Spatial Ability and Map-Based Software Applications

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ABSTRACT

Location-based applications are growing in importance as agencies are placing more and more computing into their field applications. The development of software for these applications needs to consider the wide range of user skills. The present work looks at the impact of spatial ability on a typical Census Bureau application (address verification). A study of a text guided software system for address verification was conducted. The participants were tested to determine their logical reasoning, visualization, and perspective taking abilities. The participants performed a set of address verification tasks using a tablet in a stationary environment. The study and results are presented and discussed.

Keywords: usability, spatial ability.

I. INTRODUCTION

Human computer interaction (HCI) researchers have recognized the importance of individual differences in cognitive abilities for designing effective software applications. Zhang and Norman [15] argue that a cognitive task is never solely dependent upon the internal mindset of the users nor is it solely related to effectiveness of software design. Both individual differences and system design have the potential to influence computer performance. Among these differences, spatial ability has been found to be one of the strongest predictors of human computer performance [2,3,4,12]. Lohman [8] defined spatial ability as "the ability to generate, retain, retrieve, and transform well-structured visual images" (p. 98).

Spatial ability has several dimensions. Two important components are visualization and orientation. Spatial visualization has been defined as the "ability to manipulate or transform the image of spatial patterns into other arrangements" [5, p. 173]. Spatial orientation has been defined as the "ability to perceive spatial patterns or to maintain orientation with respect to objects in space" [5, p. 149]. Visualization and orientation have been shown to be distinct from one another [6] yet most research on computer performance examines either one or the other [9]. The importance of spatial ability in software user performance suggests that it may be advantageous to the user if software systems were able to accommodate individual differences in spatial ability. Sein, Olfman, Bostrom, and Davis [10] investigated visualization ability in relationship to the usage of three applications (email, modeling software, and operating systems). They found that persons with high visualization skills learned fastest on all of the applications.

Another area related to interface design that we found support for in the literature is guided systems. Berger et al. [1] found that student's performance in discovery systems was dependent on the level of their cognitive abilities. Sein et al. [10] showed that low spatial users' performance could be improved by reducing the need for discovery. Meanwhile, Zhang [14] showed that externalization of help aids and extra navigation information can offset the costs of using them. Vicente et al. [11] suggest the use of a task list and instructions for users as a possible accommodating strategy for users of a spatial user interface.

 ISBN: 978-1-61208-177-9

To investigate these ideas, we developed an address verification software system. In this task, Census Bureau field staff evaluate whether the location of an address on the ground is properly represented on the map. If a map error is detected, the location of the housing unit on the map is modified to correct the error. This task can be cognitively demanding. In the field, the user makes a comparison between the location of a housing unit as represented on the map and on the ground.

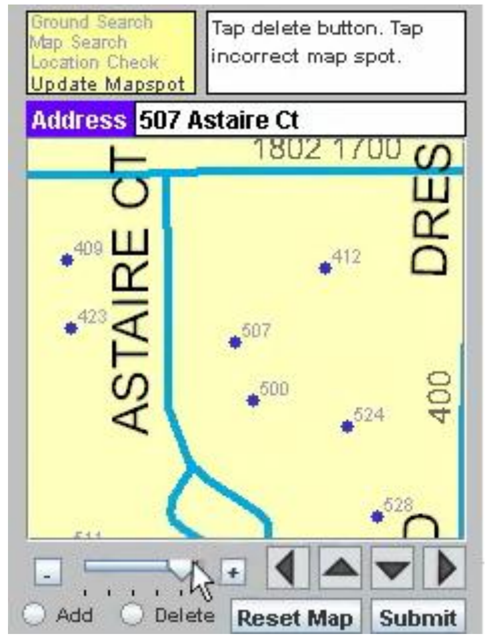
Figure 1: The computer set up used in the experiment.

Our goal was to investigate whether spatial ability (especially visualization and perspective taking) plays a role in this task and whether the use of task lists and relevant instructions would help bridge performance gaps between persons with low and high spatial ability by reducing the need for discovery. We tested whether using a guided system would reduce the need for discovery for participants with lower spatial ability. We hypothesized that spatial ability would impact the map operations (e.g., zoom and pan) as well as the overall performance (i.e., time and accuracy).

