Landmarks on Mobile Maps: Roles of Visual Variables in the Acquisition of Spatial Knowledge

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Abstract /

This study presents the evaluation of a new design of mobile maps to overcome the limit of the small screen by visualizing landmarks which are normally invisible as located beyond the displayed map extent. The visualization of distant landmarks adapts a specific cartographic visual variable: size, fuzziness, or transparency, respectively, to conceptualize distances in three ranges: nearby, intermediate, and far. To evaluate the effectiveness of each design on acquisition of spatial knowledge, this study carries out an online experiment and then a field experiment in the actual environment. In the online experiment, participants see the static default screen of the mobile maps with landmarks. In the field experiment, participants can interact with the mobile map App which allows them to tap, pan, or zoom the map. Results show that both online and field experiments yield similar findings, although the results from field experiment with allowed interaction are better. In general, the visualization of distant landmarks contributes to the spatial learning. Individual visual variables such as fuzziness and transparency, however, facilitate the acquisition of spatial knowledge better than size.

Keywords /

mobile map; distant landmarks; visual variables, spatial knowledge; orientation

INTRODUCTION

Using maps is an essential means of acquiring spatial knowledge for wayfinding. With the increasing usage of mobile devices in one's daily lives, mobile maps have become a major source, compared to traditional paper maps. Many researchers suggest that the small screen size on mobile devices limits the acquisition of spatial knowledge. In particular, user's acquired spatial knowledge and accuracy from mobile maps decrease as screen size shrinks (Dillemuth, 2009). In the specific case of using mobile devices for navigation, the passive following mode together with mobile maps lead to spatial disorientation (Gardony et al., 2013; Ishikawa et al., 2008). Although many factors lead to the degradation of acquired spatial knowledge and orientation, this study focuses on the small map display and evaluates a new design of visualizing spatial information on the small screen to facilitate the acquisition of spatial knowledge.

Small screen size limits the amount of spatial information that can be displayed at once. If a method can imply information of locations beyond the mapped extent on the screen, one can acquire more spatial knowledge of the surroundings. Researchers in the field of human-computer interaction suggest possible ways to visualize distance to locations beyond the mapped extent. For example, methods such as Halo approach (Baudisch & Rosenholtz, 2003) and Wedge approach (Gustafson et al., 2008) can convey distance to locations at the edge of the mobile screen using the geometry of partial arc or triangle, respectively. Users need to mentally complete the arc or triangle to imply the distant location. These methods overcome the limit of small screen size by visualizing distance to a location beyond the displaced map extent. The identity of the visualized distant location, however, remains generic in these methods. Building on previous approaches, we introduce the visualization of landmarks at distant locations. The knowledge of landmarks, which refer to visually salient objects due to their characteristics of colors, sign, and visibility (Sorrows & Hirtle, 1999), can serve as nodes to organize spatial knowledge, which is important to developing mental representations (Siegel & White, 1975) and wayfinding success (Couclelis et al., 1987). People not only memorize landmarks easily but also integrate them with path information when they are building mental representations. Locations in the environment and paths of connecting them work as anchors and vectors of developing spatial knowledge (Allen et al., 2014; Mittelstaedt & Mittelstaedt, 1980). Therefore, providing information of landmarks, especially those beyond the mapped extent, may effectively enhance the acquisition of spatial knowledge of the larger surroundings. We term the landmarks located beyond the mapped extent *distant landmarks* in this study.

This new design starts with evaluating the effectiveness of visualized distant landmarks without the consideration of their distance (Li et al., 2014). After testifying the roles of landmark identity, the authors explore ways to visualize the distance to distant landmarks. As a way of symbolizing distance, which is metric information, the authors then select visual variables of cartography (MacEachren et al., 2012) suitable for representing distance (metric) information (Li, 2017). Theoretically, effective visual variables for visualizing distant landmarks are *size*, *fuzziness*, and *transparency*. However, the effectiveness of these visual variables on facilitating the acquisition of spatial knowledge is unknown, which motivates the design of this study.

This study creates three designs for visualizing distant landmarks, each of which adapts one of the three visual variables. This study investigates the effectiveness of selected visual variables to provide empirical evidence of the new design for enhancing acquiring spatial knowledge through mobile devices. Using the same design, this study first carries out an online experiment and then a field experiment in the actual environment. The difference is that participants in the online experiment can only see a static screenshot of the design, while participants in the field experiment can interact with the design by zooming, panning, and clicking on the mobile phone screen. On the one hand, the purpose is to investigate if the added interaction with the small screen can influence the acquisition of spatial knowledge. On the other hand, another purpose is to test the reliability of the online experiment, which might be a cost-efficient solution for evaluating future designs of distant landmarks.

