The effects of Mobile Pedestrian Navigation Systems on the Concurrent Acquisition of Route and Survey Knowledge

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Abstract. In this paper we report results of an experiment that investigates the effects of mobile pedestrian navigation systems on the development of route and survey knowledge acquired by the users. In the experiment directions were presented incrementally step-by-step in different modalities (i.e. audio, graphics) and through different media (PDA, clip-on display). The experiment has been carried out in the field in a Wizard-of-Oz like study. Results show that as expected all subjects had problems in building up survey knowledge of the environment. In contrast, route knowledge was learned much better. We also observed a slight gender effect showing that women had an advantage of a visual presentation condition, whereas for men the presentation mode didn't matter. Finally, we discuss some implications on the design of pedestrian navigation systems.

1 Introduction

On the one hand, pedestrian navigation systems seem to have the potential to provide useful mobile assistance in unknown environments. On the other hand, the ubiquitous availability of the assistance might have the side effect that users do not make an effort to acquire spatial knowledge because such knowledge is not necessary any longer for reaching the destination. From experience we do not yet know how such kinds of systems influence the acquisition of knowledge on route and environment information, and hence we ran the following experiment. We tested the spatial knowledge that was remembered after participants navigated through an unknown terrain (a zoo) guided by a pedestrian navigation system.

Usually, humans acquire spatial knowledge about landmarks and their locations within the environment. Because this is knowledge about locations within a two-dimensional coordinate system in a more global reference system, it is often called a mental map [1] or survey knowledge. Such maps can be used to predict the spatial relations between landmarks, as for example the direction in which a destination is located relative to the actual own position or another known landmark [2]. Survey knowledge is acquired from physical maps but together with landmark knowledge it is acquired also from active exploration of the environment [e.g., 3]. Our research has been motivated by our own experiences with car-navigation systems that provide incremental (i.e. step-by-step) instructions in guiding drivers to their destination. Our feeling was that those systems do not provide much survey information on the environment (i.e. the position and directions of relevant landmarks within a global frame of reference). This can lead to problems if drivers have to reorient themselves either due to technical deficits of the system (e.g. if satellites are not available) or due to dynamic changes in the environment that are not reflected in the data (e.g. blocked roads). In those situations drivers have to find their way on their own and usually need to rely on survey knowledge of the environment to find deviations or short cuts from their current position to their destination. Due to the nature of use of pedestrian navigation systems these problems will occur more often. The lack of GPS-signals on narrow streets and pedestrian zones are occurring more frequently and additional positioning systems (e.g. odometers), which are able to counterbalance these effects are usually not available. Under such circumstances it seems to be important to design pedestrian navigation systems in a way that the concurrent development of survey knowledge is continuously supported. The results reported in this paper originate in a first experiment aiming at investigating the influence of differently designed pedestrian navigation systems in this respect.

In both designs we provided landmark (LM) information together with the to-be-taken directions. We used pictures of intersections and decision points – i.e. locations where walking directions were changed – in a viewer-centred perspective as landmarks [4] and we provided the direction in two different ways. In the visual condition we presented a line on each picture which indicated the trajectory of the intended path. In the oral condition we placed a read dot at the location where the direction had to be changed, and we presented the new direction by verbal means via headphones (cf. Figure 1). Because the visual, but not the oral condition provided LM and direction information in an integrated manner, we expected that the visual condition caused better memory than the verbal one [5]. Participants used one of these systems for navigation, and afterwards when they had reached the destination they were administered to an unexpected memory test for their landmarks memory and for their survey memory. Because males and females differ in spatial navigation and especially in the usage of LM [6,7,8] we additionally introduced gender as further independent variable. Half of the participants were male and half female.

Figure 1: An example of the picture of a landmark visible (a) in the visual version and (b) in the oral version of the task

2 Experimental Design

The experiment has been carried out in the zoo of Saarbrücken, which has a fairly complex network of small paths and routes (see figure 3c). 32 subjects were tested, half males and half females. All of the subjects were unfamiliar with the topology of the zoo and between 15 and 40 years old. A specific route in the zoo consisting of 15 street segments and 16 major decision points had been chosen for the experiment. Decision points in this context are crossroads with unique appearances. Throughout the trial every subject had to walk along the same route and pass the decision points in the same order. At every decision point an image of the decision point was presented either on a PDA[1] (16 subjects) or a head mounted clip-on[2] display (16 subjects). The images were augmented to clarify the given directions. Directions were given either via audio (16 participants) or visually (16 participants). In the visual condition (Figure 1a) a line indicated the direction to take and in the audio condition images were augmented with a virtual reference point (Figure 1b) to clarify the directions given through the audio comment (e.g. “Turn right at next decision point”). It is known that each of the decision points has its own local reference system [9]. However, by augmenting pictures with reference points, it was possible for us to use a general reference model that allows comparing results between locations. After a short explanation, subjects had no problems in understanding the audio commentary.