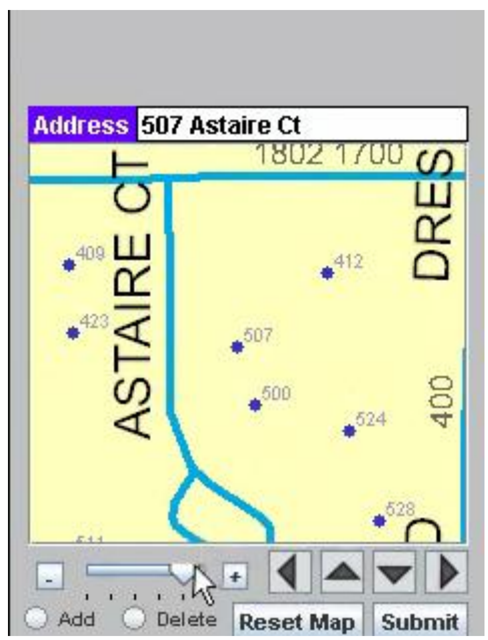
II. METHOD

A. Overview

We conducted a user study to evaluate whether spatial ability affected user performance for an address verification task using software interfaces with or without textual protocol and software guidance. We recruited 24 subjects from the community to perform 10 address verification scenarios. Subjects were grouped by gender and age. Within each group, each subject was randomly assigned to the guided or unguided interface treatment. Unlike our paper map study [13], the present experiment was designed to impose a rigid protocol on the participants. The application recorded the time it took participants to perform each step in the procedure, the number of attempts to match each address, the number of attempts to fix the map, the accuracy in fixing the map, and the number of times specific buttons or other software tools were used.



a) Guided User Interface.



b) Unguided User Interface.

Figure 2**.** The guided and unguided interfaces.

B. Participants

The twenty-four subjects were recruited through fliers posted on the Iowa State University campus, local grocery stores, coffee shops, the public library, and word of mouth. This method was used because it mimicked recruiting strategies used by the Census Bureau to recruit address listing staff. The twenty-four participants were equally split by age (<=30, >30) and by gender (female, male).

C. Experimental Task and Computing Environment

The experimental task involved comparing a housing unit configuration on the ground (simulated with photographs of the two sides of the street – Figure 1) with the corresponding information in the map. Possible outcomes from comparing ground and map locations are: *1)* the ground situation is correctly reflected in the map requiring no further action; *2)* the map has an error of commission that requires a map spot to be removed; *3)* the map has an error of omission that requires a map spot to be inserted; and *4)* the map has an error in the housing unit location that requires the map spot to be relocated.

To successfully perform the task, the following steps need to be executed: 1) find the address on the ground (i.e., in the photos presented to the subject), 2) locate the address on the software map, 3) answer a question posed by the software as to whether or not the address was on the map, 4) if so, answer a question posed by the software as to whether or not the address was in the correct location on the map, and 5) fix the map if an error was identified. Software was developed to instantiate the experimental task. The software generated displays of photographic images of the ground setting on two monitors, one for each side of the street (Figure 1). In addition, the software presented a map-based interface on a tablet PC. The two monitors used in the second session to display the street photographs were Dell UltraSharp 2000FP 20-inch Flat Panel Monitors (16 inches in width and 12 inches in height). The physical dimensions of the map software on the tablet PC were reduced to emulate the size of a handheld. The specific measurements were 2 1/4 inches in width by 3 inches in height for the active interface area and 2 1/16 inches in width and 1 7/8 inches in height for the map display area. The computer used to display the interface was a Gateway Tablet PC M1300. This tablet had a 12.1-inch active matrix LCD color screen and was configured in a landscape display for the experiment (9 3/4 in x 7 1/4 in) (Figure 1). The interface mimicked the size of a handheld computer that might be used in the field. The guided version of the software displayed an interface that included guidance on what the user should be doing. The unguided version of the software had the same functionality and layout, but provided no guidance (Figure 2).

The guided version included a yellow box at the top of the screen that provided real-time feedback on the step to be executed by the subject. To the left was a list of steps that the subject had to accomplish to complete each scenario. As the user progressed through each step, the current step was highlighted within the list. To the right was an instruction box that provided information about what actions needed to be accomplished on each screen to complete the step. For example, if the user was on a screen in which they were required to fix the map, the screen would tell them one of the specific fixes that needed to be accomplished, such as “Tap delete button”. Map-related functions were the same on both interfaces, and included zoom, pan, reset map, add map spot, and delete map spot. Both interfaces also included an address bar that presented the target address for each of the 10 different scenarios. The software recorded each user action and generated a summary of performance measures for analysis. Specific variables included time spent on each screen, number of attempts to answer each address matching question, positional accuracy in fixing maps, and number of times each map tool was used.

