree, for example, or walking on sidewalk where the route indicates to walk on grass were counted as errors. The aerial photograph was expected to result in fewer errors than the generalized map, since it contained more details and visual cues than the generalized map.

A second focus of the experiment was to consider subjects' performance as related to their spatial abilities, previous experience with maps and mobile devices, and familiarity with the study area. It has been shown (for example, Hegarty, Richardson et al. 2002; Prestopnik and Roskos-Ewoldsen 2000; Sholl, Acacio et al. 2000) that individual differences have a significant impact on performance with environmental spatial tasks of navigation and wayfinding. It was hypothesized that these characteristics would affect subjects' performance on the task, and therefore would show significant correlations with time to route completion, amount of map browsing, and accuracy.

Data was collected in the form of computer logs, observations by the researcher, and through questionnaires completed by the subjects. The mobile device logged all operations to a file, recording each action of zoom in, zoom out, and move up, down, left, and right, along with pixel coordinates of the image center, current zoom level, and time to the nearest second. During the task, subjects were followed at a short distance by a researcher, whose function was ostensibly to assist with any technical problems or inquisitive passers-by, but who also recorded observations on where and when subjects stopped or made errors. A questionnaire completed by each subject prior to the task used a 5-point scale to collect self-report data on general familiarity with the UCSB campus, experience with using maps to navigate, experience with mobile computers such as PDAs or video games, and asked a series of questions to assess sense of direction spatial abilities. Spatial ability, in terms of environmental orientation, was measured using the Santa Barbara Sense of Direction Scale, a self-report survey that provides a reliable, quantified assessment of the type of spatial abilities associated with locating oneself in an environment and maintaining orientation during movement through an area (Hegarty, Richardson et al. 2002).

After completing the navigation task with both conditions, subjects completed a questionnaire to evaluate and compare both maps. Questions on a 5-point scale asked subjects about their familiarity with the areas covered by the routes, to rate and comment on the difficulty of using the device in general, and for each map, to rate the level of detail, indicate which feature types were most and least useful for orientation, which characteristics, of shape, texture, size or color, were most and least helpful in identifying features, and whether subjects felt they used the pan and zoom extensively or not very much. In addition, open-ended questions asked which of the two maps was easier to use and why, and had subjects comment on the most difficult thing about following the route. These questions were designed to acquire information about user perceptions and preferences about the maps and the mobile device, as well as to identify subject behavior or strategies that could be linked to the quantitative data from the log file.

4. Results

A summary of the data is presented in Tables 1 and 2. Paired t-tests at a 0.05 significance level (t critical for 15 df = 2.13) were used to compare subjects' performance from one display condition to the other. For the self-report data, correlation tests were conducted to assess the relationships between variables (r critical for 14 df = 0.497). It should be noted that the small sample size of 16 may not be large enough upon which to base substantive correlations, but follow-up studies beyond this pilot test will include a larger number of subjects and can serve to verify the relationships. Table 3 contains a summary of the significance tests on the variables.

Table 1. Summary statistics for generalized map vs. aerial photograph

	Time to route completion (min:sec)	**Browsing: # zoom levels used**	**Browsing: # zoom level changes**	**Accuracy (# errors during task)**
Generalized Map (GM)	Mean: 10:52 Range: 7:53 - 17:48	Mean: 2 Range: 1 - 3	Mean: 2 Range: 0 - 10	Mean: 2 Range: 0 - 4
Aerial Photograph (AP)	Mean: 12:32 Range: 9:19 – 22:20	Mean: 3 Range: 1 - 6	Mean: 9 Range: 0 - 38	Mean: 2 Range: 0 - 4

Table 2. Summary statistics for subjects' self-report data

Spatial Ability (1=low, 7=high)	**Familiarity with area** (1=very familiar, 5=not at all)	**Map Experience** (1=extensive, 5=none)	**PDA Experience** (1=extensive, 5=none)
Mean: 4.9 Range: 3.4 - 6.2	Route 1 Mean: 2.5 Range: 1 - 5 Route 2 Mean: 3.3 Range: 1 - 4	Mean: 2.6 Range: 1 - 4	Mean: 3.3 Range: 1 - 5

