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Orientation Aids for Mobile Maps

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***Abstract*—Using mobile maps to represent urban, work, or entertainment environments offers new possibilities to plan and carry out tasks. One potentially critical problem in mobile map usage is the misalignment between the user's frame of reference and the frame of reference of the map. In the experiment reported here, three different 'orientation aids' were tested in the context of restricted space, such as a large factory hall. The aim of the study was to find out how user interface design can help the user mentally align misaligned frames of reference for efficient mobile map use. The results of the experiment (N = 12) suggest using a 'you are here' marker and landmark highlighting, while canonical direction symbols proved to be less plausible. Further, a maximum number of seven targets on the map is suggested.**

Keywords- mental spatial orientation; mental rotation; mobile maps; orientation aids; reference-frame misalignment.

I. Introduction

It is common to consider people using the concepts of psychology. If the focus is on a developing child, the branch of psychology is called development psychology; if it is on car drivers, it is common to speak about traffic psychology. Therefore, when we consider people as users of technology, it makes sense to speak about user psychology [1][2][3]. The leading idea of modern user psychology is explanatory coherence, which means that researchers of human-technology interaction consider how consistent the outcomes of their research are with what we in general know about human mind, that is, cognitions, emotions, motive, and personality [2]. Here, the focus is on the possible explanatory roles of human visuo-spatial memory in analysing users working with maps.

People acquire knowledge from the environment by directly experiencing and interacting with it. However, in many tasks, information beyond direct spatial experience is required. A map is one widely used tool to provide such information. Inherent in the map usage, however, is the problem of combining environmental information from two sources, direct spatial experience and the map. A map provides an objective spatial representation of the environment with a world-oriented, that is, exocentric (or allocentric) frame of reference [4][5]. On the other hand, people themselves represent environment with respect to their own position, that is, egocentrically [4][5]. This difference in the frames of reference may lead to problems during a map use due to a phenomenon called reference-frame misalignment [4][6]. When the frames of reference are misaligned, a lot of evidence suggests that map-based decision times increase and become more error prone [4]-[9].

The use of small mobile displays in work and entertainment contexts has increased, and hence the problem of reference-frame misalignment has become relevant in mobile map design [7][10][11]. If such problems are to be solved efficiently, scientific knowledge concerning the domain of map use and reference-frame misalignment should be provided for the designers of mobile maps. As mentioned, the practice of combining useful psychological knowledge with practical solutions is called user psychology [2][3]. In our case, this means generating experiment-based insights for both cognitive and practical understanding of mobile map use using psychological theories, methodology, and concepts. This is the aim of the present article, which will operate in the domain of designing mobile interfaces for large enclosed spaces, such as factory halls. An example of a mobile map useful in such a context is a map-based controller for crane automation. In the design of map-based mobile interfaces for operating with complex systems, such as port or industry cranes, any errors from reference-frame misalignment need to be minimised due to safety and efficiency concerns.

In tasks requiring map-based and experience-based environmental information, task times and error rates seem to increase in a proportion to the misalignment between the user's and the map's reference-frames. This effect is due to the mental rotation required to combine information from the two misaligned sources [6][8][9][12][13]. The cognitive demand of mentally rotating maps may also be associated with the complexity of the stimuli especially if the environment is new to the user [6][14]. The amount and complexity of stimuli on the map is especially critical in the case of mobile maps, as the screens are usually small and the interface must be designed frugally [15]. Additionally, as the number of objects on a small display increase, the visual search time increases [16]. It seems that the limited amount of short-term capacity limits the efficiency of map use due to the increased demand in both visual search and mental rotation [9][17].

Different user interface modifications for maps have been proposed to reduce the cognitive demand caused by the misaligned reference-frames. Rotating the map automatically is one obvious proposal, but its effect on the efficiency of the map use is not clear [18], cf. [11]. Letting the user choose

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between exocentric and egocentric perspectives, depending on the use situation, would often be preferable [19], but this effect may be difficult to accomplish with small displays and would be solving a problem by including new design problems. Further, automating the map rotation completely may be confusing to the user. However, there exists a variety of less intrusive ways to aid the map user in both mental rotation and visual search required in efficient map use.