DESIGN

The study adapts the conceptualization of distance carried out in a previous study (Li & Zhao, 2017). As a result, the representation of distance to landmarks is at the ordinal level. The three levels are nearby, intermediate, and far distant landmarks. Eleven were landmarks selected from a survey of residents who were familiar with the environment. Based on their distance to default user location, distance within 2,000m from the user's location is considered nearby; distance between 2,000m and 3,000m is considered intermediate, and distance over 3000m is considered far. This design results in three distant landmarks and eight local landmarks on the default map, in addition to the indicator of user's location. Each distant landmark is bounded in a bold square to imply the nature of being distant. When a landmark does not have a bold square, it indicates a local landmark at its actual location on map. Using the visual variable *size*, 90 x 90 pixels icons are for nearby distant or local locations, 60 x 60 pixels icons are for intermediate distant locations, and 30 x 30 pixels icons are for far distant locations, respectively. Using the visual variable *fuzziness*, icons in the intermediate group and in the far group are blurred by 3% and 6% respectively, both horizontally and vertically. Icons in the nearby and local categories are not blurred. Using the visual variable *transparency*, 75% and 50% opacity is applied respectively, to the icons for middle and far distant landmarks. Icons in the nearby and local categories retain 100% opacity. All icons are created using the tool Inkscape (inkscape.org) with open-source elements from Flaticon (flaticon.com). Figure 1 illustrates the concept of visualizing distant landmarks and three scenarios of using a specific visual variable transparency and Google Maps as the base map.

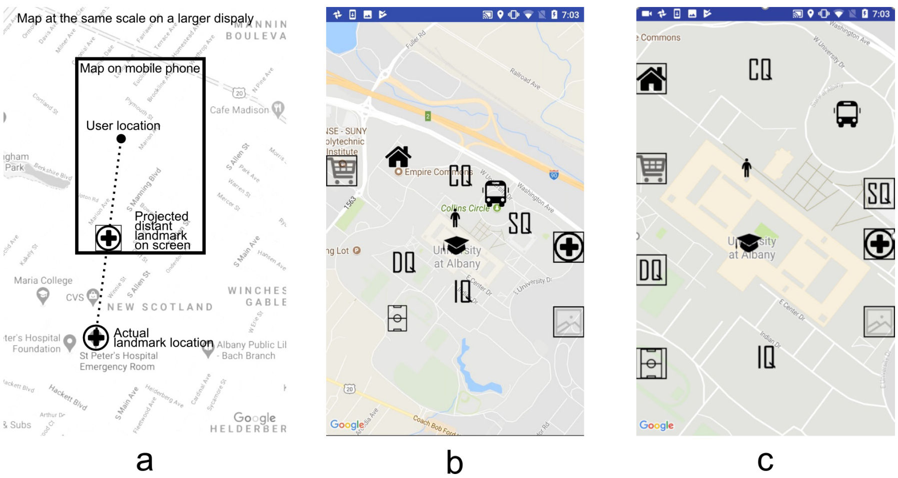

Figure 1 /

Illustration of visualizing a distant landmark on mobile map and screenshot of the designed mobile map with the visual variable *transparency*. Based on the distance, a distant landmark is projected to the edge of mobile map with a bounding square (a). On the default map scale, there are three distant landmarks representing three different level of distance (b). When the map scale increases to include a smaller area, many local landmarks become distant landmarks, which are projected at the edge of the screen (c).

ONLINE EXPERIMENT

To evaluate the acquisition of spatial knowledge using a distant landmark design, this study carried out an online experiment first. The online experiment only used a static screenshot of the default map (e.g., Figure 1.b) of each scenario on the platform of Amazon Mechanical Turk (MTurk).

Participants were from all over the world, which represented a very diverse group that could shed light on the effectiveness of designs in each scenario. In total 164 individuals participated in the online experiment. Each participant could only sign up for one scenario. After excluding the incomplete and invalid responses (6 in the size scenario, 6 in the fuzziness group, and 1 in the transparency scenario), the final dataset consisted of complete responses from 50 participants in the size scenario, 51 participants in the fuzziness scenario, and 50 participants in the transparency scenario.

Methods

Each participant was required to answer 10 questions by typing their answers. This was done to avoid participant's random guessing as they needed to understand the design. If a participant's typed answer was not relevant to any of the icons or part of the App, the participant's answer was considered invalid and excluded from data analysis. Instructions oriented each participant that he or she was in an environment with a mobile device as shown on their screen. The human symbol at the center indicated his or her location in an unfamiliar environment (Figure 1.b). Other icons showed important landmarks in the surroundings. The instructions informed each participant of the name of each icon, the design of distant landmarks in each scenario, and how distant landmarks varied. To complete the tasks, participants in the size scenario needed to compare the relative sizes of icon to determine the relative distances symbolized in distant landmarks. Participants in the fuzziness scenario needed to compare the fuzziness of symbol to determine the relative distance in distant landmarks. Participants in the transparency scenario needed to compare the opacity of symbol to determine relative distances symbolized in distant landmarks.