Table 3. Summary of significance tests

	Time to route completion	**Browsing: # zoom levels used**	**Browsing: # zoom level changes**	**Accuracy (# errors during task)**
Map Conditions: Generalized Map (GM) vs. Aerial Photograph (AP)	Significantly shorter time with GM than with AP. t(15) = 2.66 p = 0.02	Significantly fewer with GM than with AP. t(15) = 2.89 p = 0.01	Significantly fewer with GM than with AP. t(15) = 2.99 p = 0.009	No significant difference.*
Environmental Spatial Ability	Correlation of higher ability with shorter time for GM (r = -0.60) not AP (r = -0.34)	Not significant r(GM) = -0.005 r(AP) = 0.20	Not significant r(GM) = 0.056 r(AP) = 0.15	Not significant* r(GM) = -0.15 r(AP) = -0.07
Familiarity with Area Covered by Route	Not significant r(Rte1) = 0.31 r(Rte2) = 0.11	Not significant r(Rte1) = 0.16 r(Rte2) = -0.01	Not significant r(Rte1) = 0.20 r(Rte2) = -0.19	Not significant r(Rte1) = 0.46 r(Rte2) = 0.06
Map Experience	Correlation of more map experience and faster time. r(GM) = 0.72 r(AP) =0.54	Not significant r(GM) = 0.38 r(AP) = 0.19	Not significant r(GM) = -0.11 r(AP) = -0.26	Not significant r(GM) = 0.20 r(AP) = 0.12
PDA Experience	Not significant r(GM) = 0.15 r(AP) = -0.05	Not significant r(GM) = -0.06 r(AP) = -0.22	Not significant r(GM) = -0.25 r(AP) = -0.009	Not significant r(GM) = -0.12 r(AP) = 0.01

* When considering dataset as a whole. A closer look at the locations and types of errors suggests meaningful relationships.

As Table 3 indicates, there were significant differences between the map conditions for time and map browsing. The number of errors in each condition when the data is considered as a whole is not different between conditions, but breaking down the locations of common error shows some clear patterns (discussed below). In terms of the other variables, there were significant correlations with environmental spatial ability and time performance, and map experience and time. Comparing the performance of males and females did not indicate significant differences, but true relationships may be masked by the small and unequal sample of men versus women. Future studies with larger numbers of subjects will provide more definitive conclusions on gender differences.

4.1 *Time to route completion*

The generalized map was more effective than the aerial photograph in terms of time to route completion. Additional analyses of time performance with the routes, and with map types, did not show significant differences, providing supporting evidence for equivalency in the routes and suggesting that the routes did not favor one map over the other.

Subjects' environmental spatial ability correlated with their time performance. For the generalized map, higher spatial ability strongly corresponded to faster times to route completion. The fact that the aerial photo did not result in such a significantly strong correlation suggests that the difference between the representations had a stronger effect on those of higher spatial ability. Grouping subjects into "higher" and "lower" spatial categories based on their spatial score being above or below the mean reveals that the lower spatial group did not show significant differences in time performance from one map type to the other, but the higher spatial group did show significant differences (Table 4). Within the group of lower spatial abilities subjects, four out of the eight subjects actually took more time with the generalized map than with the aerial photograph. These results suggest that the generalization helped people with higher spatial abilities, and did not help (or perhaps even hindered) those with lower spatial abilities. The primary difference in the maps is the degree of realistic detail, since the generalized map is a classified and simplified version of the aerial photo; therefore, the generalized map requires more effort to mentally reconcile the representation to the real world than the aerial photo. It is important that mobile maps be appropriate for people of either high or low spatial ability. A follow-up experiment testing a representation that blends some of the detail of the aerial photograph with the color-coded, simplified features of the generalized map may result in a map that is more effective for both groups.

Table 4. Spatial abilities and time to route completion

	Time to route completion (t critical = 2.36)
Lower spatial abilities group	Mean: 12:52 (GM), 14:00 (AP) t(7) = 1.01
Higher spatial abilities group	Mean: 8:52 (GM), 11:04 (AP) t(7) = 3.72

Familiarity with the study area did not seem to affect subjects' time performance, perhaps because there was not a great variation in familiarity among subjects. All sixteen subjects were familiar with the UCSB campus in general, and most rated themselves as having average or above average familiarity (on a 5 point scale). Subjects were more familiar with the area covered by route 1 than that of route 2, and when grouped by spatial scores, the higher ability subjects reported greater familiarity than the lower ability subjects for both routes. Small differences in familiarity did not seem to have much of an effect; testing subjects with no familiarity of the area against subjects with higher familiarity might yield different results. This is a priority area of investigation since a primary use of mobile maps is as a navigation aid for unfamiliar areas.