The experiment consisted of two parts, a *study* part where participants were taken on a walk through the zoo for about 20 minutes, of course, without telling them in advance about the later test, and a *recall* part where participants were tested to investigate how much they remembered about the route they had taken. During the trial, subjects were told to go ahead, while the experimenter followed with a separate handheld at a distance of 5-20 meter behind them. The experimenter had the task to trigger the presentation of route instructions via a wireless LAN connection with the help of the second PDA. After the walk through the zoo, the subjects had to self-assess their own spatial abilities by completing a questionnaire, with questions like “Do you have problems to remember route instructions?” or “How easily do you get lost in a foreign

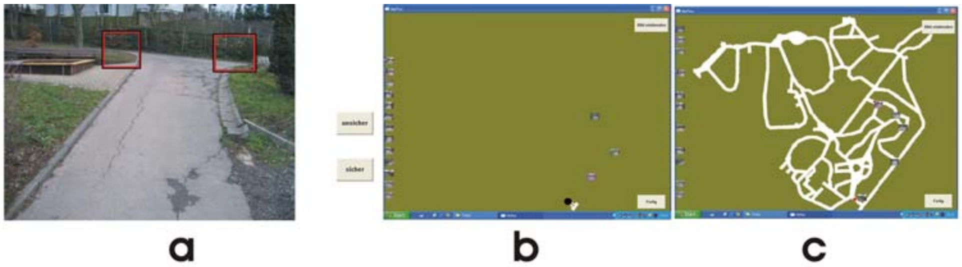

Figure 2: Screenshots of the three spatial test-applications

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[1] HP iPAQ 5450

[2] MicroOptical

city?” This questionnaire was introduced to find out whether individual differences in the preferred navigation behaviour interact with the presentation mode [10,11]. Additionally completing the questionnaire introduced a retention interval of several minutes for the following memory task. After having filled out the questionnaire, subjects had to work trough three interactive tests on a tablet PC where the recall of their spatial knowledge was tested. The first one aimed at testing directional knowledge, whereas the second and third tests were designed to test the acquired survey knowledge.

To test the directional knowledge (i.e. the ability to remember what direction had been taken at which decision point), the same images that were presented during the walk – without the lines – were displayed on the tablet PC in random order. The images contained sensitive areas (the rectangles in Figure 2a) that could be tapped by the subjects to indicate the direction that they had taken at each decision point. Before making a decision, subjects were asked to judge their confidence by pressing one of two additional buttons labelled “sure” and “unsure”.

For testing survey knowledge, subjects had to position thumbnails of the decision points on an area that represented the zoo. In one version only the start position of the route was marked with a spot (see Figure 2b) and no further information was given. In a second version the subjects had to place the thumbnails on a road-map of the zoo (Figure 2c). All LMs were lined up at the left and right of the zoo map and participants moved the thumbnails via drag and drop to the position where they thought this LM is located. By a double click the thumbnails could be enlarged to enhance identification of the LM.

3 Results

We counted the number of correct directions in the LM direction task, and the Euclidean distance between correct and selected location. Because the clip-on and the PDA presentation did not differ, we collapsed the data across these conditions. The results are given in Figure 3a and b. The data clearly confirm the hypothesis. Mobile navigation systems providing step-by-sep instructions caused a considerable LM knowledge but they did not help much in building up survey knowledge of an unknown environment.

When looking at the results of the directional test (see Figure 3a) one may note that direction memory was relatively good. In the average 12 out of 16 directions were correctly remembered after walking the route once which is a quite good memory performance considering the incidental study condition. However, we have to take into account that not only the PDA information was available but additionally the real environment was perceived, and that participants walked without any concurrent task so that they had plenty of time to encode the surrounding. Additionally, a gender effect can be observed. Females performed worse under the audio condition (63 % correct) than the visual condition (75 % correct, $F(1,28)=3.07$, $p<.06$), whereas males always remembered 75 % correct.

An explanation of this effect could be the fact that a priory females tend to remember path descriptions by verbal means [12]. Hence in the oral condition, they probably have used a verbal encoding, which is less memory efficient than a visual strategy for learning a LM-direction association [5]. In the visual presentation mode the stimulus provided environmental support for a visual encoding, and this enhanced memory. In contrast, males might always encode LMs in a visual code– even in the oral condition – so that they did not benefit from the provided visual information, or perhaps more correctly they were not harmed by oral presentation conditions. As an alternative it