The ten questions consisted of four categories: 1) one question to name the closest and one questions to name the furthest landmark; 2) two questions to name the closer landmark between two local landmarks (*e.g., Between the bus stop and classroom, which is the closer location to you?*); 3) three questions to name the closer landmark between one local and one distant landmark (e.g., *Between supermarket and classroom, which is the closer location to you?*); and 4) three questions to name the closer landmark between two distant landmarks (e.g., *Between supermarket and museum, which is the closer location to you?*).

The first category of questions verified if participants understood the icons in the design. The other questions investigated if participants could distinguish the relative distance information symbolized in local and distant landmarks. A correct answer to each question resulted in 10 points for calculating their performance (rate of correct points in each category of questions). The presentation of results was also based on the four categoies of tasks.

Results

Participants in all three groups took similar time (in seconds) to complete the experiment without significant differences among all three scenarios (Size: M = 293.86, SD = 240.51; Fuzziness: M = 284.22, SD = 453.75; Transparency: M = 252.04, SD = 337.35, p = .83). The performance in each category of tasks is the dependent variables in a one-way ANOVA using scenario (visual variable) as the independent variable. This statistical analysis is to compare the roles of each visual variable on acquiring distance knowledge from the designed interface. In the tasks of selecting the closest and furthest landmarks, participants needed to identify the shortest and longest distance from their location to a specific landmark. They had no difficulty finding the closest land-mark regardless of their scenarios. The performance of selecting the furthest landmark represented by the distant landmarks using a particular visual variable, however, was different.

In general, participants had very poor performance finding the most distant landmark in all three scenarios (Size: M = 0.22, SD = 0.42; Fuzziness: M = 0.61, SD = 0.49; Transparency: M = 0.44, SD = 0.50). However, size scenario results had the lowest accuracy. One-way ANOVA shows significant differences among three scenarios (F (2, 148) = 8.55, p < .001, partial η^2= .10). Post-hoc comparison using Tukey-HSD indicates that the participant's performance in size scenario is significantly lower than that in fuzziness scenario (p < .001). The difference between size and transparency is marginal (p = .055). This suggests that size is the least effective visual variable for representing distance to distant locations beyond the mapped area. Figure 2 shows the participants' performance in this category of tasks.

In the tasks of comparing distance between two local landmarks, participant's performance was similar (Figure 3). All participants in both size and transparency scenarios made no error (M = 1.00, SD = .00) while participants in the fuzziness scenario made very few errors (M = 0.94, SD = 0.24). All three types of visual variables show no different effects for Text Boxlocal landmarks.

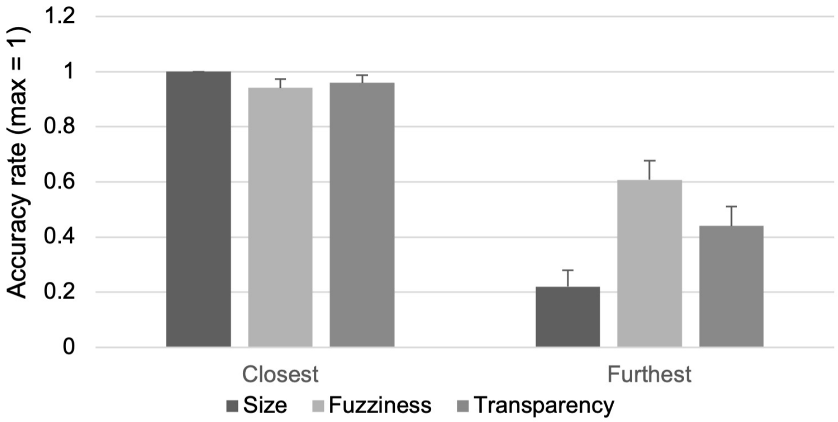

Figure 2 /

Participants' performance of selecting the closest and the furthest landmark in the online experiment.

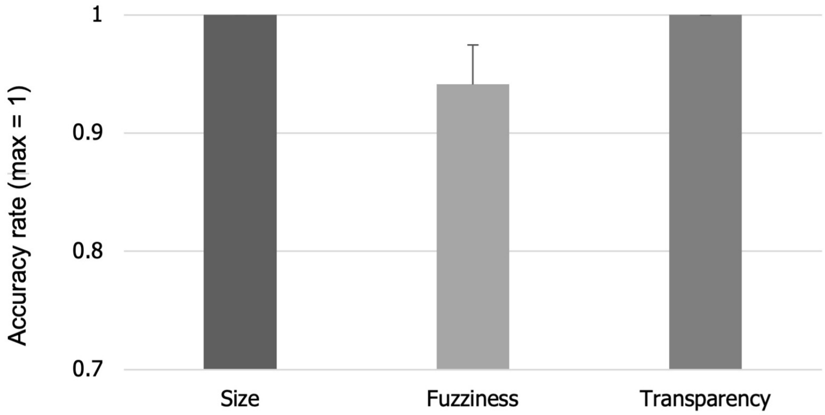

Figure 3 /

Participants' accuracy in the task of comparing two local landmarks.