For the experiment reported here, three map aids were designed to help the user mentally rotate a stationary, non-rotating mobile map. These ‘orientation aids’ were used to investigate the problem of misalignment in mobile maps and provide suggestions for the design of mobile map interfaces. The amount of objects on the map (map complexity) and reference-frame misalignment were manipulated to find out how different orientation aids would help the map user in making inferences based on the combined information from a map and an environment.

The first aid, a ‘You are here’ marker, familiar to the users of GPS navigators and stationary shopping mall maps, shows the location of the user on the map [15][19][20]. Maps with ‘you are here’ marker are not always as useful as one might imagine, especially if the marker is not accurate [21]. However, locating the user accurately on the screen has become technologically easier. For example, the studies of ‘you are here’ markers conducted in virtual worlds show that they are relatively easy and effective map aid, e.g., [19][20]. ‘You are here’ markers seem to aid processing of spatial information by offering cues to one’s location and its relation to the environment, but only if the location is salient and asymmetrical [22].

The second aid, landmark highlighting, makes a salient environmental object or feature visible on the map by making it distinct among the other map elements [23][24]. Conceptually and perceptually distinct locations (i.e. landmarks), have been shown to be effective aids in pedestrian navigation, for example [24]. Especially, if the map is complex, hierarchical, and has many objects, highlighting one of the more salient features provides for faster visual search [23]. Highlighted landmark also helps in mental rotation, as the user can discard other, less salient objects from the process and focus on visually salient features [24].

Third, direction symbols, such as the compass pointing to the north of the map, are often used to refer to the cardinal directions used in the map [4]. In a closed space, such as a factory hall or a shopping mall, it is possible to associate cardinal directions of the environment with the map. For example, associating the north wall of a factory with a certain symbol, and adding the same symbol to the map of the factory, may help the map user to align the two reference frames. Direction symbols associating the map directions with environmental directions may be especially effective when the environment is known to the map user [6][14].

Following hypotheses were formulated and tested in a laboratory experiment. The first two hypotheses were included to confirm that there indeed would be such effects as mental rotation and visual search associated with map use. Hypotheses H3–H5 were derived from the three orientation aids.

H1. As the misalignment between the referential frames of the map and the environment increases, map based decision times increase.

H2. Adding more objects increases map based decision times.

H3. Adding a ‘you are here’ marker to indicate the location of the user in the environment decreases map based decision times.

H4. Adding a landmark highlighting to represent a salient environmental feature decreases map based decision times.

H5. Adding direction symbols, referencing to the environmental directions decreases map based decision times.

The structure of the paper is as follows. Section 2 describes the laboratory experiment designed for testing the hypotheses above. The results of the experiment are reported in Section 3 and discussed in Section 4. The final Section 5 contextualises these results.

II. METHOD

Twelve (N = 12) participants were recruited for the first experiment. Their mean age was 23.8 years, SD = 3.3, and six of them were male and six female. All of the participants were right-handed, and had at least some experience with maps: when asked to estimate their own map using skills on a scale from 1 (‘no skills’) to 5 (‘expert’), seven of the participants gave the scale midpoint, ‘average skills’, and five reported having ‘advanced skills’ (scale value 4). This self-rating was not found to correlate with performance in the experiment.

Two sets of pictures were made, one for environments, and one for maps representing those environments. The goal was to create an abstract closed space with salient objects, such as one could find in a large factory hall. The environment pictures were photographs of wooden cubes, which were placed on a white canvas in an otherwise empty space with grey walls (Fig. 1). Multiple environment pictures were taken with following modifications. First, the number of the wooden cubes was four, seven, or ten. Second, camera was placed either at the front of the canvas (0°), the corner of the canvas (45° counter-clockwise), or the right side of the canvas (90° counter-clockwise; shown in Fig. 1). As the third modification, in some environments, one of the white wooden cubes was changed to a red, otherwise identical, cube, as shown in Fig. 1. For a number of different environments, two symbols, a triangle and a circle, were added to the wall. All cubes were identified with a letter.