Subjects with more practice in reading maps tended to complete the route faster than those with less experience with maps. The correlation was stronger for the generalized map than for the aerial photograph. Considering spatial abilities, the higher spatial ability group reported having more experience with maps (moderate to extensive experience) than the lower ability group (not much to moderate experience), a significant correlation (r = 0.65). Taken together, subjects reporting less map experience tended to have lower spatial ability and took more time to complete the routes. This result is not unexpected in that those who are more practiced in reading maps would be more efficient in completing the task than those with less experience. The nature of the relationship between map experience and environmental spatial ability score raises questions. Does more practice with maps improve a person's ability to orient himself in an environment? Are people with higher spatial abilities more confident in reporting their experience using maps, or do they tend to have more experience with maps than those of lower spatial abilities, perhaps because they find them easier to use than people of lower ability do?

About two-thirds of subjects reported not having much or any experience with PDAs or other mobile devices, while six reported moderate to extensive experience. The result that PDA experience did not affect time performance in this study is not surprising, considering that the tablet PC interface and scope of the user interaction was fairly simple; it did not require viewing more than one map or window at a time or navigating the computer operating system itself. Almost all subjects rated the device as easy to use, and no one had difficulty with figuring out the straightforward interface.

4.2 *Map Browsing*

While subject interaction with the map in terms of zooming varied quite a bit among individual subjects, there were significant differences in behavior from one condition to the other. Almost half of the subjects used only one or two zoom levels during the tasks, while the rest used three or more different zoom levels. Between conditions, subjects changed zoom level an average of twice per route for the generalized map, but an average of nine times with the aerial photograph. Individual behavior varied considerably, with some subjects using one zoom level for the entire task and others using 6 out of the possible 7.

These results suggest that the higher level of detail in the aerial photograph compared to the generalized map prompted subjects to use a higher level of zoom to distinguish features and determine where to navigate. With the generalized map, at a certain point it would be evident to the subject that zooming closer would provide no further information, thereby reducing the inclination to zoom further.

No significant correlations were found between amount of zooming and spatial abilities, familiarity with the study area, experience with maps or experience with mobile devices. However, the statistical results of the map browsing data when taken as a whole may mask patterns in zooming behavior in particular situations, such as zooming to maintain position or get more detail on an area versus when a subject is disoriented or lost. Therefore subjects' behavior in terms of map zooming when they made errors was considered. With the capability to zoom in or out for a different view, did subjects take advantage of this or not? Where subjects made errors, it seems that in most cases they recognized a problem or an ambiguity; many people would stop and study the map before continuing on. For this analysis, making an error, and especially stopping beforehand, is taken to indicate disorientation in the subject. In looking at how subjects utilized the zoom function when they were disoriented, eight subjects never zoomed at the time that they made an error, five subjects regularly did zoom when disoriented, and two subjects sometimes did and sometimes did not.

This behavior seems to be related to prior experience with handheld computers. Subjects' report of their previous experience with handheld computers such as PDAs when compared to their zooming behavior shows that those with more experience tended to zoom when disoriented. Those with less experience may have not remembered the zooming capability at that moment, being preoccupied with reorienting themselves. Or, they may have preferred not to zoom for some reason. Perhaps they were more used to traditional static maps, or found a changing view more confusing than helpful. This is an area that needs to be investigated more closely; all subjects understood the zooming function and tried it out during the practice session, but, at critical times when their attention was intently focused on the task of reorienting themselves, not everyone used the function. If novice users do not or cannot take advantage of a function that can assist them at critical times, that tool is not effective.

4.3 *Accuracy*

Comparing subjects' performance from one display condition to another, there was no significant difference in the number of errors made. All of the errors were made at turn points in the routes and many were related to judging distances: subjects either walked too far in one direction before turning, or turned sooner than indicated by the route.

Correlation tests on the dataset as a whole revealed no significant relationships between number of errors subjects made and spatial score, route familiarity, map experience or mobile device experience. Based on related research on wayfinding and spatial abilities (Prestopnik and Roskos-Ewoldsen 2000) it was expected that familiarity would have an effect on accuracy, but again, perhaps the lack of a significant relationship is due to the small sample size, or small variation in familiarity as reported by subjects.

In looking at particular points on the routes where multiple subjects made errors, some patterns do emerge. Some errors can be ascribed to ambiguity in the map and are related to subjects' spatial abilities, with others the source of error is related to the map type and in one case, the reason for the error is not clear at all.