In the tasks of comparing, one local landmark and one distant landmark, difference exists across scenarios (F (2, 148) = 3.90, p = .022, partial η^2= .05). Post hoc comparison using Tukey-HSD indicates that participant's performance in size scenario (M = 1.00, SD = .00) is not significantly different than that in fuzziness scenario (M = 0.97, SD = 0.16), but different from that in transparency scenario (M = 0.92, SD = 0.20), (p = .018). There is no difference in performance between the fuzziness and the transparency scenario. This is to imply that when both local landmark for a location on screen and distant landmark for a location off screen are involved, visual variable size seems more important. But considering its ineffectiveness for indicating the location of longest distance, it may not be the best option for actual use.

In the tasks of comparing two distant landmarks, significant difference exists among the three scenarios (F (2, 148) = 44.53, p < .001, partial $\eta 2$= .38). As shown in Figure 5, post-hoc comparison using Tukey-HSD shows that participants in the fuzziness group have the lowest accuracy (M = 0.55, SD = 0.22) compared to that in the size scenario (M = 0.64, SD = 0.21 and transparency scenario (M = 0.91, SD = 0.17). Accuracy from both size and fuzziness scenarios does not show difference. When all involved landmarks are distant landmarks, visual transparency has the greatest effect while size has the least effect.

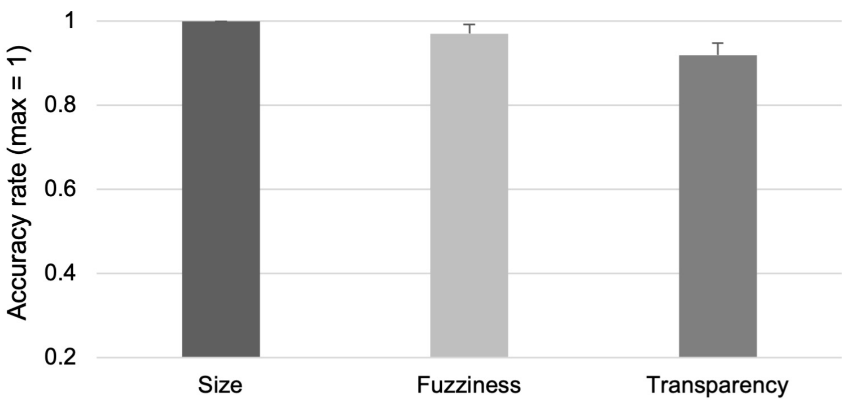

Figure 4 /

Participants' performance in tasks of comparing one local and one distant landmark.

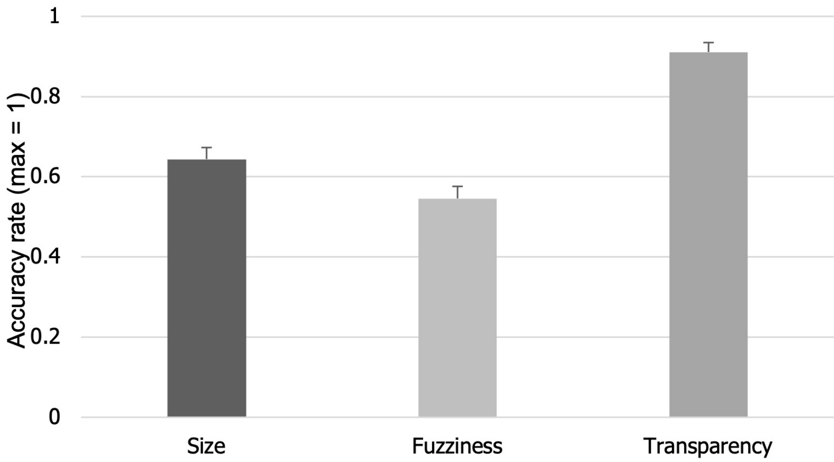

Figure 5 /

Participants' accuracy in comparing two distant landmarks.

Discussion

It is not surprising to find that almost all participants had no problem finding the closest landmark to them as well as comparing distances of local landmarks. These local landmarks simulated the existing mobile map display in everyone's daily experiences. The distance between a landmark symbol and user's symbol was intuitively visualized on screen. Participant's performance in both tasks also shows similar results indicating that they have little problem understanding local landmarks.

In the tasks of comparing one local landmark and one distant landmark, participant's performance was also good with slight differences among scenarios. Transparency seemed slightly more difficult for comparing landmarks in two qualitatively different categories (i.e., a local landmark vs. a distant landmark). One likely reason is that these participants still treat symbols of distant locations as indicating their positions on screen. Therefore, participants still employed the distance on the display as the only criterion for comparing distance instead of comparing the transparency or fuzziness of icons. When there was a distant landmark at the edge of screen whose position was closer to the center than the position of a local landmark, some participants may have assumed that the distant landmark's symbol indicated a closer location.