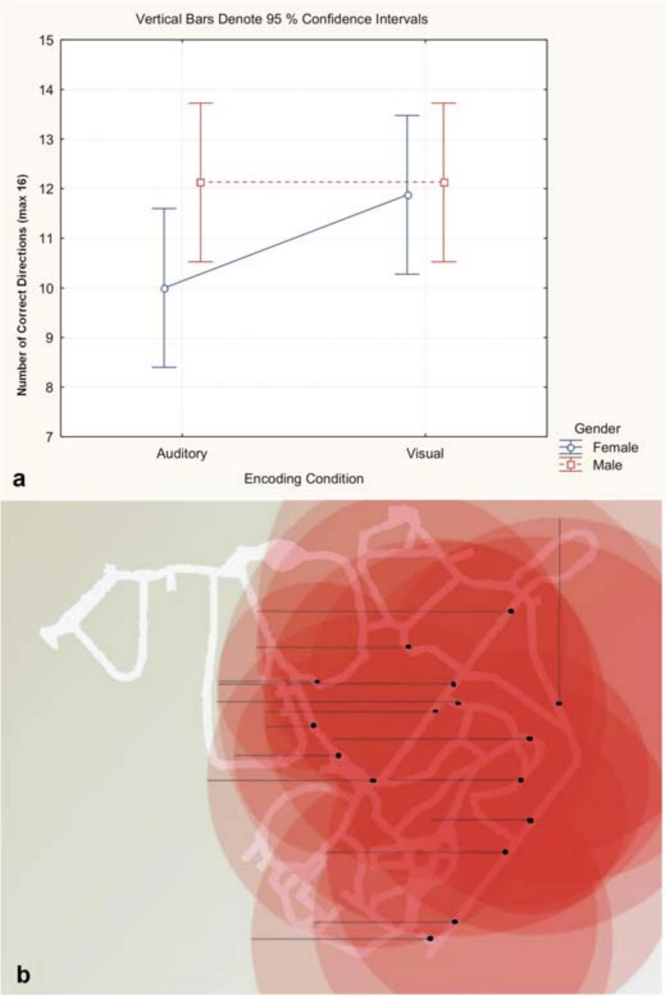

Figure 3: Results show a gender effect for the presentation mode in the landmark direction task (a) and a poor survey knowledge (bad recall of landmark positions) (b).In Figure a proportion of correct directions dependent on presentation mode and gender is depicted. In Figure b the original LM positions are shown and a circle around each

location indicates the average deviations between the selected and the correct locations.

might be possible that males used more efficiently the environmental information which was available to all participants independent of their instruction condition. If they did so, the type of navigation assistance would be of minor importance for memory.

Figure 3b shows the accumulated results of the survey test. The dots indicate the correct positions of the 16 decision points. The overlapping circles represent the standard deviation of the placing (averaged over all subjects it is nearly 50% of the relevant map size). The lines represent the radius of each circle and give a quantitative idea of the differences of placing decision points. In this test the gender had no significant influence on the subject performance. On the contrary, memory was generally very poor. Obviously participants did not acquire survey knowledge during tour guided by the pedestrian navigation system.

First evaluations of the questionnaires indicate that subjects' meta-memory of their own spatial abilities is internally consistent. Answers to different questions on the same topic were logically correct. Additionally, it went out that the spatial tasks do not define homogeneous skills. One aspect of spatial abilities comprises all questions concerning the beliefs about orientation in space (directions, distances, homing vector, etc.) – may it be active (giving directions) or passive (comprehension). This ability is also positively correlated with the self-estimated map reading competence ($r = .59$), and subjects with a high competence declare trying to gain a birds–eye overview. However, it is only loosely connected to subjects' rating of the ease of getting lost in a new city ($r = .11$) and also not to memory ($r = .02$). If subjects rated themselves as getting lost with a high probability they assigned themselves bad spatial knowledge and they avoided processing of spatial information (they did not enjoy reading maps and they let others doing the navigational planning). Memory is a different, partially independent aspect of spatial processing. This is defined by the ability of remembering a route after travelling it once and the capacity of remembering a route as a passenger.

4 Design Implications for Pedestrian Navigation Systems

The first evaluation of the results has shown that mobile pedestrian navigation systems that mainly rely on step-by-step instructions are bad at conveying survey knowledge of the environment to their users. This can have bad implications if the system looses the ability to determine the position on its own (e.g. when it looses GPS signal). Therefore we are currently aiming at designing pedestrian navigation systems that help to build up survey knowledge concurrently all the time throughout its use. We plan to use our general purpose navigation platform M3I [13] that can be configured in such a way to make use of two synchronized displays. One display is head-worn and another one faces up from a bum-bag that users wear around their waists. The clip-on display can be used to provide step-by-step information similar to those given throughout the experiment. The second display can be used similar to a paper-based map indicating the current position of the user on a map. Another idea is to emphasize the actual decision point on the map and to visualize the spatial relationship between local landmarks on the map. Considering the individual differences and the consistencies between the personal beliefs (meta-cognition) and actual performances, it might also make sense to be able to configure such a navigation system to match the preferences of their users. This would lead to a class of navigation systems that provide spatial assistance on different levels of granularity and by different modes. The M3I platform allows for multimodal (speech & gesture-based) interaction. We believe that allowing users to interact with a map interactively and to query information about landmarks should have a positive effect on the acquisition of survey knowledge.

5 Conclusions and Future Work

In this paper we have presented a first experiment that demonstrates effects that step-by-step instructions in different modalities have on the user's ability to concurrently learn some spatial properties of the environment. We plan further to investigate the influence of different types of maps that are presented in-between the directional instructions on the acquisition of survey knowledge. Based on these future experiments we will continue to refine the design of a pedestrian navigation system that provides more than just step-by-step instructions and simple maps.

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