For the photographic images, we used manipulated photos of streetscapes. The original photos were taken in areas of Story County that were not highly trafficked so that subjects would not recognize street configurations. The experiment used maps that were compiled based on Iowa data from Black Hawk County and the Department of Transportation (DOT). These maps were similar to TIGER/Line shape files that are used by the Census Bureau. The manipulation created settings that challenged the users in ways that were consistent with the objectives of the study. For example, we removed a structure from a photo to create a vacant lot on the ground where the map included an existing map spot. In developing the scenarios, we created variation in relation to six factors. These factors included photo, street name, road configuration (e.g., four-way intersection, three-way intersection, etc.), rotation (e.g., north up, south up, etc.), map, and corrective action required.

D. Experimental Procedure

The experiment involved two sessions with subjects. The first session was used to test the subjects and the subjects performed the map task in the second session. During the first session, each subject was presented with an informed consent form. After having read this form and signed it, cognitive tests were administered to the subjects. A test script was used to ensure consistency. Three cognitive tests were administered to each subject. These tests included Ekstrom et al. (1976) paper-based assessments on visualization (VZ-2) and logical reasoning (Ekstrom et al. 1976) and the Kozhevnikov et al. (2006) computerized perspective taking assessment on orientation. The Inference Test on reasoning was administered first and the Paper-folding Test on spatial visualization was administered second. After the paper-based tests were completed, the subjects were taken to a computer lab where they completed the background questionnaire. Next they were trained on the Perspective Taking software (PT) and then they proceeded to complete the test. The PT results were compiled by a research team member who was not involved in working with subjects and used to randomize subjects to guided and unguided treatments within age-gender groups. The randomization procedure ensured balance in spatial ability across treatments within these groups.

The second sessions took place throughout the two weeks that followed the first session and lasted approximately one hour each. When a subject returned, s/he was informed that s/he would perform a task that comparing the location of a target housing unit on the ground with its representation on the map. Subjects were trained on the task procedure using an example scenario that was based on two color paper printouts. One color printout included two street photos and the other included a zoomed-in map that emulated the map that would be displayed on the software interface. The tablet touch screen calibration was performed by each subject to ensure that the tablet was sensitive to the user's handedness and the way in which s/he used the stylus. Finally, the user was trained to use the software to accomplish the experimental task and allowed to practice with two computerized practice scenarios. After training, the subject proceeded to complete each of 10 test scenarios. After completing the experiment, the subject received a $30 gift card.

E. Analysis Methods

The impact of interface treatment (i.e., guided or unguided) and associations with demographic and cognitive ability covariates on the subjects' behavioral and performance measures were evaluated using regression procedures. Response variables included the time required to perform each scenario, the accuracy of locations for addresses that required adding or moving map spots, the number of times the pan button was used, and the number of times the zoom button was used. Accuracy of a newly placed housing unit map spot was derived by computing the distance (in meters) between the centroid of the parcel in which the housing unit was located and the location of the housing unit inserted by the subject. Because preliminary analyses indicated that the location accuracy variable required a transformation to meet regression analysis assumptions, a log transformation was applied to this variable prior to fitting the regression model. The interface treatment variable was expressed as an indicator variable indicating whether the subject was assigned to the guided treatment or not. Demographic variables (expressed as classification variables) included in the model were age category (18-29 years of age, 30-39 years of age, 40-59 years of age, or 60 years and older) and gender. For the cognitive tests, we standardized for visualization, perspective taking, and logical reasoning. To avoid problems with collinearity among spatial ability measures, we ran 3 sets of analyses: a) we used only VZ, b) both VZ and the *spatial difference* (VZ-PT) were used, c) average (VZ+PT)/2 and the spatial difference were used. Regression models were fit using an ordinary least squares (PROC GLM in SAS, citation). We examined residuals for departures from assumptions of homogenous variance and linearity. Tests of whether regression parameters were equal to zero were conducted to identify which covariates were associated with each response variable.

III. RESULTS

Table 1 presents the test results from the analysis for time, log accuracy, zoom button usage, pan button usage, and map reset button usage. Guidance was not related to any performance measure, after accounting for the other explanatory variables, except gender. In analysis c) we found a significant negative association between average of visualization and perspective taking and time to perform the task. The estimated regression coefficient was -320 (SE=145) indicating that as the average of the visualization and perspective taking standardized test scores increased by one unit, the average time spent on completing the full exercise was reduced by an estimated 320 seconds (holding other variables constant). Analyses a) -327 (SE=189) and b) -245 (SE=74) found similar results for association between VZ and the time required.