In summary, this experiment compared three visual variables in terms of their effects on acquiring distance knowledge based on visualized local and distant landmarks. Each visual variable had different effects on acquiring distance knowledge. In particular, the visual variable size does not seem to effectively help users identify the furthest location. The other two visual variables, fuzziness and transparency, had a stronger overall effect on understanding distances when comparing locations on screen and off screen.

There are two main reasons leading to these results. The first is that participants in each scenario may not have fully understood how the change of size, fuzziness, or transparency indicates relative distance off screen. Instead of choosing an icon of the smallest size or the most transparent for the furthest landmark, participants may have used the distance between the icon's positions on screen as their criterion. The second reason is related to the use of online environment. The static screenshot used of the online environment may have made it harder for participants to distinguish the change of size, fuzziness, and transparency in symbols, as it prohibits any interaction with the design. A follow-up question is whether a user can perform better in terms of acquiring spatial knowledge if he or she can interact with the map interface such as tap, pan, or zoom using their own mobile phone.

FIELD EXPERIMENT

To answer the follow-up question, this study carried out a field experiment in a real-world environment. As mentioned earlier, one objective is to investigate if the interaction with the map in a real environment would lead to different performance. Another objective is to verify if the online experiment, a cost-efficient setup, can lead to reliable results.

Methods

For this field experiment, the design of local and distant landmarks is implemented as a prototype. This prototype is installed on an Android phone (Google Nexus 5X) with a 5-inch screen. The interface of the mobile map is the same as that used in the online experiment. The only difference is the enabled interaction on the mobile phone, as a user can tap an icon to know its name, can pan the map to see other areas, or can zoom the map to a larger or smaller scale. When a user pans or zooms the map, the distance between each landmark and the user is recalculated and visualized on the map. As Figure 1b and 1c show, when a user zooms the map to a larger scale, many local landmarks fall out of the mapped extent, and hence are visualized as distant landmarks at the edge of the screen.

In addition to the same 10 tasks used in the online experiment, the field experiment employed additional tasks to investigate if participants could establish spatial orientation in the real-world environment: Participants were asked to give directions from their actual location to an unseen distant location (e.g., Science Library Entrance), that is not visualized on the App. One task was carried out at the beginning of this experiment to verify participants' unfamiliarity with the environment. Another one was carried out after using this App to investigate if participants establish spatial orientation in the physical environment. In addition, three psychometric tests measured participants' spatial ability.

A self-rated measure was not employed in this experiment as the test had promising correlation with participant's acquisition of spatial knowledge and performance in the environment without the interaction with additional sources such maps. Since this experiment still involves the use of mobile maps while in the environment, we adapted the tests from studies which have a similar involvement of environment, map, and spatial performance. For example, previous studies investigating spatial learning using maps between online and field experiments validate these tests (see Liben et al., 2010). Three tests collected scores of participants from a 0 to 10 scale in Paper Folding Test (PFT), Mental Rotation Test (MRT), and Water Level Test (WLT). The PFT was used for testing visuospatial memory (Linn & Petersen, 1985). MRT is based on the adapted version research for testing mental rotation ability (Vandenberg & Kuse, 1978). WLT measures spatial perception based on objects' orientation and configuration.

Environment

The underground tunnel system on one of the authors' university campus was the site for this field experiment. The tunnels are constantly reported to be places for students to easily get lost due to their highly symmetric structure, limited visual cues to the outdoors,

Figure 6 /

Three testing locations in the underground tunnels: i) tunnel underneath Arts and Science Building, ii) lower level in the tunnel underneath the Lecture Center, iii) tunnel underneath Fine Art Building (Base map source: Open Street Map).

and lack of appropriate signage. Three locations were selected in the tunnels. Test locations were separated from each other by about a two- to three-minute walk (see Figure 6).

Participants and Procedure

In total, 20 participants from two nearby university campuses, who were unfamiliar with the tunnel system took part in the experiment. Their ages ranged from 18 to 28 years-old (M = 21.45, SD = 2.48). The field experiment began in a laboratory with close access to the tunnel system. The lab was also used for a participant to store their personal belongings and give their consent. The experimenter then lead each participant to the tunnel system to perform tasks using the App. The order of locations and visual variable scenarios were randomized for each participant. At the first test location, the participant was asked to give an initial estimation of direction to an unseen distant location, which was not visualized in the App. This was to check if a participant was familiar with the environment. At a testing location, participants answered the same ten questions, the same as those in the online experiment, while using the App. Participants could tap, pan, or zoom in the App to help them answer the questions. The App recorded the frequency of tapping, panning, and zooming as a measure of interaction. At the last testing location, participants estimated the direction to the unseen distant location again. After all tasks, the participant and the experimenter came back to the lab and completed the three psychometric tests with a three-minute timer for each task.