In route 1, there were two locations where multiple subjects made errors. Figure 5 shows one portion of the route where almost half of subjects made an error in each condition. An arrow has been added to the center image for the reader's benefit to indicate direction of travel and the point at which the photo on the left was taken. The error here can partly be ascribed to ambiguity in the map, since the sidewalk forks about 5 meters before the turn as marked, with one branch continuing straight and one veering to the right along the edge of the building. The tree canopy occludes the view of the sidewalk, requiring the subject to find other cues to determine where to walk.

Figure 5. Section of Route 1, at zoom level 5. Blue arrow in center image indicates direction of travel but does not appear in the original display.

In the generalized condition, three subjects turned right several meters beyond the location indicated by the route, and one took the path that veered to the right before the turn. With the aerial photo, 3 of 8 subjects took the path that veered to the right before the turn. Five of the seven total subjects who made this error had an environmental spatial ability score below the mean; these five also made an error at the end of the route as described below.

The other point of error in route 1 was towards the end of the route, shown in Figure 6. These images illustrate the effect of classification on the information available in the map. The triangular section in the center of the image is all vegetation, as shown with light green in the generalized map, but the aerial photograph reveals the distinction between the grass and the bushes along the sidewalk, a detail that should provide more visual cues to assist the subject with accuracy. Another distinction between the images is that the sidewalk intersection located where the route turns left is much more prominent in the generalized map than in the aerial photograph.

Figure 6. Section of Route 1 at zoom level 4. Blue arrow in center image indicates direction of travel but does not appear in the original display.

Three out of 8 subjects made an error here with the generalized map; two turned left several meters before the indicated turn, and one continued beyond the turn, turning left several meters further up the sidewalk. With the aerial photograph, however, subjects' behavior is surprising. Six of 8 subjects made an error, with four continuing along the sidewalk, turning left at the intersection of sidewalks. The other two followed the edge of the grass, turning left further up the sidewalk where the bushes meet the grass. Subjects of both low and high spatial abilities made errors here. Since the airphoto provides more visual cues that should improve accuracy, this unexpected amount of errors may be attributable to a visibility issue. What looks clear on a large monitor in an office, even on a printed page, can look substantially different in outdoor illumination conditions. Color contrast may have been thus affected. Another possible interpretation is that in using sidewalks as a primary feature for navigation, as reported by almost 60% of subjects, subjects paid less attention to other features and did not see cues provided by other features, such as the vegetation. Assessing the images for feature contrast is a further step to investigate this pattern of errors, and additional research can investigate the effect of image contrast on visibility.

Route 2 had two major locations of error, one attributable to feature ambiguity in the maps, the other unclear as to the cause.

Figure 7. Portion of Route 2 at zoom level 4. Blue arrow in center image indicates direction of travel but does not appear in the original display.

This part of the route (Figure 7) had subjects walk between two buildings, via a courtyard that was separated from the main sidewalk by sections of a concrete-block wall. The wall does not appear as a feature in either of the maps, but the route turning right and right again guides subjects through the courtyard. Although a majority of the subjects made errors at this location, the nature of the errors vary quite a bit. In the generalized map condition, 6 of 8 subjects made errors here. Four subjects missed the first turn to the right, continuing straight as far as the end of the next building before backtracking and making the turn correctly. All four were in the lower spatial score group. Two subjects turned right too soon, passing through a break in the wall and connecting with the route as it goes between the buildings. These subjects were in the higher spatial abilities group. In the aerial photo condition, 5 of 8 subjects made errors. Two were lower spatial and 3 were higher spatial. Only one subject walked too far going straight ahead, and then backtracked too far before turning right. Two subjects walked through some vegetation in between the two wall segments. And two subjects negotiated the right turn through the wall correctly, but upon making the second right turn continued too far past the turn to the left that would take them between the buildings. In this case, where the map does not completely correspond with the real world, subjects had a more difficult time reconciling the map to reality, and not all of them were successful. Since maps only represent selected information, especially in the mobile case where display size and resolution are limiting factors, it is important that the key information be presented. What the key information is, for any given activity and individual user, is yet to be determined, and cited by others as a critical area for research (Reichenbacher 2001; Hampe and Elias 2004; Nivala and Sarjakoski 2003). Maps will inevitably have errors or omissions, especially when an environment changes before a map can be revised, but an understanding of how users react and behave when faced with these limitations can help in designing effective maps. Of course, providing subjects information about their current location, such as with a GPS receiver, might mitigate this problem, as users could compare their location as shown on the map with the location of their destination, reducing the reliance on environmental features for orientation. Still, if the inadequate map does not correspond with what users see around them, they may believe the GPS is in error. Indeed, the user should expect some amount of error, as GPS signals are weak or lost entirely in locations such as under tree cover or near tall buildings. Additional research in this area is important in order to determine what and how much information is necessary with and without a location indicator.