There was a significant negative association in analysis c) between error in housing unit location (log meters) and spatial difference. The estimated

 ISBN: 978-1-61208-177-9

Table 2. P-values for ANOVA F-tests for each interesting performance variable.

Source	Time (sec)	Accuracy (log m)	Zoom (# zoom actions)	User Map Resets (# reset actions)	Pan (# pan actions)
Age			0.02 [b]		
Gender		0.02 [c]	0.009 [b]		
Gender * Interface			0.01 [b]		
VZ	0.001 [b]		0.03 [b]	0.03 [a]	0.03 [a]
Spatial Difference (VZ-PT)	0.006 [b]	0.02 [c]			0.02 [c]
Spatial Average	0.05 [c]				

a) Analysis only with VZ.
b) Analysis with both VZ and Spatial Difference.
c) Analysis with both the average and Spatial Difference.

regression coefficient was -.69 (SE=.26), indicating that for every unit increase in the difference between visualization and perspective taking standardized test scores, the user-determined housing unit locations was an estimated .69 log meters closer to the target location. There was also a significant association between gender and accuracy in analysis c). The estimated regression coefficient was 1.25 (SE=.48) which indicated that females tended to be 1.25 log meters less accurate than males.

Analysis c) found significant negative association between age and the use of the zoom. The estimated regression coefficient was -5.18 (SE=2.15), which meant that older subjects tended to make less use of the zoom tool. Analysis b) saw a negative association -5.56 (SE=2.36) between VZ and zoom. A positive association 19.82 (SE=6.83) also showed up between guided females and the use of zoom in analysis b). A significant negative association of the differences between visualization and perspective taking scores and use of the pan buttons was found in analysis c). The estimated regression coefficient was -52.13 (SE=19.94) which meant that subjects with high visualization relative to perspective taking scores tended to make less use of the pan tool. Finally, a negative association was found in analysis a) for the use of the reset map button (-1.93 (SE=0.82)).

IV. DISCUSSION

An important goal of this research was to investigate the relationship of spatial ability and user software performance for a map-related task in relation to two specific sub-factors of spatial visualization and orientation (i.e., perspective taking) abilities. It is clear from the analyses that the results were sensitive to the relationship between the two spatial parameters used. To get a complete understanding, we used the three combinations of parameters (a,b,c) shown in the legend of Table 1. Our results indicate the maps were more sensitive to VZ than the average of the two spatial parameters. We found that higher visualization scores tended to be correlated with faster performance times and fewer map operations (zooms, pans, and map resets). The association between spatial ability and user performance is consistent with findings from a large body of literature in software use (Dahlbäck et al., 1996; Egan, 1988; Vicente, Hayes, & Williges, 1987; Egan & Gomez, 1985). In addition, our results extend this finding to map-based interfaces.

We also saw that for this set of data that there were differential effects of spatial ability sub-factors corresponding to visualization and perspective taking. Subjects with higher spatial differences were able to more accurately record the location of addresses that were missing from the map.

Pan usage was also lower for subjects with higher spatial differences, which is a likely result of pan usages being lower for subjects with higher VZ scores. Older subjects tended to use the zoom tool less frequently. Based on their successful completion of the tasks, there isn't any indication that this impacted their overall performance.

Spatial ability has also been found to vary by gender, and when this factor is significant, results indicate that spatial ability tends to be higher for men relative to women (Linn & Peterson, 1985). We found that on average, male subjects most accurately placed housing units on the map when the ground situation showed a housing unit that was not initially present on the map. In addition females relied to some degree on the guided interface.

The logical reasoning abilities of the participants were not significant for any of the performance parameters.

The lack of a relationship between the availability of the software layout (i.e., guided treatment) and spatial ability was somewhat surprising. Based on the connection between discovery of the software structure and visualization scores in the literature, one would have expected more value from the guided interface. The question of interest is whether the fact that our software broke the task into a series of rather simple self-contained subtasks (Figure 2) reduced the participants' need for discovery in the sense detailed by Sein et al. (1993). There are two directions we will be able to go to better understand why we didn't see a relationship. One issue is the complexity of the task. We are currently conducting two studies to provide more information on what participant skills are being used in the address verification task. Future experiments will be designed to look at other forms of guidance to help us determine whether our guidance structure and/or content was inadequate.

ACKNOWLEDGEMENTS

We gratefully acknowledge the scientific guidance of Elizabeth Murphy and Kathleen Ashenfelter of the U.S. Census Bureau. This research was funded in part by a professional services agreement with the U.S. Census Bureau and by the National Science Foundation grant No. 0092696.

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