Results

Similar to the analyses of the online experiment, each performance and interaction measured with the App was entered as a dependent variable in a repeated measures ANOVA. The purpose of using the analysis is to compare if specific visual variables have different effects on the acquisition of spatial knowledge and the development of spatial orientation in the actual environment. The within-subject variable is the scenario of three designs while spatial ability is the between-subject variable in each repeated measure. To code the spatial ability, the authors used the combined scores of PFT and MRT, as participants show no difference in the WLT. If the combined score of both tests was above 50% of the maximum combined score, corresponding participants were placed in the high spatial ability group. Likewise, participants whose combined score were lower than the

50% of the maximum combined score, were placed in the low spatial ability group. All participants completed the experiment with an average duration of 43 minutes. The range of time was between a maximum of 57 minutes and a minimum of 30 minutes.

Interaction with App

The repeated measures ANOVA with Greenhouse-Geisser correction shows that the number of panning in the App differ significantly among three scenarios (F (1.08, 19.41) = 8.75, p = .001, partial η^2= .33) (Figure 7). Participants in the size scenario panned 11.85 times more than those in the fuzziness scenario and 12.15 times more than those in the transparency scenario. The effect of spatial ability on the panning frequency was marginal (F (1, 18) = 24.20, p =.057, partial η^2= .57). Participants with higher spatial ability (M = 9.50, SD = 10.90) panned fewer times than those with lower spatial ability (M = 22.90, SD = 21.88). There was no interaction effect of visual variable and spatial ability on panning. Neither the visual variable nor spatial ability had significant effect on tapping or zooming. Regarding usability, size seemed least effective as it required more interaction with the App in order to understand the design, especially if a user's spatial ability was not high.

Acquisition of Spatial Knowledge

Performing the same tasks as in the online experiment, participants in the field experiment performed accurately in selecting the closest landmark (Size: M = 0.90, SD = 0.31; Fuzziness: M= 0.85, SD = 0.37; Transparency: M = 0.95, SD = 0.22). This shows how the interaction enabled in the field experiment contributed to participant's performance. Participants in the field experiment, however, differed in their accuracy of selecting the furthest landmark among three scenarios, as shown in Figure 8. The repeated measures ANOVA with Greenhouse-Geisser correction showed that the participant's accuracy of selecting the furthest landmark differed significantly among three scenarios (F (1.49, 26.78) = 5.23, p = .019, partial η^2= .23). Participants in the size scenario had the lowest accuracy (M = 0.65, SD = 0.49) while they had very high accuracy in the fuzziness (M = 0.95, SD = 0.32) and transparency scenarios (M = 0.95, SD = 0.23). Similar to the findings in the online experiment, the visual variable size seemed least effective for supporting the acquisition of distance knowledge of locations beyond the mapped area.

Spatial ability had a significant effect on the performance of comparing the distance between two local landmarks (F (1, 18) = 6.79, p = .018, partial η^2= .27). As shown in Figure 9, participants with lower spatial ability with regard to a scenario had poorer performance (M = 0.85, SD = 0.17) compared to those with higher spatial ability (M = 0.93, SD = 0.13). This significant effect of spatial ability also existed in the performance of comparing one local landmark with one distant landmark (F (1, 18) = 10.97, p = .004, partial η^2 = .38). Regardless of the visual variable, participants with lower

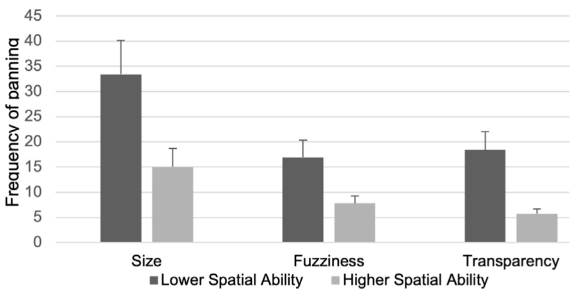

Figure 7 /

Participant's mean frequency of panning by visual variables and spatial ability.

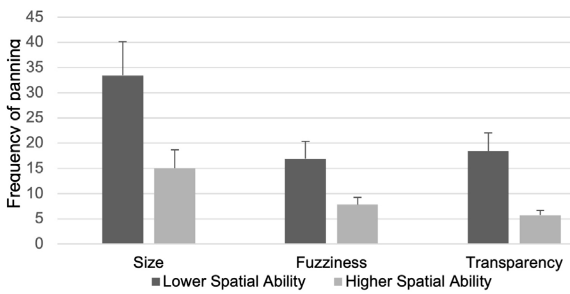

Figure 8 /

Participant's performance of selecting the furthest landmark by scenario and spatial ability.