The map pictures were constructed to accurately represent the configuration of the wooden cubes in the environment as black ‘target’ icons (Fig. 2). When the environment contained a red cube or direction symbols, corresponding orientation aids were added to the map: a red target instead of a black one to highlight a landmark, and direction symbols at the sides of the map to match the symbols on a wall. In order to test ‘you are here’ markers, a red dot was added to the map to indicate where the environment picture was taken, that is, where the participant

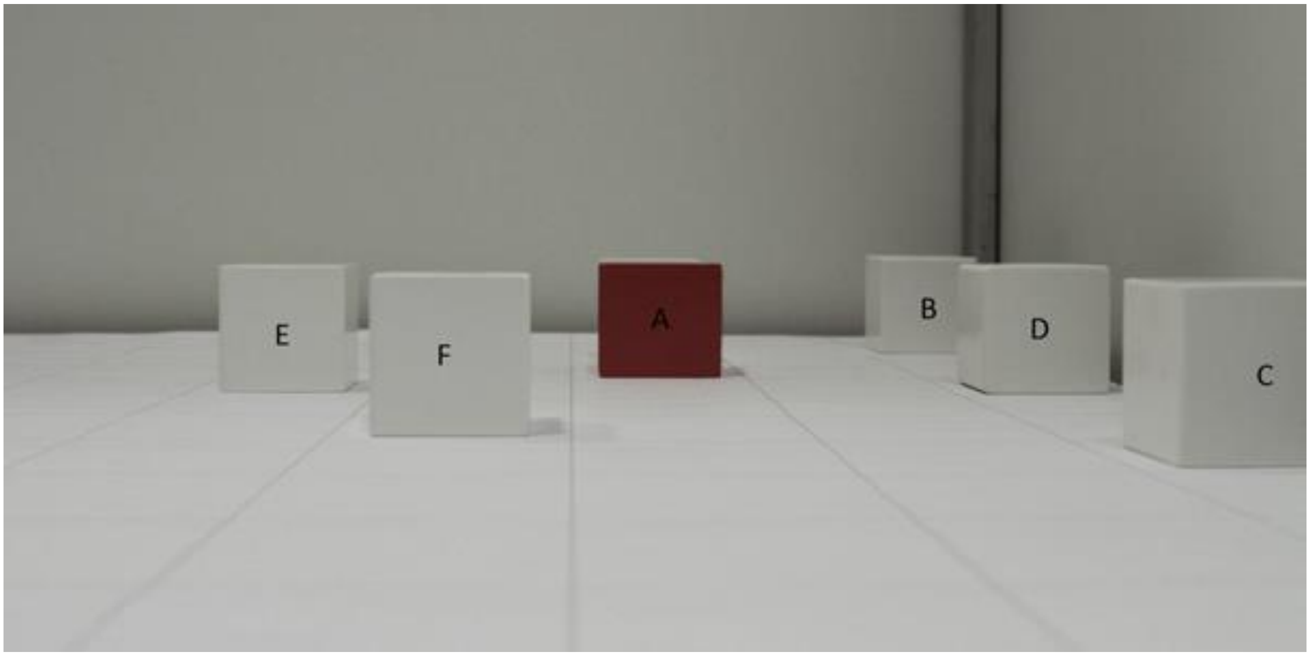

Figure 1. An example of the environment picture used in the experiment with landmark highlighting and 90° camera positioning. Corresponding map picture is seen in Fig. 2.

was 'standing' in the environment. Half of the maps were rotated 180° to increase the variation in misalignment between the environment and the map picture. This brought the total number of possible misalignments to five: 0°, 45°, 90°, 180°, and 135°. Due to environment rotations, some of the cubes were partly or almost fully occluded (e.g., Fig. 1, behind the A block). However, this did not benefit any single orientation aid, as the map templates were same for all tested aid.

One task consisted of an environment picture, a corresponding map picture, and a statement in the form of matching letter and number. (e.g., 'A = 5'). The task of the participant was to judge whether the statement was correct or incorrect by pressing either green (correct) or red (incorrect) button in front of them. Half of the statements were correct, and half incorrect. Each participant was presented 72 tasks (3 different number of cubes, 2 map rotations, 3 environment rotations and 4 orientation aids including a no aid -baseline). The order of the tasks was randomised for each participant. Before the tasks, the participants were given four easy tasks to practice the procedure.