The other section of route 2 at which more than half of subjects made errors is shown in Figure 8.

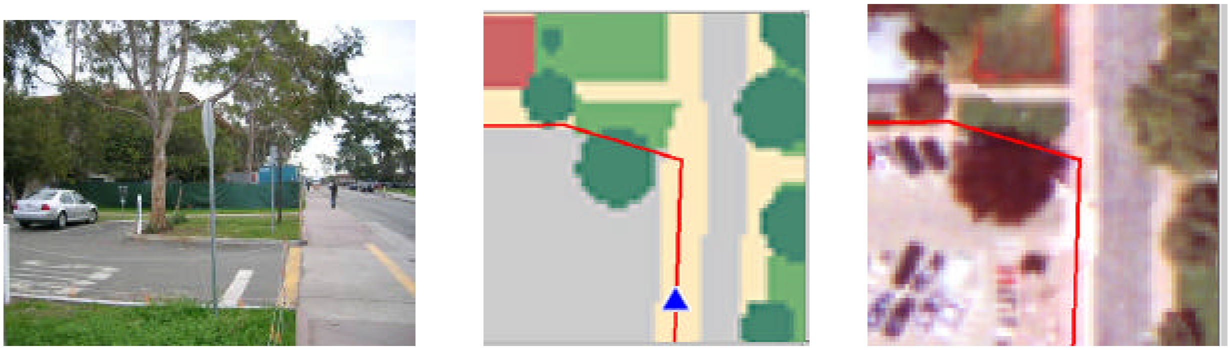


Figure 8. Section of Route 2 at zoom level 6. Blue arrow in center image indicates direction of travel but does not appear in the original display.

With the generalized map, half of the subjects made an error, with three subjects turning left too soon, walking in the parking lot in front of the tree rather than around it on the grass. One subject continued along the sidewalk, turning left at the sidewalk intersection, following the sidewalk rather than cutting across the grass. In the aerial photo condition, five out of 8 subjects made an error. Three subjects followed the sidewalk rather than cutting across on the grass, while 2 turned too soon, walking in front of the tree. These nine subjects were evenly distributed over spatial ability and map type. These errors are surprising since it appears fairly clear that the route goes around the tree and diagonally, and not near the sidewalk at all. Perhaps visibility was a factor, or uncertainty due to the appearance of the tree on the ground versus from above.

In summary, the route 1 errors show some patterns, in that the lower spatial ability subjects tended to make errors where the turn point was ambiguous due to tree canopy occlusion, regardless of map type. It is not surprising that subjects with higher spatial ability would be less prone to making errors at a point of ambiguity, since they are likely to be able to judge distances better than those with lower spatial scores. At the end of the route, twice as many errors were made with the aerial photo condition than with the generalized condition, regardless of spatial ability. This would suggest that the map representation influenced these errors. Route 2 errors seem to be independent of map type or spatial ability; the first one described can best be attributed to insufficient information in the map, while the second one remains unclear. For this study, locations of common error were not anticipated, although routes were designed to be intricate enough to require subjects to continually rely on the map. An interesting follow-up study would be to specifically design locations of error into the experiment, to quantify and assess the effects of missing, distorted, or wrong information on subject performance.

5. Discussion

Overall, the statistical analysis points to the generalized map as being more effective than the aerial photograph for the route-following task. However, when individual differences of the subjects are considered, the determination of which map was more effective depends on the subject. For subjects with poorer environmental spatial abilities, the aerial photograph condition seemed to be more effective, resulting in about the same or even faster time to route completion than the generalized map.