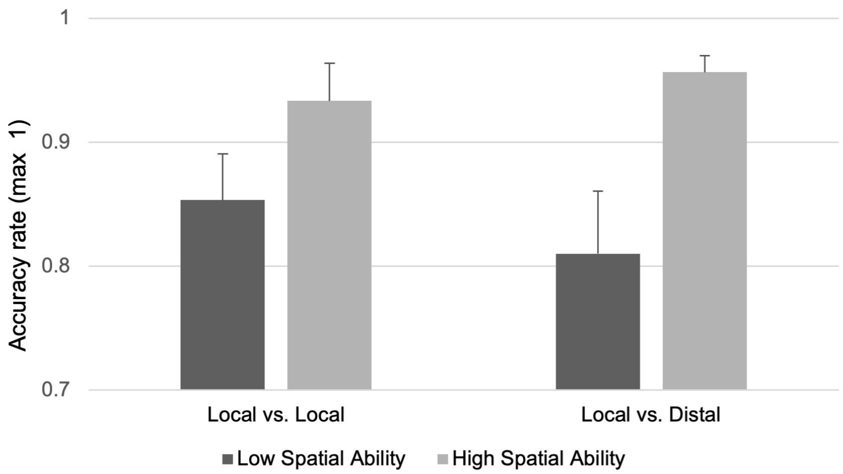

Figure 9 /

Participant's performance of comparing the distance between two local landmarks (local vs. local) and between one local landmark and one distant landmark (local vs. distant).

spatial ability had lower accuracy (*M* = 0.81, *SD*= 0.23) compared to those with higher spatial ability (*M* = 0.96, *SD* = 0.06). No main effect of spatial ability nor visual variable was significant in the accuracy of comparing the distance between two distant landmarks. The field experiment further clarifies that a user's spatial ability can impact the acquisition of spatial knowledge, regardless of visual variables.

In the field experiment, participants estimated the direction to a distant location which was not visualized in the App. This was to investigate if users could establish spatial orientation through establishing directions to locations in the environment. As shown in Figure 10, the pointing errors to the unseen object were impacted by spatial ability in both before- and after- App performance (Pre: F (1, 18) = 4.68, p = .044, partial η^2 = .21; Post: F (1, 18) = 14.73, p = .004, partial η^2 = .46). The pointing errors decreased after using the App but did not differ among the three scenarios. With very brief usage of the App, the spatial ability of participants differently impacted their acquisition of spatial knowledge at the survey

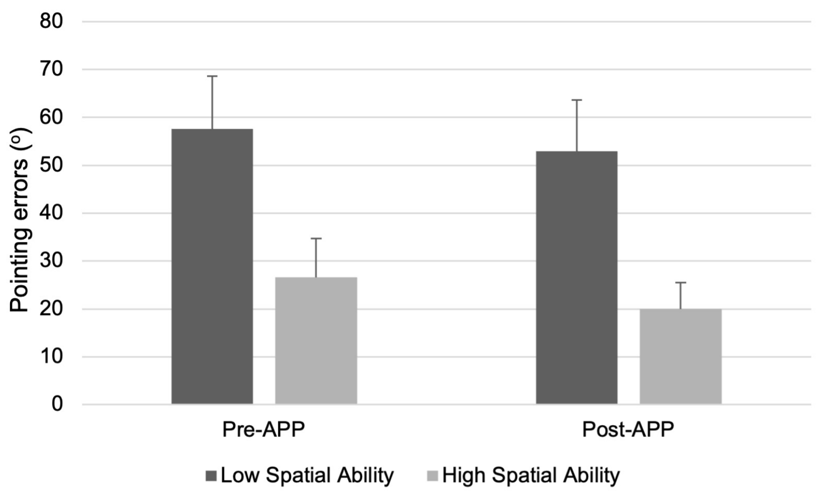

Figure 10 /

Pointing errors of participants before and after using the App.

level. In general, the App using different visual variables contributes to the development of spatial orientation, but spatial ability is a critical factor that determines the accuracy of one's spatial orientation.

Discussion

The results of the statistical analyses reported in previous section compare differences among individual's visual variables that have implication for their effectiveness. This section discusses the effects of these visual variables in relation to the findings of the online experiment, and on the usability of the results, acquisition of spatial knowledge and development of spatial orientation, as well as the implication of these results for future studies.

Usability

Results clearly show that icon size is not effective for visualizing distant landmarks, as it requires a user to pan more on the screen to understand the symbolized landmarks and acquire spatial knowledge. Participants in both fuzziness and transparency scenarios pan significantly fewer times to learn about all visualized landmarks and the surroundings. Results also show that the participant's spatial ability influences the frequency of panning in this experiment. If a user's spatial ability is relatively higher, he or she pans fewer times than those with lower spatial ability. In short, the visual variables of fuzziness and transparency seem more important than size for providing better usability. This suggestion is further supported by the effects of visual variables on acquiring spatial knowledge.

Acquisition of spatial knowledge

When a participant was asked to compare the distance between two landmarks, he or she needed to acquire the distance knowledge symbolized in the landmarks. The result of comparing the closest distance in the field experiment was consistent to the online experiment. The participant's performance in naming the closer location between a pair of visualized landmarks, which can be both local, both distant, or one local and one distant, showed all three visual variables effectively represented both local and distant landmarks, with the lowest accuracy above 85%. In addition, spatial ability has some impact on the performance. When comparing two local landmarks or one local vs. one distant landmark, higher spatial ability leads to better performance. In short, with the visualized distant landmarks, participants using the App can acquire spatial knowledge to distinguish their relative distance correctly.