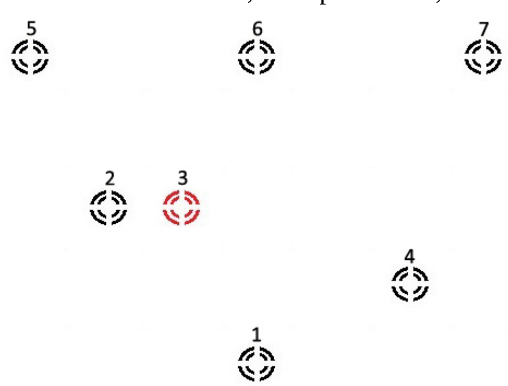

Figure 2. An example map picture, corresponding to the environment picture in Fig. 1. Red cube (target 3) is highlighted.

The participants were seated in a quiet laboratory room alone with the experimenter. In front of them, they had a 40-inch computer screen for the environment pictures, and to the left of it a 17-inch computer screen for the map pictures. The environment picture was scaled to take the whole 40 inch of the larger screen, but the map picture took less than half of the smaller screen and was therefore closer to a real mobile map size. A keyboard with one green and one red button was placed in front of the large screen. For half of the participants, the green button was on the left-hand side, and for the other half, on the right-hand side. The participants were instructed to have the index fingers of their both hands at the buttons. The participants completed a task by pressing either green or red button to indicate their agreement with the statement concerning the relation of the environment and the map. The reaction time (RT) was written into a log file, and the next task given after a brief pause. RTs have been often used in experimental studies of cognitive processing, also in studies of mental rotation and orientation [8][13]. Shorter RTs indicate that the processes associating stimuli with actions are less mentally demanding.

The data analysis was conducted using multilevel modelling ('Generalised linear mixed model' procedure in IBM SPSS 20), which is suitable for analysing nested longitudinal data, such as repeated RT measures within different experimental manipulations [25]. Contrasted, for example, with repeated measures analysis of variance, multilevel models are better suited to analyse nuanced effects, such as the size of individual intraclass correlation (i.e. how much RTs of a single participant correlate with each other) and learning during the tasks. The problem of individual differences in RTs (some participants tend to be faster than others in overall performance) has previously been solved with data normalisation [8], but multilevel models take this effect better into account.

In the multilevel model, RTs were predicted as gamma distribution with a log link, because the target distribution had only positive values and a positive skew (as is often the case with RT distributions; the gamma assumption was supported with a Q-Q plot) [25]. Because of the log link function, the coefficients of the resulting model can be interpreted as parameters in an exponential function. Fixed predictors in the model were the number of cubes in the task, the misalignment between the environment and map pictures, the included orientation aid (with baseline as a reference group), and the task number (to indicate learning as the experiment progresses).

III. Results

On average, the participants made less than three incorrect responses in the 72 tasks. Incorrect responses were deleted from the dataset, which resulted in 832 individual RT responses from the 12 participants. The mean of the mean RTs of the participants was 11.8 seconds, SD = 7.7. The mean of the fastest participant was 7.4 seconds per task, and the slowest participant took on average 22.3 seconds to complete a task. This difference in individual abilities (some are generally faster than others) was expected and taken into account in the multilevel model. The intraclass correlation coefficient was .37, indicating that there was, on average, a moderate correlation between the RTs of a single participant.

All of the fixed effects included in the multilevel model were statistically significant as seen in Table 1, which displays the model coefficients. These coefficients indicate the effect as a comparison to the first term of the effect variable. For example, the negative coefficient of landmark aid means that compared to the 'no aid' reference group the orientation aid reduced the RTs. The predicted RTs can be calculated as an exponential function of the terms. The predicted average RT (in milliseconds) for the first task with four cubes, no misalignment, and no orientation aid, would be calculated using only the intercept (because the reference groups are zero), and would hence be $e^{9.4}$ = 12209.9 milliseconds (12.2 seconds). For 'you are here' aid, for example, the average RT would be $e^{9.4-0.358}$ = 8450 (8.5 seconds) with four cubes, and $e^{9.4-0.358+0.345}$ = 11932 (12.0 seconds) with ten cubes.