Considered another way, both representations worked: all subjects were able to successfully complete the task with both map types. While it seems clear that a well-designed map would be preferable for use on a mobile device over a photograph or other remotely sensed image, the advantage of the latter is that it can be more up-to-date than a designed map, and requires minimal processing. Despite ongoing efforts to automate processes, generalization requires the skills of a cartographer, time, and of course, resources. For maps used in a mobile context, especially for navigation and wayfinding, having accurate, up-to-date information is a priority. Thus, what is the tradeoff between current, relatively raw imagery, and an older but carefully designed map? In this study, one of the major locations of error was a place where a wall feature did not appear on the map. It was concluded that this missing information in the map was the cause of confusion and error for a majority of subjects. Missing or erroneous information in a map can be the result of recent construction in an environment or a natural event, beyond any purposeful omission or aggregation of features as dictated by the cartographer or the map scale. Research by Casakin, Barkowsky et al. (2000) concluded similarly that distorted or oversimplified depictions of path and intersection features in a map cause confusion and error in wayfinding. The result from patterns of errors in this study, taken together with the conclusion that there was no overall difference in accuracy between the map conditions, suggests that a more current map, even with a lot of detail, would be preferable to an outdated but well-designed map.

This study demonstrated that considering the locations and types of errors subjects made was important in the analysis in that patterns were revealed that were masked by the statistical analysis of the data taken as a whole. The causes of and influences on the errors described here are subject to interpretation, but provide a foundation for further research to test specific situations in which there is ambiguity in the map due to obscured features, missing information, poor image contrast at key intersections, or an inappropriate amount of detail. The patterns of how subjects of different spatial ability and familiarity with the area behave can help in anticipating problem areas during map creation, and can inform design decisions to try to prevent confusion for the user.

As a pilot study, this research points to directions for the focus of continuing studies, and provides a starting point from which to test additional levels of generalization in map representation for mobile devices. As noted in the previous section, priorities for further research on mobile maps include the relationship of environmental spatial ability to level of map generalization, the effect of familiarity with the environment on performance, and the influences on zooming preferences for novice users and those with more practice using maps on mobile devices. Additionally, investigating the influence of a location indicator from GPS is an important next step. Subjects commented that keeping track of where they were on the route and which direction they were heading was difficult at times. Reducing the burden for the user of determining his current location by incorporating GPS information supports more effective movement through an environment (Suomela, Roimela et al. 2003). In that case, what bearing does location information have on the map representation? Can the map then be generalized to a minimalist schematic, or do users still need a certain amount of detail for context? How much detail?

Beyond these questions, the roles of previous experience with maps, and continuing practice with digital maps on a mobile device must be considered. Interaction behavior of a novice user would likely change as that user becomes more familiar with the device and discovers his preferences for zooming and the type of information he uses for navigation and wayfinding, which in turn would have an effect on the information that he would need displayed in the map. This research focused on a route-following task designed to require subjects to continually interact with the map as they made their way through an environment. Different types of user activity were not considered, but assessing map representations for use in additional activity contexts is necessary for a more complete understanding of what makes maps effective for handheld mobile devices. Alternative mobile devices, such as wearable computers with head-mounted displays, provide another mechanism of spatial information delivery, and maps designed for handheld systems would likely need to be different for a heads-up display.

Finally, while the experimental design proved successful overall for achieving the goals of the study, the research was not without challenges. Visibility of the computer display in varying illumination conditions, especially bright sunlight, was a challenge, and one that has been noted by others (such as Kray, Elting et al. 2003). As mobile devices continue to advance technologically, this issue may be mitigated. The other major limitation was the logistics and time constraints associated with field studies. Routes had to be carefully designed to be in areas for which the aerial photograph was accurate, long enough to require subjects to use panning and zooming, but not so long that the task would take an excessive amount of time. Each subject spent about one hour completing the experiment, including the practice routes, two conditions, and questionnaires. Rescaling the amount of subjects for a bigger study is a significant endeavor; therefore it is crucial that continuing experiments be carefully designed and prioritized. Some of the questions for further study raised here can be initially addressed through lab-based studies, but ultimately, since the mobile context is so different from an indoor, relatively static setting, field testing is necessary to gain a true understanding of mobile map use.

6. Conclusion

This pilot study sought to investigate how people use digital maps on small devices while engaged in mobile activities, by comparing two variations of a map representation, and considering characteristics such as environmental spatial ability, familiarity with the area, and previous experience with maps and handheld devices. While the results are contextualized for this type of study area and population, the relationships and patterns that emerge demonstrate the importance of considering individual subjects' characteristics when approaching mobile map design. Future studies will further elaborate and verify these relationships, and consider additional variations of context. Ultimately, an understanding of how people interact with digital maps while moving will bring effective spatial representations to mobile devices, whether they are being used for navigation, data collection, or other field-based activities.

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