The performance for judging the longest distance, however, is worth noting. The results of the online experiment show very low accuracy across all scenarios. In the field experiment, the interaction with the actual App benefits participants understanding the design and using it for acquiring distance knowledge through designed landmarks. Although the size visual variable yields much higher accuracy than that in the online experiment, it leads to the lowest accuracy of 65%. In the field study, it is still much higher than in the online experiment. In addition to usability, size also seems not an ideal visual variable to visualize distant landmarks, compared to fuzziness or transparency, due to its small effect on the acquisition of spatial knowledge.

Spatial orientation in the environment

One additional goal of the field study was to investigate if using the App can facilitate one's spatial orientation in the environment. In the field experiment, participants needed to align their mental representation of the tunnel with the campus to estimate direction to the unseen distant location. The scenario and spatial ability did not influence the performance pre- and post-using the App. Participant's larger errors before using this App confirmed their unfamiliarity with the tunnel. The unfamiliarity with the tunnel made it harder for them to align it with their mental representation of the campus. There is no clear difference among all three visual variables regarding their effects on spatial orientation, as their effects seem similar in this aspect. Spatial ability, however, seems a more influential factor that differentiates participants regarding spatial orientation. Participants with higher spatial ability consistently had higher accuracy of spatial orientation than those with lower spatial ability, regardless pre- or post-using the App.

Although the chosen locations in the tunnel were not familiar to participants, once participants could correctly align their quickly learned tunnel space with the outdoor environment, they could use what they knew about the outdoor environment to help with their spatial orientation. This may explain the significant effect of spatial ability in the estimation tasks. Spatial ability is categorized based on the combined score of the paper folding tasks (PFT) and mental rotation tasks (MRT) which reflect the visuospatial memory and mental rotation ability of a person. Therefore, if a participant is good at mental rotation, he or she can easily rotate their mental map of the learned tunnel space and align it with the campus environment, which contributes to the higher accuracy of the pointing task. In future studies, instead of using spatial ability test, self-ratings such sense of direction, spatial strategies can also be included and used to correlate participant's performance to further clarify the roles of spatial ability and the visual variables on spatial orientation.

CONCLUSION

Through the two experiments, one online and one in the field, this study has assessed the potential of using an online environment in assessing the effects of design. An online environment can be a cost-efficient solution for assessing the acquisition of spatial knowledge, even though limited user information is collected. In the meantime, it is important to note that the performance online is slightly poorer than in field experiment, but the difference of performance among designed scenarios are consistent with that in field experiment. The performance of participants online is likely impacted by the use of static screenshots. The results, however, can shed light on user's performance in a real-world environment. For comparing various scenarios, the online experiment is a cost-effective choice, although it cannot provide all necessary data for a more comprehensive understating as in a field experiment. For example, due to the protection of participants identity on the online platform, personal information such as spatial ability was not collected. Although the online experiment implemented mechanism such as qualifying questions for excluding invalid answers and requiring participants to type all their answers instead of simply clicking, participant's responses could still include ones that were guessed. To overcome these limitations, future research can adapt the use of virtual applications to simulate the actual design on mobile phones. Users can interact with the application by using a mouse or the touchpad of a computer. This can be a suitable improvement for carrying out online experiments, which enables user's interaction with the App while acquiring spatial knowledge from the map.

The field experiment confirms the finding in the online experiment with more details and enhanced performance. The design of distant landmarks using chosen visual variables can serve as reference points for users to acquire spatial knowledge of a larger extent of an environment. Due to the actual interaction with the App, participant's performance is more accurate than that in the online experiment. Using this design in an actual environment that is challenging to community members, this study shows the efficiency of using symbolized landmarks to help users orient in an environment and acquire spatial knowledge, especially distance knowledge. In particular, this study compares the differences using three visual variables including size, fuzziness, and transparency to indicate the distance to distant locations. Based on the results in both experiments, size seems the least effective visual variable for designing distant landmarks based on the results of both usability and acquired spatial knowledge. Instead, fuzziness and particularly transparency are more efficient. They lead to higher efficiency as they do not require more interaction and lead to better acquisition of spatial knowledge. Both these visual variables seem to intuitively indicate on the screen that the further the location is, the harder it is to see the location clearly.

The limitations of this study should be noted and further addressed in future studies. First, it is important to note that the sample size in the field experiment is relatively small, as it has been challenging to recruit participants who are not familiar with the site. Second, only one visual variable is used in one design. It is not clear if combined visual variables lead to better performance. In future studies, it is necessary to apply both fuzziness and transparency to one distant landmark and evaluate their effectiveness on spatial learning. Third, future studies should consider additional factors such as a person's familiarity and self-rated sense of direction. After the initial evaluation of the effectiveness of visualized distant landmarks on acquiring spatial knowledge, it is necessary to investigate their roles on actual navigation tasks.

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