The results indicate that compared to no aid, all of the orientation aids decreased RTs statistically significantly, when controlling for other effects in the model. The effect of 'you are here' marker was the largest of the three, and the effect of the direction symbols the smallest. The change in RTs when adding a 'you are here marker' for example, in an otherwise similar task, is

$$\frac{e^{9.410-0.358}}{e^{9.410}} = 0.699073. \quad (1)$$

In other words, while holding other effects fixed, adding a 'you are here' marker to a baseline map (no orientation aids) decreases RTs by 1–0.699 ≈ 30%. The corresponding number for landmark highlighting is 26%, and for direction symbols 16%. 'You are here' marker and landmark highlighting decrease map based judgment times more than the direction symbols.

Using the same formula, it is possible to calculate that an increase from four to seven cubes causes RTs to increase 4.8%, while increasing the number of cubes from four to ten causes an increase of 42%. Increasing misalignment to 45° increases RTs by only 7%, but a misalignment of 180° predicts 24% longer RTs when compared to 0° misalignment. These results indicate a clear linear effect of misalignment on map based judgments.

Mean normalised RTs by orientation aid, by the number of cubes, are also displayed in Fig. 3, but it should be noted that the multilevel model calculations offer more precise measure of the effect of orientation than the normalised RTs. However, the visual representation of the RTs restates the results of the multilevel model. What Fig. 3 adds to the multilevel model interpretation, is that it seems that with ten blocks, the helpful effect of symbols vanishes.

TABLE I. COEFFICIENTS OF THE FIXED EFFECTS IN PREDICTING RTS IN MAP BASED JUDGMENTS.

Fixed effect	Coefficient (s.e.)[a]
Intercept	9.410** (0.12)
Task number	–.002** (0.001)
Aid: landmark	–.297** (0.047)
Aid: symbols	–.173** (0.048)
Aid: 'you are here'	–.358** (0.047)
Aid: none	
Misalignment: 190	.219** (0.061)
Misalignment: 135	.206** (0.058)
Misalignment: 90	.101* (0.050)
Misalignment: 45	.068 (0.058)
Misalignment: 0	
Number of cubes: 10	.345** (0.041)
Number of cubes: 7	.074 (0.041)
Number of cubes: 4	

a. s.e. = standard error. *p < .05. **p < .01. N = 12, cases included = 832.

IV. Discussion

The multilevel model supported all five hypotheses (H1–H5) of the study. The increase in RTs as the function of the increase of misalignment (H1) was observed to be relatively linear, suggesting linearity of the mental rotations required to align the map with the environment, a result which is in line with previous results concerning mental rotation and orientation [8][12]. It is possible that the linearity assumption can be replaced with more precise estimates, such as Fitt's law, which has been shown to hold for mental rotation [26], but this investigation would require different a kind of analysis. Further, it is possible that data on non-prototypical angles, would prove interesting, as it has been shown that there is a bias towards perceiving non-prototypical angles as prototypical [27]. Regardless, the effect size of the

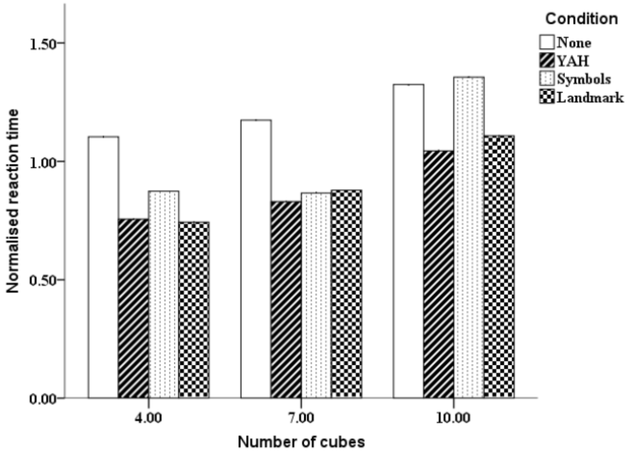

Figure 3. Mean normalised RTs between the orientation aids, by the number of cubes.

misalignment was smaller than the effect size of the number of cubes. This result is somewhat different from earlier similar experiments with reference-frame misaligned maps, e.g., [4]. One possibility is that the orientation was relatively easy, as both the environment and the map had clear, rectangular borders. Future experiments should consider this geometrical detail.

The effect size of the number of blocks (H2) was large, but it seems that the relationship between the number of blocks and RTs is not linear. In fact, almost no increase was observed in RTs when increasing the number of blocks from four to seven. It seems the tasks become more difficult only after seven items. This finding is in line with similar findings concerning search in interrupted visual search tasks [16], and may be at least partly explained by the capacity of the visual short-term memory [9][17]. When a map user is combining information from two sources (the map and the environment), information needs to be rehearsed in visual short-term memory in order to make successful alignment of the differing reference frames [9].

All three orientation aids were confirmed to decrease RTs, giving support to H3–H5. Hence, the laboratory experiment supports the use of the proposed solutions for decreasing judgment times, and possibly errors, when using mobile maps in restricted spaces. Comparing the effect sizes, it seems that landmark highlighting and a ‘you are here’ marker provided better support for map based judgments than direction symbols, especially with larger number of targets. The difference between ‘you are here’ marker and landmark highlighting, on the other hand, was small. Further experimentation should be planned to investigate interaction effects between the orientation aids and the number of items in the small display. Another suggested interaction study should focus on combining different orientation aids together.

The results reported here are also limited to a controlled laboratory setting, which is useful in studying cognitive mechanisms, but not for technology use in the real world. Hence, next steps for ascertaining ecological validity of the results would be to implement the orientation aids on an actual mobile map. Further, users with real-life goals should be utilised in testing the aids. In the laboratory experiment reported here, the participants did not have real-life goal. Both cognitive aspects, studied with experiments, and real-life, goal-oriented action, are necessary for successful designs.

While both ‘you are here’ marker and landmark highlighting have been proposed as orientation aids before, e.g., [7][19][20], the experiment reported here was first to compare these aids, and do so in the context of small displays. The results confirm the usefulness of the aids with varying number of environmental and map items, and varying degrees of reference-frame misalignment. The main results cohere with two important cognitive paradigms, visual rotation [12][13], and a number of important memory and stimulus set size effects such as visual short-term memory and Sternberg-paradigm [17][28][29]. This is in line with the user psychological research strategy of explaining or supporting laboratory user experiments and subsequent design by means of coherence between them and traditional findings of basic research [3].

V. CONCLUSION

In the design process of orientation aids for mobile maps, three orientation aids for improving map-based decisions were evaluated. A laboratory study suggested that having either a ‘you are here’ marker, a landmark highlighting, or canonical direction symbols as an orientation aid decreases RTs in map-based judgments. Another finding suggested that an increase in the number of items on the map quickly increases map based judgment times. Further, there seems to be an interaction effect between the orientation aid and the number of targets on the map: with ten targets, the direction symbols were not as efficient as the other two orientation aids. These findings can be used to design map-based mobile displays for efficient operation within relatively confined spaces, with relatively small number of important environment targets.

The central result of the study reported here is therefore that having either ‘you are here’ marker or landmark highlighting on the map is enough to allow for efficient map use, at least in a confined environment. These markers are not, however, a feasible option if their accuracy is questionable [21], and hence they are recommended only for situations, in which the accuracy can be guaranteed. Compared to ‘you are here’ marker, landmark highlighting offers technologically easier and stable way to aid in map based judgments, and should be considered as a viable alternative. On the other hand, landmark highlighting may not always be possible due to the dynamic nature of environments, such as factory halls. Therefore, while both orientation aids have been proven useful, the context of the use will need to be taken into account when choosing between orientation aids. Further, as individual differences between spatial cognition have been found [30], it is suggested that the choice of orientation aids may at some cases be left to the user.

Increasing the complexity of interaction in already complex environments poses problems for interface design. New features, such as orientation aids in mobile maps may make work tasks more efficient, but may also introduce additional usability problems, interferences, and sources for anxiety to the users. In order to facilitate the use of more complex automated features, new, smart interface solutions need to be conceptualised. The experiment presented in this article demonstrates how the understanding on human cognitive processes can give experimental insight into the evaluation of new design concepts.

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